Safety Reports Series
No. 118

Ageing Management for Nuclear Fuel Cycle Facilities

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AGEING MANAGEMENT
FOR NUCLEAR FUEL
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AGEING MANAGEMENT FOR NUCLEAR FUEL CYCLE FACILITIES

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FOREWORD

As of 2021, more than 50% of nuclear fuel cycle facilities worldwide have been operating for more than 30 years. The safety and reliability of these facilities are challenged by the effects of ageing on their structures, systems and components. As a consequence, a number of IAEA Member States are implementing ageing management activities, including refurbishment and modernization projects.

A large body of knowledge exists in Member States regarding the degradation mechanisms and methods available to minimize ageing and mitigate its effects in the nuclear fuel cycle facilities. Sharing this knowledge and exchanging operating experience improves the ability of Member States to develop and maintain systematic ageing management programmes for these facilities.

This publication provides practical information on the establishment of effective ageing management programmes for nuclear fuel cycle facilities in the operational stage. The publication also covers ageing management considerations at different stages in the lifetime of a nuclear fuel cycle facility. The information in this publication will be useful to the operating organizations, regulatory bodies and other organizations involved in the safety of nuclear fuel cycle facilities, including designers and technical support organizations.

The IAEA wishes to thank all those who contributed to the development of this publication. The IAEA officers responsible for this publication were L. N. Valiveti, J. Rovny and A. Shokr of the Division of Nuclear Installation Safety and K. Agarwal of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

IAEA Safety Standards Series No. SSR-4, Safety of Nuclear Fuel Cycle Facilities [1], establishes a requirement for design considerations for the management of ageing (Requirement 32) and a requirement for implementing an effective ageing management programme to ensure that safety functions are fulfilled during the entire lifetime of the facility (Requirement 60). The ageing of nuclear fuel cycle facilities is a concern because a majority of the facilities worldwide are now more than 30 years old, and operating experience feedback confirms that the ageing of structures, systems and components (SSCs) can cause events of safety significance. Examination of the Fuel Incident Notification and Analysis System (FINAS) database[1] has revealed that 23% of the events occurred either as a result of deficiencies in maintenance, inspection and periodic testing or as a result of the ageing of SSCs. This is summarized in IAEA-TECDOC-1932, Operating Experience from Events Reported to the IAEA/NEA Fuel Incident Notification and Analysis System (FINAS) [2].

Nuclear fuel cycle facilities generally handle large quantities of radioactive material. Furthermore, corrosive, reactive and hazardous chemicals are also used in various processes of nuclear fuel cycle facilities. Multiple barriers for the confinement of radioactive or other hazardous materials are generally provided in nuclear fuel cycle facilities considering a defence in depth approach. These barriers may include static containment methods, such as gloveboxes, containers, hot cells or enclosures, or dynamic containment methods using exhaust or ventilation systems. However, there may only be a single barrier for confinement of the radioactive or hazardous material in some places (e.g. ventilation ducts or sampling lines) within nuclear fuel cycle facilities. The failure of such barriers could result in immediate releases of radioactive or other hazardous materials out of their containment.

The materials handled in nuclear fuel cycle facilities may be abrasive (powders) or corrosive (acids, alkalis, etc.) or may contain impurities (e.g. silica content in yellow cake obtained from processing of uranium ores) or other undesired material (e.g. certain fission product content in the spent fuel feed of reprocessing facilities), depending on the upstream processes adopted. The particulate form of these impurities in process fluids might result in erosion and clogging of the piping or other SSCs. The physical and chemical characteristics

[1] Analysis of events that were reported to the FINAS database from the year 1992 to the year 2020.

of the impurities or chemicals used might also result in abrasion or corrosion of the SSCs. Nuclear fuel cycle facilities also have several areas where there are interconnected vessels and equipment, with restricted or difficult access for conducting maintenance, inspection and other surveillance.

Potential consequences of ageing and related failures in these facilities include loss of confinement of hazardous chemicals and radioactive materials, accumulation of radioactive and fissile materials (in places like vessels, piping or ducts), loss of control of chemical reactions, decreased neutron absorption capacity in neutron absorber components, unavailability of monitoring and alarm systems (due to ageing or obsolescence) and failure of utility systems necessary to ensure safety functions (such as cooling water, compressed air, steam supply, inerting or ventilation). These failures caused by ageing can lead to fire, loss of nuclear criticality safety barriers, release of radioactivity, release of hazardous chemicals or a combination of these consequences. Another characteristic of ageing is its potential for common cause failures that can challenge multiple levels of defence in depth simultaneously.

Obsolescence or non-physical ageing occurs when SSCs become out of date in comparison with current technology, knowledge, standards or regulations, or when documentation becomes out of date. It is necessary to predict items that could become obsolete before the obsolescence can have an adverse effect, whether directly or indirectly, on the safe operation of the nuclear fuel cycle facility.

In-service inspection and maintenance programmes are necessary to ensure the availability of items important to the safety of the nuclear fuel cycle facility. However, fulfilling the safety functions provided by SSCs throughout the long operating period (lasting several decades) requires an additional programme for the ageing management of SSCs in nuclear fuel cycle facilities. A dedicated ageing management programme contributes towards ensuring the availability of safety functions throughout the service life of the SSCs.

Effective ageing management throughout the service life of SSCs requires the use of a comprehensive and systematic approach that provides a framework for the coordination of all programmes and activities related to the understanding, detection, monitoring and mitigation of ageing effects in nuclear fuel cycle facilities. The ageing management programme needs to ensure that all the ageing effects are recognized and the necessary actions for addressing them are implemented through the established management system of the facility.

This publication addresses the aspects of ageing management related to nuclear fuel cycle facilities that are covered by IAEA Safety Standards Series No. SSR-4 [1]. Recommendations on the safety of specific types of nuclear fuel cycle facilities are provided in the following IAEA Safety Standards Series publications:

- SSG-5, Safety of Conversion Facilities and Uranium Enrichment Facilities [3];
- SSG-6, Safety of Uranium Fuel Fabrication Facilities [4];
- SSG-7, Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities [5];
- SSG-15 (Rev. 1), Storage of Spent Nuclear Fuel [6];
- SSG-42, Safety of Nuclear Fuel Reprocessing Facilities [7];
- SSG-43, Safety of Nuclear Fuel Cycle Research and Development Facilities [8].

Recommendations on measures for criticality safety in these facilities are provided in IAEA Safety Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [9].

1.2. OBJECTIVE

The objective of this publication is to provide information on methods, approaches, practices and strategies for ageing management of nuclear fuel cycle facilities. The approaches presented in this publication can be applied to different types of nuclear fuel cycle facilities through all the stages of the facility's lifetime. This publication also provides examples of Member States' experience in managing the ageing of nuclear fuel cycle facilities. The publication is intended for use by operating organizations of nuclear fuel cycle facilities, regulatory bodies, technical support organizations, vendor companies (such as designers, engineering contractors and manufacturers) and research establishments related to nuclear fuel cycle facilities.

Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

1.3. SCOPE

This publication addresses aspects of ageing management for all types of nuclear fuel cycle facilities covered in IAEA Safety Standards Series No. SSR-4 [1] during various stages of their lifetime, from design until decommissioning.

1.4. STRUCTURE

This publication has seven sections and four annexes. Section 2 presents basic concepts related to ageing and ageing management, discusses the impact of ageing on the defence in depth concept adopted in the design and operation of nuclear fuel cycle facilities and looks at the interrelation between the service conditions and ageing of SSCs. Section 3 provides information on considerations for dealing with ageing during the various stages of the lifetime of a nuclear fuel cycle facility. Section 4 defines the elements of a systematic ageing management programme and focuses on approaches to the implementation of appropriate actions or activities. Section 5 covers the management of ageing in SSCs from the point of view of their obsolescence. Section 6 discusses the interface between ageing management and various technical areas and programmes in a nuclear fuel cycle facility, while Section 7 covers the management system for ageing management.

Annex I presents examples of various service conditions, associated degradation mechanisms and resultant ageing effects in the SSCs of nuclear fuel cycle facilities. Annex II provides an example of an ageing management measure envisaged during the design stage for a dry spent fuel storage facility (DSFSF) in Argentina. Annex III provides an example of an ageing management programme for a nuclear fuel fabrication facility in Romania. Annex IV provides an example of an ageing management programme for a DSFSF in Ukraine.

2. AGEING AND SAFETY OF NUCLEAR FUEL CYCLE FACILITIES

2.1. AGEING

Ageing is a general process in which the characteristics of an SSC gradually change with time or use. In the context of this publication, it is used with a connotation of changes that are (or could be) detrimental to protection and safety (i.e. as a synonym for ageing degradation[2]). Ageing may be further categorized into physical ageing and non-physical ageing.

[2] ‘Ageing degradation’ means the ageing effects that could impair the ability of an SSC to function within its acceptance criteria.

2.1.1. Physical ageing

Physical ageing is the ageing of SSCs due to physical, chemical and/or biological processes (ageing mechanisms[3]) [10]. Examples of physical degradation mechanisms include wear, radiation embrittlement, corrosion and microbiological fouling.

Degradation caused by ageing can be caused by changes in microstructure or chemical composition (as in the case of creep or embrittlement), geometrical changes like material loss, cracking or distortion (like in the case of erosion, corrosion or deformation) or a combination of these. In polymeric materials, ageing can result in the bleeding of plasticizers, which leads to a loss of ductility of the material. Examples of various service conditions, associated degradation mechanisms and resultant ageing effects in the SSCs of nuclear fuel cycle facilities are provided in Annex I.

Additional information on ageing and its consequences is available in IAEA Safety Standards Series No. SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants [11], IAEA Safety Standards Series No. SSG-10, Ageing Management for Research Reactors [12], IAEA Nuclear Energy Series No. NP-T-3.24, Handbook on Ageing Management for Nuclear Power Plants [13], IAEA Nuclear Energy Series No. NP-T-3.5, Ageing Management of Concrete Structures in Nuclear Power Plants [14], and HSE Research Report No. 912, Management of Ageing: A Framework for Nuclear Chemical Facilities [15].

2.1.2. Non-physical ageing

Non-physical ageing is defined as the process of becoming out of date (i.e. obsolete) owing to the evolution of knowledge and technology and associated changes in codes and standards [10]. Examples of non-physical ageing effects include the unavailability of qualified spare parts for old equipment, incompatibility between old and new equipment and outdated procedures or documentation. The aspects of non-physical ageing are further addressed in Section 5 on management of obsolescence. Additional information on physical ageing and obsolescence in nuclear fuel cycle facilities is available in OECD/NEA’s CSNI Technical Opinion Papers No. 15, Ageing Management of Nuclear Fuel Cycle Facilities [16].

[3] An ‘ageing mechanism’ or ‘degradation mechanism’ is a specific process that gradually changes the characteristics of an SSC with time or use. Henceforth, the term degradation mechanism is used in this publication.

In this publication, the term ‘ageing’ is generally used to indicate physical ageing, whereas the term ‘obsolescence’ is used for non-physical ageing.

2.2. AGEING MANAGEMENT

Ageing management is defined as “engineering, operations and maintenance actions to control within acceptable limits the ageing degradation of structures, systems and components” [10]. Examples of engineering actions include design, qualification and failure analysis. Examples of operations actions include surveillance, carrying out operating procedures within specified limits and performing environmental measurements.

Effective ageing management throughout the lifetime of SSCs requires the use of a systematic approach. An ageing management programme is a systematic framework for coordinating all activities relating to the understanding, detection, minimization, monitoring and mitigation of ageing effects on the SSCs. The elements of an ageing management programme[4] for a nuclear fuel cycle facility are further described in Section 4.

2.3. AGEING AND DEFENCE IN DEPTH

In nuclear fuel cycle facilities, defence in depth is achieved by a system of multiple physical or functional barriers (accomplished by administrative means or by SSCs) for the prevention and mitigation of events and accidents. Defence in depth provides multilayer protection against accident conditions through appropriate design, operation and verification methods.

Ageing might lead to the failure of a barrier, or the failure of a component of a barrier, ultimately leading to the failure of the barrier itself. It might also lead to simultaneous impairment of one or more levels of protection provided by the application of the defence in depth concept because of the increased possibility of common cause failure of multiple SSCs. An example of how ageing could lead to the simultaneous unavailability of multiple systems is the failure of multiple cables (resulting from reduced insulation resistance due to ageing) during a

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[4] In this publication, the phrase ‘ageing management programme’ refers to a single facility level programme for the nuclear fuel cycle facility. The practice in nuclear power plants is that the ageing effects and degradation mechanisms are studied and managed at the level of the structure or component. However, ageing management programmes for individual structures or components are integrated into an ageing management programme at the system and/or plant level.

flooding event. Another characteristic of ageing is that it could aggravate the potential consequences of events. For example, the degradation of fire barriers provided to limit fire in a certain area could contribute to the spread of fire to other areas.

An effective ageing management programme provides for maintaining defence in depth through the incorporation of design features and engineering practices that provide safety margins, mainly by the use of design, technology and materials of high quality and reliability. Equally, the effectiveness of an ageing management programme can be supported by the technological and procedural barriers deployed to ensure defence in depth, viz.:

(a) Compliance with the operational limits and conditions;
(b) Execution of relevant tasks and activities in accordance with approved operating and maintenance procedures and good practice.

2.4. SERVICE CONDITIONS AND AGEING

Service conditions comprise the physical conditions prevailing, or those expected to prevail, during the service life of an SSC, i.e. the period from initial operation to final withdrawal from service of an SSC. Service conditions include environmental conditions (e.g. conditions of humidity; thermal, chemical, electrical, mechanical and radiological conditions), and operating conditions (conditions in normal operation[5], error induced conditions) and conditions during and after events [10].

The ageing of SSCs is influenced by the conditions to which they are subjected during normal operation and anticipated operational occurrences. The prevailing environmental conditions characteristic to the nuclear fuel cycle facility also affect ageing. The effects of ageing may result in the reduction or loss of the ability of the SSCs to function within accepted designed and authorized criteria. The effect of accidents (design basis accidents and beyond design basis accidents) on the ageing of SSCs needs to be evaluated on a case by case basis, subject to their occurrence.

2.4.1. Normal operation

The operating conditions, such as temperature, pressure and process chemistry, can affect the ageing of SSCs. Additionally, factors like radiation

[5] The conditions in normal operation also include the conditions during the maintenance and shutdown states of the facility.

level, accumulation of materials and wear and tear in normal operation conditions can also affect the material properties and ageing of SSCs in nuclear fuel cycle facilities.

2.4.2. Anticipated operational occurrences

Certain anticipated operational occurrences, such as spillage of material, leakages, deviation in process chemistry and erroneous maintenance, may cause adverse chemical conditions or mechanical damage that may lead to corrosion, deterioration of systems or accelerated ageing. After an anticipated operational occurrence at a nuclear fuel cycle facility, it is necessary to investigate and take corrective actions to stop any accelerated ageing.

2.4.3. Environmental conditions

The environmental conditions that can affect the ageing of SSCs include the presence of chemicals in the exposed environment and climate related conditions such as temperature, humidity, rainfall, frost and wind, as well as site conditions such as salinity and dustiness. The effects of these conditions are corrosion, erosion or undesirable chemical reactions, and they may cause damage to equipment.

Annex I provides examples of possible effects of service conditions on the ageing of SSCs in nuclear fuel cycle facilities.

3. AGEING MANAGEMENT CONSIDERATIONS AT DIFFERENT STAGES IN THE LIFETIME OF A NUCLEAR FUEL CYCLE FACILITY

Management of ageing is necessary to assure the safety of a nuclear fuel cycle facility during all stages of its lifetime. Ageing management in nuclear fuel cycle facilities generally involves identification of SSCs for ageing management, identification of relevant degradation mechanisms and ageing effects, and implementing measures for the detection, minimization or mitigation of ageing effects. The elements of an ageing management programme for a nuclear fuel cycle facility are addressed in further detail in Section 4.

The lessons learned from operating experience and from the results of research and development can be used to enhance understanding of the effects of ageing on SSCs and improve their ageing management. The strategies for ageing management of SSCs need to be proactively established, especially at the stages of design, construction and commissioning. The ageing management programme of the facility, which is established during the operational stage, needs to be periodically reviewed for its adequacy, and necessary improvements are to be made until the decommissioning of the facility.

3.1. AGEING MANAGEMENT CONSIDERATIONS IN DESIGN OF A NUCLEAR FUEL CYCLE FACILITY

Paragraph 6.36 of SSR-4 [1] states:

"Many nuclear fuel cycle facilities use aggressive chemicals under harsh environmental conditions, often involving thermal and mechanical cycling and the transfer of materials containing abrasive particulates and, in some cases, complex mixtures of elements and compounds unique to the facility. In establishing engineering design rules and acceptance criteria, the effects of corrosion, erosion and similar processes shall be considered. These effects shall also be considered when establishing monitoring and inspection requirements and, where appropriate, for the management of facility ageing."

Requirement 32 of SSR-4 [1] states:

"**Design safety margins shall be adopted so as to accommodate the anticipated properties of items important to safety, to allow for the effects of materials ageing and degradation processes.**"

Paragraph 6.117 of SSR-4 [1] states:

"The design and layout of items important to safety, including containment systems and neutron absorbers, shall take account of ageing degradation of materials and the potential for premature failure. Where components provide a safety function, replacement components of equivalent quality shall be provided."

Paragraph 6.118 of SSR-4 [1] states:

"Where details of the characteristics of materials whose mechanical properties may change in service are unavailable, a system of monitoring

> shall be developed in the design to minimize the risks brought about by the effects of ageing, process chemistry, erosion, corrosion and irradiation on materials (see Requirements 26 and 60).”

All potential degradation mechanisms and ageing effects for SSCs that will perform passive and active functions need to be identified, evaluated and taken into account in the design. In the design stage, appropriate margins need to be provided in the design of SSCs that are important to safety to in order take into account the ageing and obsolescence of SSCs. The uncertainties associated with the understanding of ageing phenomena have to be adequately considered in provisions of these margins. The design has to consider all operating conditions and transients, including maintenance, inspection and periodic testing activities. In some cases, additional margins may already be available to address ageing because of the conservative assumptions used in the applied design standards. For the determination of additional margins necessary for ageing, the possible changes in utilization of the nuclear fuel cycle facility need to be considered in addition to the ageing and obsolescence anticipated during the lifetime of the facility.

The selection of the materials for the construction of SSCs needs to take into account the possible effects of ageing to ensure that the SSCs can perform their functions as per the design intent throughout the lifetime of the facility. For nuclear fuel cycle facilities, consideration needs to be given to the compatibility of materials of construction and welds, the manufacturing processes of items important to safety and the use of materials that will withstand operating conditions such as harsh corrosive environments, thermal loads, fatigue and radiation. The necessity of protective coatings to mitigate the effects of ageing on SSCs needs to be considered in the design stage. Site specific characteristics, such as saline environment, temperature and humidity, that may affect degradation mechanisms also need to be taken into account during the design of the facility. If the nuclear fuel cycle facility is of generic design, the impact of site specific characteristics on ageing of SSCs needs to be assessed during the site evaluation stage. Where limited data are available related to the effects of ageing on the materials of construction of the SSCs, tests and investigations may need to be conducted to determine the suitability of the materials. Further information and references related to the identification and understanding of ageing are provided in Section 4.2.

During the design stage, provisions for monitoring the ageing of SSCs important to safety and the operating life of the nuclear fuel cycle facility need to be considered. For example, the provision of on-line corrosion monitoring or placing of corrosion coupons in process equipment will permit the monitoring and trending of ageing during the lifetime of the nuclear fuel cycle facility.

Particular consideration has to be given to SSCs that are difficult or impossible to access (e.g. in underground, high radiation or other difficult to access areas) and non-replaceable SSCs whose service life extends to the design life of the facility. In such cases, additional design margins considering ageing effects need to be provided, or specific measures have to be taken (e.g. remote intervention by a robot or manipulator, or use of indirect measurements) for assessing the ageing. The number of inaccessible SSCs should be minimized by design. Indirect testing measures may also be considered in the design for timely detection of degradation due to ageing (e.g. chemical analysis of the contents of a non-accessible vessel to detect corrosion). The aspect of accessibility for conducting necessary testing, examination and mitigatory actions for ageing management needs to be considered during the design of the layout (building, equipment, piping, etc.) of the nuclear fuel cycle facility. An example of certain design provisions for the monitoring of ageing in a DSFSF in Argentina is given in Annex II.

Requirement 26 of SSR-4 [1] addresses the design for maintenance, periodic testing and inspection of items important to safety in nuclear fuel cycle facilities. The possible effect of these activities on the ageing of SSCs needs to be considered. The interface between ageing management and these areas is addressed in Section 6.1. Facility specific guidance regarding design for the maintenance of nuclear fuel cycle facilities is provided in Refs [3–8].

The design basis for ageing considerations needs to be appropriately documented in relevant design documents, design specifications and other documents to be used by designers and suppliers. During the design stage, the ageing of SSCs needs to be taken into consideration in the safety assessment. The safety analysis report needs to include strategies for ageing management during the lifetime of the facility, identification of SSCs affected by ageing, and proposed monitoring, testing, inspection and sampling programmes for the detection of ageing effects.

During the design stage, it is necessary to consider data from relevant operating experience related to ageing that have been obtained from other similar facilities, technologies and equipment operating at similar service conditions. The operating experience to be used needs to include facility specific, equipment specific, technology specific, environment specific and general operating experience. Additional data from research and development programmes can be referred to if specific operating experience data related to ageing are not available.

The concept of defence in depth is applied in the design of the facility through the deployment of various levels of protection, by means of equipment and barriers to limit the escalation of anticipated operational occurrences. Since ageing can affect multiple barriers and levels of defence in depth simultaneously (e.g. the simultaneous degradation of two consecutive barriers or of a barrier and a detection system), the combined effects of degradation mechanisms acting concurrently may need to be taken into account in the design if such concurrent effects are credible.

Ageing management needs to be included in the general design criteria and address the following [12]:

(a) Different types of SSCs important to safety (e.g. concrete structures, mechanical components and equipment, electrical and instrumentation and control equipment and cables) and measures to monitor their potential degradation;
(b) The means by which environmental conditions to which SSCs are exposed are to be maintained within specified service conditions (e.g. location of ventilation, insulation of hot SSCs, radiation shielding, damping of vibrations, avoidance of submerged conditions and selection of cable routes);
(c) Appropriate monitoring and sampling programmes for materials in cases where it is found that ageing effects might affect the capability of SSCs to perform their safety functions throughout the lifetime of the facility.

3.2. AGEING MANAGEMENT CONSIDERATIONS IN CONSTRUCTION OF A NUCLEAR FUEL CYCLE FACILITY

The processes for procurement, fabrication and construction need to be managed and controlled within the framework of the integrated management system of the facility. Relevant information and requirements related to the conditions of fabrication, as well as other factors affecting ageing of SSCs, need to be provided to the suppliers and manufacturers of SSCs. Additional information provided by suppliers regarding the fabrication process and conditions and the service conditions that may affect the ageing of SSCs need to be properly documented and taken into account in the operation and maintenance procedures.

Pre-service inspection for purposes such as the confirmation of material composition, confirmation of dimensional specifications and conformance to fabrication procedures may be necessary in certain cases (especially for SSCs such as evaporators, melters and high level waste storage tanks, which are difficult or impossible to replace) to verify that the procured, fabricated or constructed SSCs comply with design specifications relevant to ageing. The inspection findings (e.g. geometrical errors, insufficient gap allowances for thermal expansion in pipe supports or the inadvertent formation of loose parts in pipelines, vessels, tanks or valves) and any other unexpected events or conditions during construction or transport that may have an effect on the ageing of SSCs need to be recorded. Provision of test coupons or specimens for monitoring of corrosion and other degradation mechanisms, as envisaged during the design, needs to be ensured during the construction stage. Particular attention needs to be given to detecting counterfeit, fraudulent and substandard items (e.g. verification of the quality of the materials used to manufacture valves or pipes where high resistance to chemical corrosion is required).

It is necessary to relieve the material stresses created during fabrication processes such as cold work, hot work and welding, since these stresses may not be readily identifiable and could accelerate ageing during the operating life of the facility. During the construction, fabrication, storage and transport of SSCs, it needs be ensured that inadvertent contact with, or the presence of, foreign materials (especially in the piping) does not contribute to unforeseen degradation mechanisms in the SSCs.

Manufacturing data for SSCs, relevant inspection reports and transport and storage conditions need to be recorded for future reference. Baseline data should be prepared and established for all SSCs subject to ageing. The operating organization needs to ensure that the environmental conditions are appropriate to minimize any degradation of SSCs in storage, undergoing installation or otherwise not in service (including periodic energizing, functional operation or lubrication to prevent degradation while in storage, if necessary). If there is a delay in construction, the environmental conditions that could affect the SSCs and their ageing need to be identified and documented.

The information on ageing management aspects available in IAEA-TECDOC-1957, Ageing Management of Nuclear Power Plants During Delayed Construction Periods, Extended Shutdown and Permanent Shutdown Prior to Decommissioning [17], can also be suitably applied to nuclear fuel cycle facilities under construction.

3.3. AGEING MANAGEMENT CONSIDERATIONS IN THE COMMISSIONING OF A NUCLEAR FUEL CYCLE FACILITY

During commissioning, the baseline data related to ageing management need to be collected and recorded for future reference, analysis and determination of monitoring and mitigatory actions during the operation phase of the nuclear fuel cycle facility. The operating organization needs to establish a systematic approach for the measurement and recording of ‘as-installed’ baseline data related to ageing of SSCs. Baseline data facilitate the assessment of ageing of SSCs during operation or in root cause investigations, if premature ageing occurs. In cases where the construction phase has been delayed, conducting additional pre-service inspections or testing may be considered in order to verify the baseline condition of SSCs and evaluate their degradation during storage.

Environmental conditions during functional tests of SSCs need to be recorded and checked for consistency with design and qualification assumptions. Certain operating conditions, such as hotspots (temperature or radiation) and vibration, that can influence material degradation need to be identified during commissioning and assessed for their effect on ageing, especially for concrete structures and the cables. The parameters that can influence the ageing of SSCs need to be identified during commissioning and tracked throughout the lifetime of the nuclear fuel cycle facility.

During commissioning tests, certain SSCs are subjected to higher stresses (e.g. during pressure tests and endurance tests) for the purpose of testing and confirming their performance capability. The areas where these stresses could have exceeded the values envisaged in design or equipment qualification need to be recorded to analyse their impact on equipment performance and ageing.

Errors introduced during commissioning (and errors from design, fabrication and construction that have not been identified and rectified during commissioning) may later induce accelerated ageing in SSCs. For example, if the wrong chemicals are used, residual aggressive agents may be difficult to remove from the systems and may cause early corrosion and cracks. During commissioning, the usage of cleaning agents and other chemicals needs to be monitored. Additionally, the testing fluids used during commissioning need to be within specified quality control parameters. For example, the water used for hydrostatic testing of stainless steel pipes or vessels should have a specified limit on contaminants such as chlorides, since residual chlorine after testing may initiate pitting corrosion. These aspects may not have been anticipated in the design stage and may have adverse effects on ageing.

An independent review or a regulatory review of the baseline data generated may be necessary before moving to the operational stage.

3.4. AGEING MANAGEMENT CONSIDERATIONS IN THE OPERATION OF A NUCLEAR FUEL CYCLE FACILITY

Requirement 60 of SSR-4 states:

> “**The operating organization shall ensure that an effective ageing management programme is implemented to manage the ageing of items important to safety so that the required safety functions are fulfilled over the entire operating lifetime of the nuclear fuel cycle facility.**”

The operating organization needs to establish and implement a systematic and comprehensive programme that captures and addresses the issues related to ageing management and obsolescence of SSCs during operation of a nuclear fuel cycle facility. The experience gained and the records kept on ageing management from the preceding stages of the life cycle will benefit the formulation and execution of the programme in the operating stage. The necessary elements of an ageing management programme for a nuclear fuel cycle facility during its operation are further addressed in detail in Section 4.

The following aspects need to be considered in implementing a systematic ageing management programme during the operational stage [12]:

(a) Support for the ageing management programme by the management of the operating organization, including preservation of the design intent and knowledge of the current configuration of the facility.
(b) Early implementation of the ageing management programme.
(c) A proactive approach on the basis of an adequate understanding of ageing of SSCs rather than a reactive approach responding to failures.
(d) Effective internal and external (i.e. with contractors, vendors, suppliers and other external parties) communication regarding the requirements and priorities related to the ageing management programme.
(e) Proper implementation of maintenance, inspection, testing and surveillance activities in accordance with operational limits and conditions, design requirements and manufacturers' recommendations, and following approved maintenance procedures.
(f) Availability and use of correct operating procedures, tools and materials, and adequate qualified staff.
(g) Proper storage of spare parts and consumables susceptible to ageing.
(h) Assessment of the adequacy of the quantity of spare components for supporting extended operations, including for obsolescence, with procurement of additional spare components as required.
(i) Operating experience feedback (both generic and facility specific operating experience, including operating experience from both nuclear and non-nuclear facilities with similar SSCs) to learn from relevant ageing related events, including relevant observations from periodic safety reviews and event reports and investigations.
(j) Follow-up of possible degradation trends in SSCs between successive periodic testing.
(k) Use of databases for reliability and maintenance histories of SSCs.
(l) Use of modelling to predict degradation; use of actual measurements to validate or enhance the modelling for the purpose of increasing confidence in the predictions.
(m) Use of adequate and qualified methods for monitoring of ageing and for early detection of ageing indicators.

(n) Optimal operation of SSCs to slow down the rate of ageing.
(o) Minimization of human performance factors that may lead to premature or accelerated ageing of SSCs, through:
    (i) Training and qualification programmes;
    (ii) Encouragement and motivation of personnel;
    (iii) Fostering a sense of ownership and awareness;
    (iv) Promoting an understanding of the concepts of ageing management;
    (v) Encouraging reporting of operating experience related to ageing.
(p) Availability of the necessary competence for dealing with complex ageing issues.
(q) Availability of adequately qualified personnel for the ageing management programme activities.

The operating organization needs to identify and justify possible changes in operational conditions (e.g. changes in processes, process efficiency, process chemistry, environmental factors, corrosion, radiation, leaks) that could cause accelerated or premature ageing and failure of SSCs. Specific focus related to ageing may be necessary in the case of:

(a) Increase in facility throughput;
(b) Implementation of modifications, including temporary modifications;
(c) The cumulative effect of modifications on related parts of the system or in co-located parts of the facility that may affect each other (e.g. increased heating, vibration or reduced access for inspection or replacement of components);
(d) Replacement of SSCs.

The safety assessments preceding such modifications and changed modes of operation need to take ageing related degradation into account. In modification processes, consideration also needs to be given to potential effects on the ability to carry out future mitigative actions, such as ensuring the accessibility of specific components that may need additional examination, refurbishment or replacement from the point of view of ageing.

Modification of certain SSCs may have direct or indirect effects on other SSCs. For example, the modification of ventilation systems may necessitate breaking through the structures (i.e. walls) or damage to fire barriers. Also, ventilation system ductwork might release contamination into other areas of the facility during such modifications. The impact of such modifications on the ageing management of modified SSCs and the other affected SSCs needs to be considered. Changes in operating limits and conditions, set points and procedures may also be necessary to address the ageing issues arising from facility modifications.

3.4.1. Other considerations

(a) If the ageing management programme has been initiated only in the operational stage of a nuclear fuel cycle facility, it is likely that historical documentation related to design margins, service conditions, reliability or performance problems related to ageing in the earlier operation and pre-operational stages may not be readily available. In such cases, baseline reference data need to be developed during the initial phase of the ageing management programme. The available safety margins in SSCs with respect to the service conditions need to be assessed and continuously monitored during the subsequent phase of the ageing management programme.

(b) Premature ageing of SSCs (i.e. ageing effects that occur earlier than expected) might be caused by operation of SSCs beyond the operating limits and conditions, operating in conditions more severe than the expected normal environmental conditions, non-compliance with operational or maintenance procedures or unforeseen ageing phenomena. In such cases, the ageing management programme needs to be revised to account for the discovered ageing effects. The frequency of maintenance and surveillance of such SSCs can be revised to track the progression of ageing. The ageing affects may be controlled or mitigated by taking suitable technical measures (e.g. coating exposed surfaces to protect them from environmental conditions) or by modifying the operating conditions to control the ageing effects.

(c) During the operational stage, reference data related to ageing management need to be collected and recorded periodically for analysis and planning of mitigatory actions.

(d) The documentation of a nuclear fuel cycle facility needs to be periodically updated to reflect changes in the operation or utilization programme (e.g. due to changes in throughput, materials processed or chemicals used) and the modifications made in the facility. In addition, possible changes to or obsolescence in the type of storage or retrieval used (e.g. obsolescence of storage media, changes in storage format or database type) for documentation over the lifetime of a facility also need to be considered.

3.5. AGEING MANAGEMENT CONSIDERATIONS BEFORE DECOMMISSIONING

The basic concepts of ageing management are the same for a facility whether it is in operation, in permanent shutdown, or in preparation for decommissioning. During the stages of permanent shutdown or preparation for decommissioning, the ageing management programme needs to be reviewed to identify elements of the programme that will remain in effect after the nuclear fuel cycle facility has been permanently shut down.

The maintenance, inspection and periodic testing of SSCs, especially SSCs that are required to be functional up to and during the decommissioning of the facility, is continued during this stage. In the case of deferred dismantling of the nuclear fuel cycle facility (where there is a significant time period between the end of operation and the beginning of decommissioning), it is important to consider the continued safety function of SSCs that are not in operation but may still be required to perform safety functions related to confinement, contamination control, radiation monitoring, long term cooling or ventilation. For example, the upkeep of ventilation systems, material handling and viewing equipment in hot cells may be necessary during decommissioning.

It is also important to recognize that, even if the safety functions of SSCs change during the post-operational stage, the consideration of ageing management is required to continue. For example, when operations involving radioactive materials are discontinued in an area or a building and the equipment has been removed from the area, the ventilation system no longer serves the safety function of ‘dynamic containment’, as earlier. However, since there could be radioactive material deposited in several places in the ventilation ducts, the system now serves as ‘static containment’ for the radioactive material contained within. Possible changes in service and environment conditions (e.g. humidity, temperature) that could accelerate the ageing of SSCs also need to be considered.

4. AGEING MANAGEMENT PROGRAMME FOR NUCLEAR FUEL CYCLE FACILITIES

The aim of an ageing management programme for a nuclear fuel cycle facility is the identification and implementation of effective and appropriate actions and practices that provide for timely detection and mitigation of ageing effects in SSCs. A systematic ageing management programme for a nuclear fuel cycle facility comprises the following elements:

(a) Identification of SSCs for ageing management;
(b) Identification and understanding of ageing in SSCs;
(c) Minimization of ageing effects;
(d) Detection, monitoring and trending of ageing effects;
(e) Acceptance criteria, corrective actions and mitigation of ageing effects;
(f) Feedback from operating experience and other R&D results on ageing;
(g) Documentation of ageing management.

These elements are further described in the following sections.

4.1. IDENTIFICATION OF SSCs FOR AGEING MANAGEMENT

Evaluating and quantifying the extent of ageing in every individual SSC of a nuclear fuel cycle facility may not be necessary, considering that there will be large numbers of SSCs with different safety functions, varied importance to safety and a wide ranging extent of susceptibility to ageing. It would be useful to apply a systematic approach to focus resources on those SSCs that are susceptible to ageing and whose failure to operate as intended could have an adverse effect on the safety of the facility.

A process needs to be established to identify the SSCs to be included in the scope of the ageing management programme. This process needs to identify the SSCs that are susceptible to ageing effects that can, directly or indirectly, adversely affect the safe operation of the facility. The non-radiological aspects of safety (especially involving safety of hazardous chemicals) also need to be considered in determining the impact on safe operation of the facility.

A complete list of SSCs in the facility needs to be compiled as an input to the identification process. The initial list can also be compiled from the list of SSCs covered in the maintenance and surveillance programmes of the facility, including structures, mechanical systems, electrical systems and instrumentation and control systems. This list of SSCs needs to be reviewed for completeness.

From this input, a list of SSCs important to safety needs to be compiled on the basis of whether a failure or inability of an SSC to function within predetermined acceptance criteria could, directly or indirectly, lead to the loss or impairment of a safety function. The SSCs that are necessary to cope with certain internal events (e.g. internal fire or internal flooding), external hazards (e.g. extreme weather conditions, external flooding or a seismic event) and other SSCs for ensuring preparedness and response for a nuclear, radiological or chemical emergency also need to be considered for inclusion in the list of SSCs important to safety.

For each of the SSCs identified as important to safety, specific structural elements or components whose failure could lead directly or indirectly to the loss or impairment of safety functions need to be identified. The result of this process is a comprehensive list of structural elements and components important to safety.

From this list, the components and structural elements for which ageing has the potential to cause failure need to be identified for consideration in the ageing management programme. Justification should be provided for the components that are excluded. An outline of this process is shown in Fig. 1.

Further categorization of the components and structural elements identified for the ageing management programme may be done to allow for the use of a graded approach in the implementation of the ageing management programme. This categorization can be based on the consequences of failure of the component or structural element for the safety of the facility. An example of such a categorization process is given in Table 1 below. The outline of this categorization process is shown in Fig. 2.

The process of identification and categorization of SSCs for ageing management needs to be justified and documented. This process can be more detailed for high hazard or complex facilities such as reprocessing facilities and mixed oxide fuel fabrication facilities. Alternative methodologies may also be considered for the purpose of identification and categorization of the SSCs for ageing management, depending on the type of nuclear fuel cycle facility and the regulatory framework of the Member States.

Annex III provides an example of the methodology used as well as a list of SSCs identified for ageing management in a nuclear fuel fabrication facility operating in Romania. Annex IV provides an example of the methodology used and a list of SSCs identified for ageing management for a DSFSF operating in Ukraine.

4.2. IDENTIFICATION AND UNDERSTANDING OF AGEING

A comprehensive understanding of the possible degradation mechanisms and ageing effects in the SSCs of a nuclear fuel cycle facility and of how these can affect the capability of the SSC to perform its function(s) is necessary for the development and implementation of a systematic ageing management programme. This understanding can be derived from the following sources relevant to the SSCs under consideration:

(a) Safety functions and other functions of the SSCs;

(b) Design basis and other design documents of SSCs, including the applied safety codes, standards and regulatory requirements;
(c) Safety analysis and licensing documentation;
(d) Fabrication process, material properties and their changes under fabricating conditions;
(e) Storage, operation and maintenance history of SSCs, including transients, events, modifications, repair, cleaning and replacement;
(f) Equipment qualification and stresses on the SSCs;
(g) Service conditions, including environmental conditions;
(h) Findings during maintenance, in-service inspections, surveillance and condition assessments;
(i) Results of earlier ageing assessments, if any;
(j) Generic and facility specific operating experience;
(k) Relevant R&D results, including the predictive models of ageing.

TABLE 1. EXAMPLE OF CATEGORIZATION OF SSCs FOR USE OF A GRADED APPROACH IN AGEING MANAGEMENT

Category	Included components and structural elements	Ageing management strategy
Category A	Components or structural elements whose failure would have a high impact on safety	All the elements of the ageing management programme are systematically applied
Category B	Components or structural elements whose failure would have a low impact on safety (the expected frequency of failures is low, and the consequence of failure would be within the dose constraints or constraints for non-radiological impacts)	The elements of the ageing management programme are applied using a graded approach
Category C	Consumables such as gaskets or seal rings and other components that are periodically replaced under the facility maintenance programme	The adequacy of periodic maintenance, replacement, inspection, surveillance or testing programmes is reviewed for ageing management

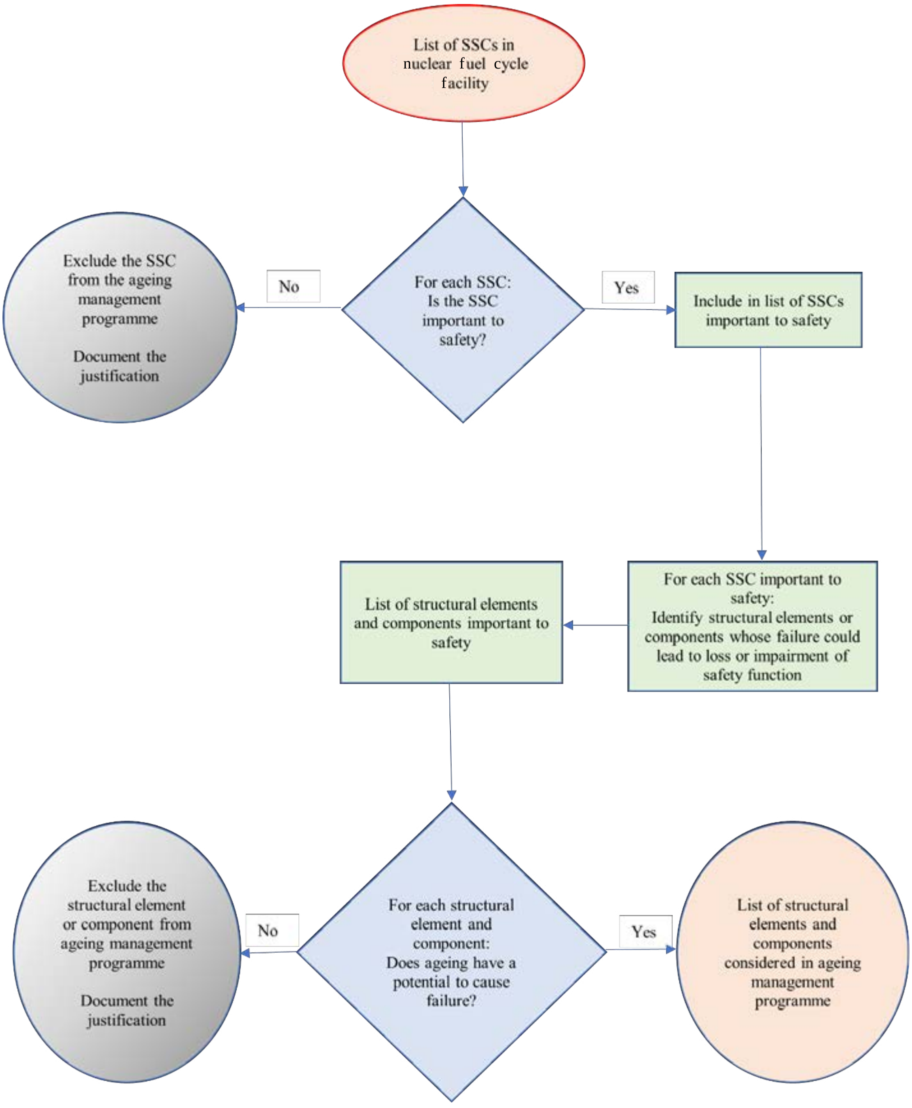

FIG. 1. Outline of the process for the identification of SSCs for ageing management.

The material properties, service conditions and environment of operation of SSCs need to be assessed to determine the potential degradation mechanisms, ageing effects and methods to detect them. The assessment of the interaction of materials and service conditions can be performed using analytical or empirical models that predict future ageing. The level of rigour and conservatism in the assessment depends on the safety significance and complexity of the SSC.

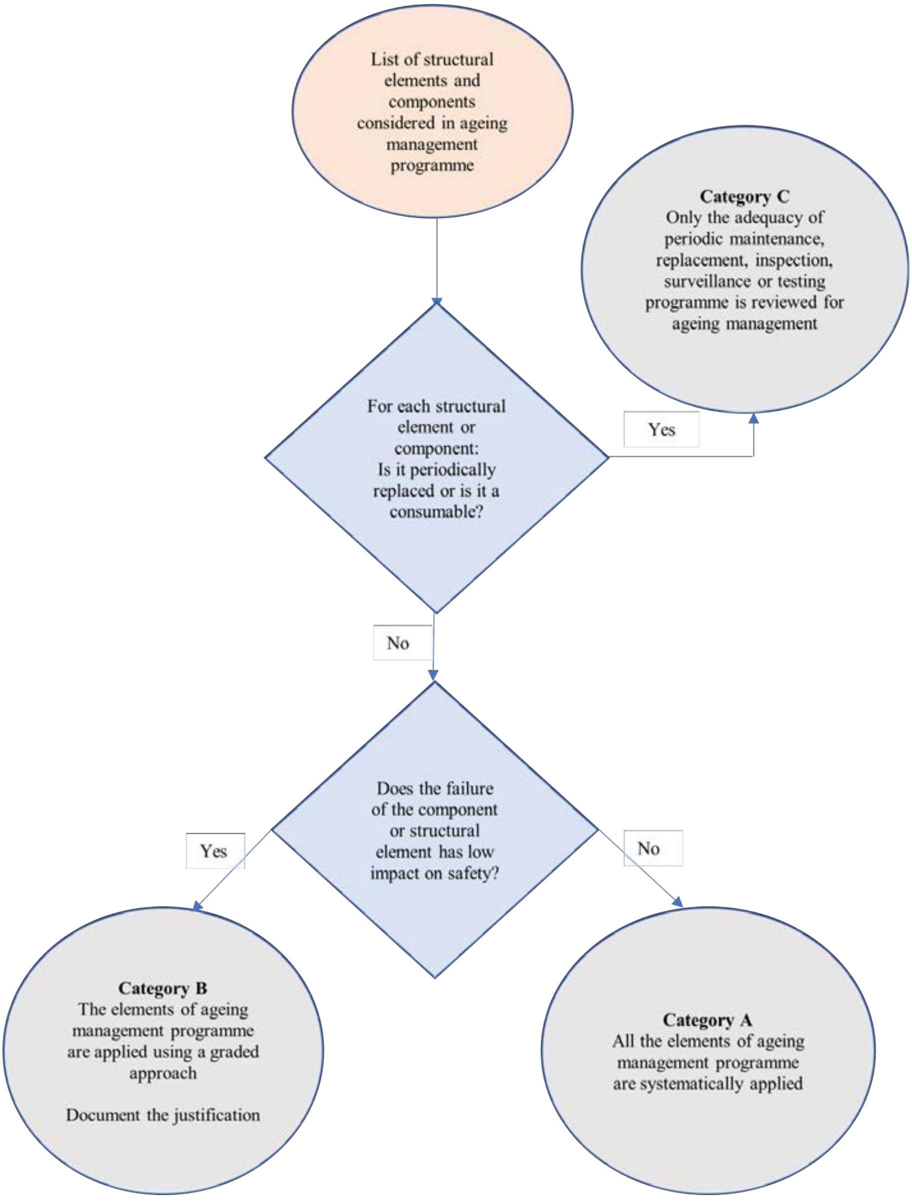

FIG. 2. Outline of the process for categorizing the components and structural elements identified for ageing management.

Evaluation of relevant operating experience and research and development programmes is needed to support better understanding of ageing effects and their degradation mechanisms and to improve the ageing management programme. For some facilities, there may not be enough available operating history or operating conditions related information to confirm the existence of a degradation mechanism or potential for ageing. Inspections and reviews (e.g. periodic safety review) need to be carried out to confirm, or reject, the presence of ageing related degradation in items important to safety. The resources of information on ageing are available from the nuclear industry and chemical industry. This information may be suitably utilized, as applicable, for ageing management in nuclear fuel cycle facilities. In cases where specific information is unavailable, engineering judgement is an appropriate option and should be supported by a rigorous safety assessment.

After the relevant ageing effects and degradation mechanisms are identified, it is necessary to verify whether the identified ageing of SSCs is adequately managed by other facility programmes, such as the maintenance programme. If the ageing of identified SSCs is not adequately managed by existing programmes, the SSC needs to be included in the ageing management programme. The methods for inspection, testing, surveillance, monitoring and assessment need to be evaluated, taking into account their effectiveness in the timely detection of ageing effects before failure of the SSC occurs.

HSE Research Report No. 912, Management of Ageing: A Framework for Nuclear Chemical Facilities [15], provides further information on various degradation mechanisms applicable to nuclear fuel cycle facilities. This report also gives the framework, competencies and processes required to proactively manage ageing in nuclear fuel cycle facilities.

Safety Report Series No. 82 (Rev. 1), Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL) [18], and USNRC Rep. NUREG-2191, Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report [19], provide further information on this topic. HSE Research Report No. 823, Plant Ageing Study: Phase 1 Report [20], provides information regarding degradation mechanisms encountered in chemical plants.

4.3. MINIMIZATION OF AGEING EFFECTS

Ageing management involves the application of preventive measures to minimize ageing as a consequence of service and environmental conditions. The minimization of ageing effects is best achieved during the design stage of the nuclear fuel cycle facility, when the end of the useful life of the equipment is considered from the point of view of the materials of fabrication and the operating environment. Ageing management considerations in the design of a nuclear fuel cycle facility are addressed in Section 3.1.

During the later stages, preventive actions for the minimization of ageing may include scheduled inspections, testing, servicing, calibration, repair, overhaul, protective coating and replacement activities. Additional preventive actions may include the following:

(a) Assessment of the effectiveness of current maintenance and restoration methods and practices;
(b) Establishment of appropriate operating conditions and implementation of necessary practices;
(c) Development of awareness and training programmes for operating and maintenance personnel in relevant aspects;
(d) Implementation of appropriate changes in design, materials, environmental conditions or operation of SSCs to minimize ageing.

These preventive actions for the minimization of ageing need to be continuously assessed and improved on the basis of the operating experience feedback of the facility and of other applicable facilities as well as relevant research findings.

For SSCs that have already undergone significant ageing, minimization can typically be accomplished by applying protective coatings, making repairs, refurbishing or replacing specific components and modernizing or upgrading systems and specific equipment. Refurbishment or replacement of like-for-like components is an ageing management activity that to some extent resets the useful life of the SSC. However, the obsolescence associated with ageing may necessitate significant upgrades or modernization of equipment.

4.4. DETECTION, MONITORING AND TRENDING OF AGEING

A condition assessment of an SSC is an assessment to determine its current performance and condition (including assessment of any ageing related failures or indications of significant material degradation) and to predict its expected future performance, future ageing effects and residual service life.

An evaluation of various examination methods needs to be performed to select those that are appropriate for detecting the effects of the identified degradation mechanisms. Ageing effects may be detected by a change in measurable operating parameters (e.g. vessel or pipe thickness, erosion, corrosion, chemical reaction rates, unusual noise or vibration, temperature, flow rate and pressure). Parameters that can indicate ageing have to be routinely monitored (either on-line or periodically). Common examination methods include:

(a) Performance tests;
(b) Visual examination and non-destructive testing;
(c) Periodic testing and inspection (see Section 6.1);
(d) Monitoring;
(e) Trending.

Often, ageing effects can be detected when carrying out maintenance at the nuclear fuel cycle facility. However, a systematic and in depth assessment of areas of the facility that may be overlooked or disregarded under normal preventive maintenance activities (e.g. inaccessible regions of the facility such as buried SSCs, or SSCs located in areas with high levels of radioactivity such as hot cells or gloveboxes) is also needed. Some degradation mechanisms, like embrittlement in polymers or hydrogen embrittlement in metals, may not be easily detectable during maintenance. Specific non-destructive testing or sample destructive tests may be necessary in such cases.

To determine whether the condition of an SSC is acceptable for continued safe operation or whether remedial measures need to be taken, the results of these examinations are evaluated using the acceptance criteria or the baseline data collected in previous examinations or during the earlier stages (design, construction or commissioning). The examination results need to be added to the baseline data for use in subsequent examinations along with records of the remedial measures or corrective actions taken. The effectiveness of the examination methods themselves (including their sensitivity, reliability and accuracy) needs to be evaluated frequently. The frequency of periodic testing and examination of an SSC needs to be in accordance with the specifications of the designer or manufacturer. The frequency may be adjusted on the basis of the likelihood of failure of the SSC or it may be based on experience, including experience acquired from other similar facilities. Any proposed changes to the frequency of examinations have to be justified, and records of the changes have to be kept.

Details of methods to identify the ageing and degradation of cables, concrete structures and metallic structures are available in IAEA Nuclear Energy Series No. NP-T-3.24 [13]. HSE Research Report No. 912, Management of Ageing: A Framework for Nuclear Chemical Facilities [15], provides further information on methods of inspection to detect various degradation mechanisms applicable to nuclear fuel cycle facilities.

4.4.1. Performance tests

Ageing effects can also be detected by performance testing of SSCs. For example, the drifting of set points or deterioration of electronic or mechanical components may cause changes in the performance of process, instrumentation and control systems. For this reason, the results of the performance test programme, which is dependent on the specific design and operation of the facility, need to be examined for evidence or indications of ageing.

4.4.2. Non-destructive testing

Visual examination methods can be used to detect certain ageing effects, such as signs of corrosion of materials or surfaces, leaks, cracks, distortion of dimensions and even discolouration. Photographs of these observations may be included as necessary in the record of visual examination.

Non-destructive examination techniques may be useful to identify ageing related degradation. These techniques include ultrasonic thickness measurements to monitor vessel and pipe wall thickness, dye penetrant testing and radiographic examination of weld joints, electrochemical corrosion testing, measurement of physical distortion, vibration measurements for identifying degradation in rotating equipment or in interconnected SSCs, radiography measurements for determining internal component conditions, thermal imaging for localization of hot spots and acoustic emission inspections for detecting material defects. For some SSCs that are replaceable or removable, sample destructive tests may be planned (e.g. to determine material embrittlement due to irradiation).

4.4.3. Monitoring

An analysis of the events reported to FINAS [2] indicates that “inadequate actions for monitoring and assessing ageing degradation and obsolescence in the SSCs” are one of the main causes of events that have occurred as a result of ageing related issues. In some of these cases, the monitoring of ageing of SSCs was not rigorous, and the deterioration of systems or components led to releases of hazardous material.

Examples of various monitoring activities that can provide information related to the ageing of SSCs in nuclear fuel cycle facilities include the following:

(a) Corrosion monitoring;
(b) Monitoring of the operability of instrumentation and control systems;
(c) Monitoring of the parameters indicating process efficiency;

(d) Monitoring for imbalance, misalignment, bearing condition, vibration or noise in pumps, motors or rotating tools;
(e) Monitoring of temperature rises in electrical and instrumentation components like motors, transformers, cables and control panels;
(f) Off-gas monitoring;
(g) Monitoring of radiation levels, concentration of particulates and aerosols in the operating areas and in the environment.

4.4.4. Trending

Examination of trends in quantitative and qualitative data can be used to assess the ageing and service life of SSCs. This is important for planning repairs, maintenance and the mitigation of ageing. Trending the data associated with degradation, failure or loss of function of SSCs can also include events or situations where the instrumentation went out of calibration or there were unexpected deviations in operating parameters (such as pressure, temperature, current or voltage), seal failure or replacement events. Unexpected deviation in the parameters can be considered an early sign of impending failure and needs to be investigated. Parameters that can be used to predict ageing effects need to be routinely monitored (either on-line or periodically) and recorded for the purpose of trending and assessment. These readings can be assessed, and trends identified, to predict the onset of ageing effects in a timely manner.

4.5. ACCEPTANCE CRITERIA

Acceptance criteria are the criteria against which the need for corrective actions is evaluated. Appropriate acceptance criteria for the results of the inspection and monitoring of ageing effects need to be established in the ageing management programme. The acceptance criteria need to rely on the design basis or on the technical requirements for the structure or component and the relevant regulatory requirements, codes and standards. They should be set so that a corrective action can be implemented before the loss of the intended function(s) of the SSC. The need for sufficient margins, including uncertainties in the measurement, modelling and understanding of ageing effects, should be taken into account in these acceptance criteria.

4.6. MITIGATION OF AGEING

Timely detection of ageing effects and taking corrective actions for the mitigation of ageing effects on SSCs important to safety is necessary for maintaining their integrity and functional capability throughout their service life.

Methods and practices that are generally adopted for the mitigation of ageing effects include:

(a) Maintenance;
(b) Modification, repair, refurbishment and periodic replacement of SSCs;
(c) Alteration of operating and environmental conditions and practices that may affect the rate of ageing of SSCs.

The effectiveness of the methods and practices for mitigating the ageing of an SSC can be evaluated on the basis of operating experience.

4.7. FEEDBACK FROM OPERATING EXPERIENCE AND OTHER R&D RESULTS ON AGEING

Requirement 73 of SSR-4 states: "**[t]he operating organization shall establish a programme to learn from events at the facility and events at other nuclear fuel cycle facilities and in the nuclear industry worldwide.**"

The ageing management programme for nuclear fuel cycle facilities needs to consider the relevant operating experience from other nuclear fuel cycle facilities and related research and development facilities. Additionally, relevant operating experience related to ageing from nuclear power plants (NPPs), research reactors, chemical plants, the petroleum industry and other relevant non-nuclear industries may also be considered. The operating experience or research results related to ageing at a component level obtained from other facilities needs to be suitably utilized considering the operating and environmental conditions. Relevant facility and industry operating experience and research results need to be systematically collected and evaluated and should be used to improve ageing management programmes.

Operating experience related to ageing management of nuclear fuel cycle facilities, NPPs and chemical plants is available in Refs [17–20]. Further information on understanding the effects of ageing on concrete structures, methods for the inspection, monitoring and assessment of these structures as well as the subsequent maintenance and repair of ageing effects is available in IAEA NP-T-3.5, Ageing Management of Concrete Structures in Nuclear Power Plants [14].

Programmes for sharing applicable experiences related to ageing management in similar facilities can be conducted at the national level. The FINAS database is a suitable platform for sharing operating experience related to nuclear fuel cycle facilities. Annexes III and IV give examples of practices in ageing management of nuclear fuel cycle facilities in some of the Member States.

An evaluation of relevant operating experience and research and development programmes needs to be performed to support better understanding of degradation mechanisms and their ageing effects and to improve the ageing management programme. If a new degradation mechanism is discovered (e.g. through feedback from operating experience or research), the operating organization needs to perform an appropriate review of the ageing management programme to determine the actions to be taken, if any, on SSCs important to safety that are operating in similar conditions.

4.8. DOCUMENTATION OF AGEING MANAGEMENT

A data collection, documentation and record keeping system needs to be in place as a necessary resource for the support of ageing management. The purpose of this activity is to demonstrate that all the ageing effects and degradation mechanisms that affect the safety and operability of the facility have been determined and that the known ageing effects will be adequately managed.

Records of design documentation, including documentation from suppliers and generic and facility specific ageing data, will also be helpful for reference during the planning and execution of an ageing management programme for a nuclear fuel cycle facility. Records of replacements, modifications and maintenance findings for relevant SSCs can be included or referenced in the ageing management programme documentation. Often, this information is maintained or controlled as part of the facility's design and record control systems. Regardless of the means of maintaining these records, it is important to ensure that the necessary documentation is readily available for the lifetime of the facility. These records and documents may also provide support for decision making with regard to the replacement or modification of equipment and would be useful in the ongoing and future assessment of the ageing management programme.

The information relevant to the ageing management programme of the fuel cycle facility that needs to be kept readily available includes the following:

(a) Methodology for the identification of SSCs to be considered for the ageing management programme and the criteria for the consideration and exclusion of SSCs in the ageing management programme;

(b) List of SSCs in the nuclear fuel cycle facility and SSCs considered for the ageing management programme;
(c) Identification and evaluation of degradation, failures and malfunctions of SSCs caused by ageing effects;
(d) Baseline data for the ageing management programme;
(e) Performance reports (ageing management programme related);
(f) Trending of ageing of SSCs;
(g) Prediction of the future performance of SSCs;
(h) Acceptance criteria relating to the ageing of SSCs;
(i) Decisions on the type and timing of preventive maintenance actions, including calibration, repair, modification, refurbishment and replacement, and decisions on adaptations of the ageing management programme based on these actions;
(j) Optimization of operating conditions and practices that minimize or mitigate ageing;
(k) Records of internal and external operational experience feedback related to ageing;
(l) Anticipated obsolescence and measures for addressing the obsolescence of technology, safety requirements and knowledge;
(m) Identification of new emerging ageing effects and research results in the relevant area;
(n) The management system for ageing management.

The above information can be compiled in the form of an ageing management programme document. An effective approach to ageing management is to periodically update the ageing management programme document to include the results of actions taken (and record the decision making process along with the basis) to minimize or mitigate identified conditions leading to ageing effects. The ageing management programme document may also incorporate a simple subsidiary summary report (performed after some predetermined period, e.g. five years) that collects the available data concerning the specific problems addressed and outlines the ageing management activities performed since the previous report. The summary report can include recapitulation of historical records, relevant evaluation and assessment reports, and safety assessments that may support decision making for continued operation. Annexes III and IV include examples of Member States’ practices related to the documentation of an ageing management programme.

5. MANAGEMENT OF OBSOLESCENCE

Mechanisms other than physical or chemical processes can also cause a type of ageing. Non-physical ageing or obsolescence includes technological ageing, non-technological ageing (such as the ageing of standards, documentation or safety requirements) and obsolescence of the knowledge of the operating organization of a nuclear fuel cycle facility.

Management of obsolescence is necessary for enhancing the safety and reliability of a nuclear fuel cycle facility. Obsolescence management requires the involvement of planning, procurement, engineering, maintenance and operations personnel and senior management. The importance of the management of obsolescence should be dealt with in the training programmes of the organizational units concerned. The effectiveness of the obsolescence management needs to be reviewed and assessed periodically.

The following subsections summarize various types of obsolescence, their effects and suggested actions for managing obsolescence in a nuclear fuel cycle facility.

5.1. CHANGES IN TECHNOLOGY

Most nuclear fuel cycle facilities were built decades ago according to the standards and with the technology available at the time of their construction. Since then, significant progress has been made in technology, especially in electronics and computer based equipment. Moreover, further technological advances may occur during the remaining lifetime of a nuclear fuel cycle facility, resulting in the introduction of new components and techniques. This may lead to difficulties in guaranteeing access to spare parts, even if the original instrumentation and control systems of the nuclear fuel cycle facility continue to function well. The new parts may not be compatible with the old systems. This may make it necessary to replace the entire instrumentation and control system of the nuclear fuel cycle facility.

The safety of a nuclear fuel cycle facility can be affected if the technological obsolescence of SSCs is not identified in advance and if corrective actions are not taken before the associated decrease in the reliability or availability of SSCs arises (e.g. malfunctioning of electrical and instrumentation systems, radiation monitoring systems and criticality alarm systems). Technological obsolescence of the relevant SSCs needs to be managed proactively, with foresight and anticipation, throughout their service life.

The following measures may be considered to address technological obsolescence:

(a) Tracking the technological progress of the components used, as well as developments in their manufacture and availability, can provide timely information about upcoming challenges resulting from advancing technologies.
(b) Shortage or lack of spare parts can often be prevented by careful stockpiling of spares. Procurement of a sufficient quantity of spares needs to be done in advance, through direct purchase or through special manufacturing orders. Inventory management, proper storage and periodic checks on the condition of spare parts are needed. Incompatibilities between old and new parts can sometimes be avoided by careful technical preparation for the procurement specifications of the new parts or components.
(c) Technological obsolescence may also lead to necessary modifications that have to be introduced. These modifications need to be implemented as per the operating organization's programme for the control of modifications in the nuclear fuel cycle facility (see Requirement 61 of SSR-4 [1]).
(d) The management of technological changes is closely related to physical ageing and can therefore be part of the facility's ageing management programme.

The obsolescence of computer systems can pose challenges to aspects of computer security, especially to the computer security of the instrumentation and control systems. Computer systems running obsolete hardware or software may not have the necessary security patches and therefore may be vulnerable to cyberattacks. Attacks on these systems may jeopardize the safety of the nuclear fuel cycle facility. Hence, the obsolescence of computer systems also needs to be considered in the ageing management programme of the nuclear fuel cycle facility.

5.2. CHANGES IN SAFETY REQUIREMENTS

The advancement of safety concepts, availability of advanced technologies and operating experience of the facilities are important factors that may contribute to changes in the safety requirements (such as standards, regulations or codes) on the basis of which the facility has been designed, constructed and operated. Changes in safety requirements could also happen as a result of national and international operating experience, newly available safety related technologies and improvements in the understanding (using the results of research and development activities) of areas that were previously unknown or uncertain.

Changing safety requirements may make it necessary to change SSCs or modify processes in nuclear fuel cycle facilities. Retrofitting, replacing or modifying some of the SSCs may be necessary to ensure that the facility is in compliance with the current safety requirements. The operating organization needs to adapt to changing safety requirements in a timely manner. The senior management of the operating organization needs to develop a strategic long term plan for the continued safe operation of the nuclear fuel cycle facility in order to be ready for any significant changes in safety requirements.

The following measures may be considered for proactively addressing issues related to the obsolescence of safety requirements:

(a) Observing developments in comparable industries (e.g. other areas of the nuclear industry or the chemical industry) within the country and internationally;
(b) Engaging with and building trusted relationships with the technical organizations and regulatory bodies that formulate the regulations and providing them with the necessary inputs regarding the revision of safety requirements;
(c) Maintaining a database of the applicable regulations and tracking the revisions;
(d) Developing long term cooperation agreements with external specialists and organizations working in relevant areas.

5.3. OBSOLESCENCE OF KNOWLEDGE

The organizational knowledge of a nuclear fuel cycle facility is linked with its operating staff, specialists and the facility documentation. The knowledge and documentation regarding the design, engineering, safety, modifications, operational experience, basis for operational procedures and regulatory requirements need to be updated and maintained over the lifetime of a nuclear fuel cycle facility. The ageing and retirement of experienced personnel may also lead to gaps in expertise related to the operation and maintenance of the facility. The operational organization needs to prevent the possible loss of knowledge regarding the facility’s design, engineering, safety, modifications and operational experience. The preservation of knowledge regarding the work done by specialized contractors is also necessary.

To prevent the obsolescence of knowledge, the facility documentation needs to be maintained as per Requirements 62 and 63 of SSR-4 [1]. The important groups of documents for this purpose are the following:

(a) Design specifications, manufacturer's data, results of equipment qualification tests;
(b) Safety reports and related safety documentation in relation to the justification of the equipment (such as safety analysis or design basis analysis);
(c) Commissioning reports of SSCs;
(d) Operating and maintenance history of the facility, design modifications and event reports (internal and external);
(e) Records of ageing related failures or significant degradation of SSCs observed during operation and maintenance of SSCs and relevant investigations.

The ageing and obsolescence aspects related to the storage and retrieval systems of the documents, records and reports over the lifetime of the facility also need to be addressed to ensure their availability.

Periodic training (including refresher training) and experience sharing programmes (internal and external) will be necessary to ensure continuity and adequate knowledge management to avoid the obsolescence of knowledge. In order to prevent the possible loss of a specialist's knowledge when they leave the organization, the appropriate proficiency of the successor must be ensured through measures such as internal training, external training and interaction with relevant specialists. The responsibilities and framework for the upkeep and development of organizational knowledge needs to be defined by the integrated management system of the nuclear fuel cycle facility. Additional information on knowledge management and its implementation is available in IAEA Nuclear Energy Series No. NG-T-6.10, Knowledge Management and Its Implementation in Nuclear Organizations [21].

6. INTERFACES WITH OTHER PROGRAMMES AND TECHNICAL AREAS

Paragraph 9.53 of SSR-4 [1] states: "[t]he ageing management programme shall be coordinated with, and be consistent with, other relevant programmes, including the programmes for in-service inspection, periodic safety review and maintenance."

The following important facility programmes and technical areas have significant interface with ageing management:

- — Maintenance, periodic testing and inspection;
- — Safety assessment;
- — Periodic safety review;
- — Equipment qualification;
- — Configuration management;
- — Lifetime extension.

6.1. INTERFACE BETWEEN AGEING MANAGEMENT AND MAINTENANCE, PERIODIC TESTING AND INSPECTION

Paragraph 9.55 of SSR-4 states: "[t]he programme for maintenance and replacement of equipment shall be adjusted in accordance with the conclusions of the ageing management programme."

Paragraph 9.54 of SSR-4 states: "[w]here details of the characteristics of materials and systems are unavailable and could affect safety, a suitable surveillance programme shall be implemented by the operating organization."

The objective of maintenance, periodic testing and inspection programmes is to ensure that SSCs function in accordance with the design requirements and intent, as well as in compliance with the safety analysis report and the operational limits and conditions. The activities in these programmes are closely related to those that need to be established in the ageing management programme.

Maintenance includes both preventive maintenance and corrective maintenance. Preventive maintenance consists of regularly scheduled inspections, testing, servicing, overhauls and replacement activities, to detect and prevent incipient failures and to ensure the continuing capability of SSCs to perform their intended functions. Corrective maintenance consists of repair and replacement of damaged or worn SSCs. In the maintenance programme, consideration needs to be given to the maintenance frequency, testing methods and procedures.

Maintenance, periodic testing and inspection activities also give the necessary inputs for detection, monitoring and trending of ageing. These programmes need to link with the ageing management programme to ensure that the implementation of the maintenance, periodic testing and inspection programmes is consistent with the postulations (e.g. maintenance intervals or testing frequency) made during the development of the ageing management programme and with the findings of the ageing management programme.

The requirements related to design and operational aspects of the maintenance, periodic testing and inspection of a nuclear fuel cycle facility are specified in Requirements 26 and 65 of SSR-4 [1].

Inadequate maintenance, frequently in conjunction with harsh service conditions, could accelerate the ageing of SSCs. Excessive testing or excessive maintenance have a potential for accelerating the degradation mechanisms and resultant ageing effects, and thus can lead to premature ageing of SSCs. Some examples of scenarios where improper maintenance activities can contribute to ageing related degradation in nuclear fuel cycle facilities are given below:

(a) Fatigue stresses due to assembling and reassembling equipment can propagate cracks;
(b) Improper lubrication can result in excessive wear of the seals, bearings or other moving parts;
(c) Air exposure can increase corrosion rates on internal surfaces normally exposed to a deoxygenated or passive environment;
(d) Increased worker activity increases the potential for physical damage to sensitive components (e.g. broken instruments, cracked sight glasses, bent tubing);
(e) Loose parts (e.g. tools and gasket pieces) can cause operational problems including plugging and blockages;
(f) Usage and spillage of chemicals and solvents can damage materials, particularly polymeric materials, or enhance corrosion;
(g) Loose bolting can result in increased noise and vibration and consequential mechanical damage, whereas excessive tensioning of the bolts will accelerate the wear.

The maintenance programme can be evaluated and updated on the basis of the experience gained and findings of the ageing management programme. The maintenance programme has to be coordinated with, and be consistent with, the ageing management programme in accordance with paragraphs 9.53 and 9.55 of SSR-4 [1].

Periodic testing is carried out to confirm the performance of SSCs and also to ensure compliance with the operational limits and conditions. Regularly scheduled tests can be used to obtain necessary information to assess ageing effects (e.g. resistance of cable insulation, leakage tests of confinement or containment structures, or hardness tests of materials). These tests need to be carried out by suitably qualified and experienced persons to ensure that indicators of ageing related degradation are detected at an early stage.

Inspection, an activity inherent to all maintenance and periodic testing, involves the examination of SSCs to determine whether they are acceptable for continued safe operation or whether remedial measures need to be taken. Inspections can also be conducted as non-routine examinations to assess ageing effects. Inspection activities may also be planned during maintenance and shutdown periods, where relevant. The coverage, including the frequency and level of detail of inspection of an SSC, needs to be consistent with its safety or operational significance.

During inspections, evidence of ageing issues can appear progressively or can occasionally be noticed suddenly. Symptoms of ageing related issues in nuclear fuel cycle facilities that need to be noted during inspections could include signs of the corrosion of materials or surfaces; degradation associated with chemicals, environment or process chemistry; plugging; deposits; leaks; cracks; distortion of dimensions; and discoloration. Consideration of manufacturers' recommendations for tasks such as the verification of tolerances may also be necessary during inspections. Operator awareness regarding the identification and reporting of ageing indicators during inspections and also in their routine activities (e.g. noticing unusual noise or vibration) needs to be developed.

The observations related to ageing and related degradation during the maintenance, periodic testing and inspection of SSCs need to be systematically collected, and a database of the same can be developed and maintained for characterizing and trending of the ageing effects.

6.2. INTERFACE BETWEEN AGEING MANAGEMENT AND SAFETY ASSESSMENT

Paragraph 3.16 of IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [22], states:

> "The process of safety assessment for facilities and activities is repeated in whole or in part as necessary later in the conduct of operations in order to take into account changed circumstances (such as the application of new standards or scientific and technological developments), the feedback of operating experience, modifications and the effects of ageing. For operations that continue over long periods of time, assessments are reviewed and repeated as necessary. Continuation of such operations is subject to these reassessments demonstrating to the satisfaction of the regulatory body that the safety measures remain adequate."

The safety assessments carried out at the design stage of a nuclear fuel cycle facility need to take into the account the possible effects of the ageing and obsolescence of SSCs during the lifetime of the facility. Subsequent safety assessments during the operational stage (including modifications and periodic safety reviews) also need to consider the ageing and obsolescence of SSCs. The influence of the ageing of SSCs on their response under accident and emergency conditions should also be considered in safety assessments.

The effect of the ageing of SSCs needs to be considered in the safety assessment during the preparation for decommissioning operations. The assessment needs to take into account the plans and procedures for decontamination and dismantling operations.

Safety assessment plays an important role in the development of an ageing management programme for a nuclear fuel cycle facility. The identification of SSCs for ageing management is performed on the basis of their safety significance, which is addressed in the safety assessment of the facility. The safety assessment also establishes the design basis of some of the SSCs, as well as associated specifications that ensure the existence of appropriate safety margins in the SSCs until the end of their useful lifetime.

Activities related to the minimization and monitoring of ageing, including the maintenance, testing, inspection, repair and replacement of SSCs important to safety, are also based on the safety assessment. Safety assessments can additionally be used (including in the context of periodic safety review) to identify practical and reasonable safety upgrades of the facility, including those that address ageing, for long term safe operation or consideration of extending the facility lifetime.

IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [23], addresses aspects of the safety assessment of nuclear fuel cycle facilities. Safety Reports Series No. 102, Safety Analysis and Licensing Documentation for Nuclear Fuel Cycle Facilities [24], provides details regarding the application of the results of safety analysis for the evaluation of ageing management of nuclear fuel cycle facilities.

6.3. INTERFACE BETWEEN AGEING MANAGEMENT AND PERIODIC SAFETY REVIEW

Paragraph 4.27 of SSR-4 [1] states:

> “The periodic safety review shall confirm that the safety analysis report and other documents (such as the operational limits and conditions and documentation on maintenance and training) remain valid in view of current regulatory requirements, or shall indicate where improvements may be necessary. In such reviews, changes in the site characteristics, changes in the utilization programme (particularly for research and development facilities),

> the cumulative effects of ageing and modifications, changes to procedures, feedback from operating experience and technical developments shall be considered. It shall also be verified that items and software important to safety comply with the design requirements."

Management of the ageing and obsolescence of SSCs is an important factor that needs to be considered in the periodic safety review of a nuclear fuel cycle facility. Evaluation of the consequences of the cumulative effects of both ageing and obsolescence on the safety of a nuclear fuel cycle facility is a continuous process and is required to be assessed in a periodic safety review.

In the framework of the periodic safety review, the operating organization needs to assess the effects of ageing on the safety of the nuclear fuel cycle facility, the effectiveness of the ageing management programme and the need for its improvement. The objective of the review is to determine whether ageing is being effectively managed for SSCs important to safety and whether the ageing management programme is effective for future facility operation.

The aspects relevant to ageing management that are covered in the periodic safety review are the following:

(a) Adequacy of the process of identification of SSCs for ageing management, the list of SSCs considered in the ageing management programme and the criteria for their selection;
(b) Adequacy of the extent of understanding of dominant ageing effects and degradation mechanisms for those SSCs and their impact on safety functions;
(c) Adequacy of the identification of ageing indicators relevant to SSCs and adequacy of a programme for the timely detection and mitigation of ageing effects;
(d) Availability of acceptance criteria and adequacy of corrective actions taken for the continued service (with required safety margins) of the SSCs.

The analysis performed in the periodic safety review will identify necessary safety enhancing actions or facility modifications that need to be implemented, including consideration of the cumulative effects of ageing and modifications. Therefore, the periodic safety review will enable the operating organization to assess the effectiveness of the ageing management programme and the need for improvements to it.

IAEA Safety Standards No. SSG-25, Periodic Safety Review for Nuclear Power Plants [25], details various safety factors considered in the periodic safety review of an NPP that are also relevant to fuel cycle facilities. Further information on the safety factors to be considered in the periodic safety review of nuclear fuel cycle facilities, including ageing management, is available in Atomic Energy

Regulatory Board Safety Guidelines No. AERB/FF&BE-FCF/SG-1, Renewal of Licence for Operation of Nuclear Fuel Cycle Facilities other than Nuclear Power Plants and Research Reactors [26].

6.4. INTERFACE BETWEEN AGEING MANAGEMENT AND EQUIPMENT QUALIFICATION

Requirement 30 of SSR-4 [1] states:

“**A qualification programme shall be implemented to verify that items important to safety are capable of performing their intended functions when necessary, and in the prevailing environmental conditions, throughout their design life, with due account taken of conditions during maintenance and testing.**”

Paragraph 6.115 of SSR-4 [1] states:

“The qualification programme for items important to safety shall include the consideration of ageing effects caused by environmental factors (such as irradiation, humidity or temperature) over the expected service life of the items important to safety.”

Equipment qualification demonstrates that, throughout its qualified life, the equipment will continue to be capable of performing its intended functions in the range of specified service conditions, including transients. Equipment qualification establishes the qualified life of the equipment, in which ageing effects and environmental conditions are also taken into account.

The environmental conditions that could cause ageing effects include humidity, salinity, contact with chemicals, radiation exposure, temperature, meteorological conditions, submergence or electromagnetic fields.

The qualified life of equipment has to be reassessed during the lifetime of the equipment, taking into account progress in the knowledge and understanding of degradation mechanisms and the actual operating environment of the equipment. Monitoring of actual environmental conditions needs to be implemented in order to acquire additional information necessary for the assessment of the ageing effects on SSCs during their service life. The qualification status of equipment needs to be properly documented and maintained throughout the lifetime of the SSC.

The equipment qualification programme, including an assessment of the effectiveness of the programme, needs to be periodically reviewed and consider the ageing effects on SSCs and possible changes in environmental conditions during the service life of SSCs.

IAEA Safety Standards Series No. SSG-69, Equipment Qualification for Nuclear Installations [27], provides guidance on addressing ageing aspects in equipment qualification for nuclear installations, including nuclear fuel cycle facilities.

6.5. INTERFACE BETWEEN AGEING MANAGEMENT AND CONFIGURATION MANAGEMENT

Configuration management is the process of identifying and documenting the characteristics of a facility's SSCs (including computer systems and software) and of ensuring that changes to these characteristics are properly developed, assessed, approved, issued, implemented, verified, recorded and incorporated into the facility documentation [2]. In this context, 'configuration' is used in the sense of the physical, functional and operational characteristics of the SSCs and parts of a facility. Configuration management begins in the design stage of the facility and covers subsequent changes during construction, commissioning, operations, modifications or safety improvements.

The typical configuration changes that happen in a nuclear fuel cycle facility that may have an impact on ageing include the following cases:

(a) Operating at limited capacity as a result of operational challenges, spillages or limited supply of raw materials and reagents;
(b) Operating at higher capacity by utilizing the operating margins available in the SSCs;
(c) Modifications in the SSCs, processes or procedures that may cause uprating or derating of equipment, change operating limits and conditions or an effect on the assumptions made in safety analysis;
(d) Change in feed quality, especially when the feed materials are received from various sources (e.g. yellow cake for a fuel fabrication facility from different vendors or spent fuel with different burn-up or cooling times for a reprocessing facility) or when there is a change in the upstream manufacturing process;
(e) Taking up special operating campaigns for the processing of specific materials (e.g. the need for reprocessing of short-cooled fuel assemblies or failed fuel assemblies, the recovery of useful radionuclides from radioactive waste as part of pre-disposal management, or experimental campaigns to test new process routes).

The impact of these configuration changes on the ageing of the facility needs to be assessed. The operating organization, within its management system, needs to establish a configuration management process aimed at ensuring that changes to the characteristics of SSCs due to ageing and obsolescence are properly assessed before any changes are made to the configuration of the nuclear fuel cycle facility. The findings of these assessments need to be recorded and incorporated into the facility documentation.

6.6. INTERFACE BETWEEN AGEING MANAGEMENT AND LIFETIME EXTENSION OF A NUCLEAR FUEL CYCLE FACILITY

Lifetime extension of a nuclear fuel cycle facility is its operation beyond the established time frame defined by the original plant design, licence term or relevant national regulations or standards. The replaceability of SSCs in nuclear fuel cycle facilities is generally greater than in NPPs. Hence, the lifetime of nuclear fuel cycle facilities is usually determined by the facility's continued usefulness and by its operational costs. Nevertheless, for some facilities with long operational lifetimes, such as spent nuclear fuel storage facilities or radioactive waste storage and handling facilities, the envisaged operating life of the facility is justified during the design stage. This is because their SSCs have little or no possibility of replacement unless sizable modifications are carried out (e.g. to building structures, high level waste evaporators or tanks buried underground without any means of approach). The lifetime extension for such facilities needs rigorous safety reassessment, taking into account the ageing and obsolescence of SSCs.

To pursue lifetime extension or long term operation of the facility, it needs to be demonstrated that the equipment will be capable of performing its intended safety functions throughout its proposed extended life for the required operation time, considering the ageing effects. Proper implementation of an ageing management programme helps in the lifetime extension of a nuclear fuel cycle facility. The data from the ageing management programme will help in establishing the current status of SSCs, evaluating future ageing, determining the need for repair, refurbishment or replacement of SSCs and determining the technical and economic feasibility of the proposed lifetime extension of the nuclear fuel cycle facility.

A safety assessment of the effects of ageing of SSCs, including items important to safety and other systems necessary for the operation of the facility (utilities such as steam, water or compressed air), needs to be performed while considering the lifetime extension of a nuclear fuel cycle facility. The possible improvements to the operational programmes (including ageing management) and management systems related to the safety and operability of the facility also need to be identified on the basis of the safety assessment.

7. MANAGEMENT SYSTEM

Paragraph 3.12 of SF-1 [22] states:

"Safety has to be achieved and maintained by means of an effective management system. This system has to integrate all elements of management so that requirements for safety are established and applied coherently with other requirements, including those for human performance, quality and security, and so that safety is not compromised by other requirements or demands. The management system also has to ensure the promotion of a safety culture, the regular assessment of safety performance and the application of lessons learned from experience."

IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [28], describes the requirements for establishing, assessing, sustaining and continuously improving effective leadership and management for safety in organizations concerned with, and facilities and activities that give rise to, radiation risks.

Requirement 4 of SSR-4 [1] states:

"**The operating organization shall establish, implement, assess and continuously improve an integrated management system for ensuring that all safety requirements are met at all stages of the lifetime of the nuclear fuel cycle facility.**"

The senior management of a nuclear fuel cycle facility is responsible for establishing, applying, sustaining and continuously improving an integrated management system that includes ageing management along with the management of operations, safety, health, environment, operating experience, quality, security and economics. The aspects of human performance and fostering a safety culture need to be considered in the implementation of the ageing management programme. The senior management of an organization is also expected to ensure that managers at all levels in the organization develop and maintain an understanding of ageing and their responsibilities relating to ageing management.

A documented management system that integrates the safety, health, environmental, security, quality and economic objectives of the operating organization needs to be in place for a nuclear fuel cycle facility. The documentation of the management system has to describe the system that controls the planning and implementation of all activities at the nuclear fuel cycle facility throughout its lifetime, including ageing management activities. The management system needs to cover four functional categories: management responsibility; resource management; process implementation; and measurement, assessment and improvement.

For the purpose of ageing management:

(a) Management responsibility includes the planning, support and commitment of management necessary to achieve the objectives of the ageing management programme.
(b) Resource management includes the measures necessary to ensure that the resources essential to the implementation of the strategy and the achievement of the objectives of the ageing management programme are identified and made available.
(c) Process implementation includes the activities and tasks necessary to implement the ageing management programme and achieve its goals.
(d) Measurement and assessment provide an indication of the effectiveness of management processes and work performance compared with the objectives or benchmarks of the ageing management programme. The opportunities for improvement are identified through measurement and assessment.

The management system has to cover all items, services and processes important to safety and include a means of establishing control over ageing management activities, thereby providing confidence that they are being performed according to the established requirements. IAEA Safety Standards Series No. GS-G-3.5, The Management System for Nuclear Installations [29], provides detailed guidance on establishing, implementing, assessing and continually improving the management system for nuclear fuel cycle facilities.

The objective of the management system as applied to ageing management is to ensure that the facility meets the requirements for safety as derived from:

(a) The requirements of the regulatory body;
(b) Design requirements and assumptions;
(c) The safety analysis report;
(d) Operational limits and conditions;
(e) Periodic safety reviews;
(f) Operating experience and results of research and development;

(g) The administrative requirements established by the management of the nuclear fuel cycle facility.

The management system needs to encompass the ageing management related activities, such as:

(a) Identification and evaluation of degradation, failures and malfunctions of SSCs caused by ageing effects;
(b) Trending of ageing effects and prediction of the future performance of SSCs;
(c) Utilization of indicators to facilitate evaluation and improvement of the ageing management programme;
(d) Confirmation (verification) processes for ensuring that preventive actions are adequate and appropriate and that all corrective actions have been completed and are effective;
(e) Optimization of operating conditions and practices that reduce ageing;
(f) Identification of new emerging ageing effects before they jeopardize the safety, reliability and service life of the nuclear fuel cycle facility;
(g) Record keeping and documentation.

The management system also needs to support the development, implementation and enhancement of a strong safety culture in all aspects of the ageing management programme.

7.1. MANAGEMENT RESPONSIBILITY

The management system for ageing management has to provide a framework for managing, performing and assessing the activities necessary to prevent, detect, monitor, assess and mitigate ageing effects. The documentation of the management system for ageing management has to include descriptions of the organizational structure, functional responsibilities, levels of authority and interactions of those managing, performing and assessing the ageing management activities. It also needs to cover other management measures, including planning, scheduling, resource allocation and human factors.

The management system for ageing management has to be outlined in a description of the ageing management programme and documented in operating procedures. The operating procedures have to address all applicable requirements specified in the integrated management system established by the operating organization.

The ageing management activities need to be planned and performed, and their results recorded, in accordance with approved procedures and instructions, which need to be included in the documentation of the management system for ageing management. Successful implementation of the ageing management programme requires that the management ensures the following:

(a) Planning and prioritization of work;
(b) Addressing all relevant regulatory requirements, codes and standards;
(c) Addressing the requirements derived from the operational limits and conditions, and from the safety analysis report;
(d) Ensuring the availability of spare parts, special tools and equipment;
(e) Following up inspection and test results in a timely fashion;
(f) Ensuring the provision of qualified personnel with suitable skills;
(g) Establishing appropriate operating procedures following relevant standards, including procedures for assessing and correcting non-conforming items;
(h) Identifying, disseminating and using information on good practice from designers, manufacturers and other operating organizations;
(i) Performing and adequately documenting the required inspections and tests;
(j) Performing root cause analyses of significant degradation of SSCs and incorporating lessons learned from operating experience;
(k) Continuous updating of the organizational knowledge base, including changes in design standards, safety standards and regulatory requirements, technical advances in the manufacturing and design of SSCs, and advances in in-service inspection and repair methods.

7.2. RESOURCE MANAGEMENT

The operating organization needs to provide adequate resources (both human and financial) to execute the ageing management programme. The management of the operating organization of the nuclear fuel cycle facility needs to participate in the ageing management activities by:

(a) Determining the required competences related to ageing management and planning the development of the necessary competences;
(b) Having frequent personal contact with personnel, including observation of work in progress;
(c) Supervising external personnel (including suppliers) who perform ageing management activities and ensuring that these personnel are adequately trained and qualified;
(d) Supporting and participating in ageing evaluations.

The management system for ageing management has to include provisions to ensure that the ageing management activities are planned, performed and controlled in a manner that ensures effective communication and clear assignment of responsibility.

7.3. PROCESS IMPLEMENTATION

The operating organization needs to identify the person who has the responsibility and accountability for implementing the ageing management programme. This person is usually the facility manager or a sufficiently senior person who has the authority to act on behalf of the facility manager.

Significant changes or failures of any SSCs important to safety have to be recorded, and the data analysed and trends discerned, to identify the causes of these changes or failures. Where the causes of failures have been determined, the information has to be used as input for the improvement of the ageing management programme.

The scope and frequency of tests and in-service inspections have to be specified and they have to be consistent with the operational limits and conditions and regulatory requirements. The recording and presentation of test results need to permit easy comparison with the results of previous inspections and tests, to permit the detection of any changes since previous tests and any deviations from baseline data or reference values.

Valid monitoring and measurements have to be performed to provide evidence of conformity with requirements and satisfactory performance in service. It is necessary to calibrate the equipment used for monitoring, data collection and inspections and tests. The calibration of equipment needs to be documented in order to demonstrate that this calibration is up to date. Inspection and tests have to be performed by qualified personnel and be in accordance with approved procedures.

The management system for ageing management needs to include measures to control records essential to the performance of ageing management activities and to the verification of the results achieved. The records process has to provide for the identification, approval, review, filing, retrieval and disposal of records.

Measures need to be established to ensure that ageing management activities are accomplished as specified in the appropriate procedures, including:

(a) Reviews and revisions of procedures;
(b) Verification by inspection, witnessing and surveillance;
(c) Checks of non-conformances and implementation of corrective actions;
(d) Follow-up of the adequacy and timeliness of corrective actions.

7.4. MEASUREMENT, ASSESSMENT AND IMPROVEMENT

An independent assessment of the ageing management programme needs to be conducted. This task may be performed by the safety committee (or by another competent body); see Requirement 6 of SSR-4 [1].

Audits need to be performed to determine the adequacy and effectiveness of all aspects of the implementation of the ageing management programme and its adherence to the requirements of the management system for ageing management. The operating organization needs to evaluate the results of independent assessment, including audits, and take necessary actions to make improvements. Performance review and continuous improvement of the ageing management programme can be useful for improving the effectiveness of ageing management activities. Where applicable, improvements have to be motivated and driven by current knowledge, and the facility programmes have to be adjusted as appropriate.

Current knowledge can be acquired from:

(a) Information on the operation of SSCs.
(b) Surveillance and maintenance records.
(c) Lessons learned as a consequence of the analysis of incidents that have occurred at other nuclear fuel cycle facilities (see Refs [2, 15, 20]) and information from the results of research for the understanding of:
    (i) New degradation mechanisms;
    (ii) Unexpected ageing locations.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. SSR-4, IAEA, Vienna (2017).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Operating Experience from Events Reported to the IAEA/NEA Fuel Incident Notification and Analysis System (FINAS), IAEA-TECDOC-1932, IAEA, Vienna (2020).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Conversion Facilities and Uranium Enrichment Facilities, IAEA Safety Standards Series No. SSG-5, IAEA, Vienna (2010).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Uranium Fuel Fabrication Facilities, IAEA Safety Standards Series No. SSG-6, IAEA, Vienna (2010).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities, IAEA Safety Standards Series No. SSG-7, IAEA, Vienna (2010).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Storage of Spent Nuclear Fuel, IAEA Safety Standards Series No. SSG-15 (Rev. 1), IAEA, Vienna (2020).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Reprocessing Facilities, IAEA Safety Standards Series No. SSG-42, IAEA, Vienna (2017).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Cycle Research and Development Facilities, IAEA Safety Standards Series No. SSG-43, IAEA, Vienna (2017).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Criticality Safety in the Handling of Fissile Material, IAEA Safety Standards Series No. SSG-27, IAEA, Vienna (2014).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection, 2018 Edition, IAEA, Vienna (2018).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants, IAEA Safety Standards Series No. SSG-48, IAEA, Vienna (2018).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management for Research Reactors, IAEA Safety Standards Series No. SSG-10, IAEA, Vienna (2010).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook on Ageing Management for Nuclear Power Plants, IAEA Nuclear Energy Series No. NP-T-3.24, IAEA, Vienna (2017).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management of Concrete Structures in Nuclear Power Plants, IAEA Nuclear Energy Series No. NP-T-3.5, IAEA, Vienna (2016).

[15] HEALTH AND SAFETY EXECUTIVE, Management of Ageing: A Framework for Nuclear Chemical Facilities, Research Rep. No. 912, HSE, UK (2012).

[16] OECD NUCLEAR ENERGY AGENCY, Ageing Management of Nuclear Fuel Cycle Facilities, CSNI Technical Opinion Papers No. 15, OECD/NEA, Paris (2012).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management of Nuclear Power Plants During Delayed Construction Periods, Extended Shutdown and Permanent Shutdown Prior to Decommissioning, IAEA-TECDOC-1957, IAEA, Vienna (2021).
[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL), Safety Reports Series No. 82 (Rev. 1), IAEA, Vienna (2020).
[19] NUCLEAR REGULATORY COMMISSION, Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR), Rep., NUREG-2191, USNRC, Washington, DC (2017).
[20] HEALTH AND SAFETY EXECUTIVE, Plant Ageing Study: Phase 1 Report, Research Rep. No. 823, HSE, UK (2010).
[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Knowledge Management and Its Implementation in Nuclear Organizations, IAEA Nuclear Energy Series No. NG-T-6.10, IAEA, Vienna (2016).
[22] EUROPEAN ATOMIC ENERGY COMMUNITY, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), IAEA, Vienna (2016).
[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Analysis and Licensing Documentation for Nuclear Fuel Cycle Facilities, Safety Reports Series No. 102, IAEA, Vienna (2020).
[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Periodic Safety Review for Nuclear Power Plants, IAEA Safety Standards No. SSG-25, IAEA, Vienna (2013).
[26] ATOMIC ENERGY REGULATORY BOARD, Renewal of Licence for Operation of Nuclear Fuel Cycle Facilities other than Nuclear Power Plants and Research Reactors, AERB Safety Guidelines AERB/FF&BE-FCF/SG-1, AERB, Mumbai, India (2010).
[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Equipment Qualification for Nuclear Installations, IAEA Safety Standards Series No. SSG-69, IAEA, Vienna (2021).
[28] INTERNATIONAL ATOMIC ENERGY AGENCY, Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2, IAEA, Vienna (2016).
[29] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Nuclear Installations, IAEA Safety Standards Series No. GS-G-3.5, IAEA, Vienna (2009).

Annex I

EXAMPLES OF AGEING OF SSCs OF IN NUCLEAR FUEL CYCLE FACILITIES

The ageing of SSCs in nuclear fuel cycle facilities can be caused by various factors. The consequence of such ageing is the degradation of the characteristics of SSCs that influence their performance. Examples of some of the service conditions, associated degradation mechanisms and ageing effects that are envisaged for the SSCs of nuclear fuel cycle facilities are provided below.

The SSCs of nuclear fuel cycle facilities encounter service conditions relating to stress, temperature, pressure, process chemistry and environmental factors such as radiation, high humidity or corrosive environments during their service life. Such service conditions can lead to the degradation of materials through, for example, one or more of the following degradation mechanisms.

I–1. ABRASION

As water migrates over surfaces such as concrete, it may transport material that can abrade the surface [I–1]. The passage of water may also create negative pressure at the water/air to concrete interface, which can result in abrasion and cavitation degradation of the concrete. This may result in pitting or aggregate exposure due to loss of cement paste.

I–2. BLEEDING

Plasticizers are generally added to polymers to make them flexible during their processing and use. The migration of such additives to the surface of polymers (known as bleeding or blooming) can cause the deterioration of mechanical properties and lead to issues such as hardening, which decreases the flexibility of the material. This phenomenon mostly affects SSCs such as electrical and instrumentation cables and piping made of polymeric materials. The degradation can be caused by environmental factors like high service temperature and exposure to ultraviolet radiation.

I–3. CREEP

Creep is a slow and irreversible deformation process that occurs under constant stress. The deformation depends on the applied stress (which could be mechanical, thermal or both) and the duration of exposure to the stress. Since creep is a gradual process, deformation caused by creep in SSCs can be detected in the maintenance and inspection programme of the nuclear fuel cycle facility.

I–4. CORROSION

Corrosion is the gradual and progressive deterioration or damage of a material (usually a metal or alloy) by chemical or electrochemical reaction with the constituents of the materials with which it is in contact or the external environment. Corrosion may lead to material loss, surface degradation and loss of strength. Corrosion may also cause the deposition of particles (corrosion products) in the process piping and other vulnerable places (e.g. valve seats), which can impair the design intent and function of a component. These particles may also contain radioisotopes, which may result in higher levels of radioactivity in unexpected areas. Such effects may cause hindrance to regular operational activities as well as maintenance work. Certain types of corrosion (e.g. intergranular corrosion, stress–strain corrosion, corrosion fatigue) may lead to loss of strength through crack enhancing. Corrosion (of reinforcing bars in the concrete) can also affect the strength and life of concrete structures. Although the service environment is the main cause of corrosion, many other service conditions, such as those causing erosion, may speed up the process.

I–5. ELECTRICAL TRANSIENTS

Electrical transients [I–1] caused by voltage spikes can contribute to ageing related degradation. Certain types of high energy electrical transients can contribute to electromechanical forces, ultimately resulting in fatigue or the loosening of bolted connections. Transient voltage surges are also a major contributor to the early failure of sensitive electrical components.

I–6. EROSION AND WEAR

Operational conditions such as fluid or powdered material transfers may cause erosion in equipment such as pipes, vessels, hoppers, chutes or heat exchangers. Erosion can also result in the deterioration of surfaces, reduction of thickness and reduction in strength. Environmental conditions, such as harsh weather or a saline environment, can cause the deterioration of building structures.

I–7. FATIGUE

Fatigue is the structural deterioration that can occur as a result of repeated stress–strain cycles caused by fluctuating mechanical or thermal loads. It may be caused by cyclic mechanical, vibration or thermal loading that results in the development and growth of microstructural damage in stressed locations. Failures related to fatigue can be caused at stress levels below the material design limits.

Mechanical fatigue often occurs in locations of a structure or component affected by imperfections and features that induce high stress concentrations. These may be the result of residual stresses consequential to the fabrication processes (e.g. cold working, hot working, annealing or quenching), or they may be owing to the presence of geometrical discontinuities such as sharp bends or sudden changes in cross-section.

Thermal fatigue is caused in regions subjected to cyclic thermal loads. In nuclear fuel cycle facilities, this may happen in equipment such as dissolvers, spray driers, steam ejectors, evaporators or other equipment, piping or components that encounter periodic variation in temperature.

Vibratory fatigue may develop in equipment like centrifuges, centrifugal extractors, off-gas fans, ventilation fans, pulse columns and associated piping that could be in vibratory motion due to the impact of process fluids or connected equipment. Vibration may cause the degradation of electronic components and instrumentation. It can jeopardize the integrity of bonds and seals, and the containment of radioactive and chemically hazardous materials can thereby be challenged. Change of position or of a set point are examples of other issues that can occur because of vibration. Repeated relative motion of adjacent components may result in mechanical wear or fretting.

I–8. RADIATION EFFECTS (IRRADIATION DAMAGE)

Exposure to high levels of radiation may cause changes in mechanical properties, chemical properties, microstructural changes and other effects in structural materials. Polymeric materials (e.g. plastic or rubber) and glass are sensitive to ionizing radiation and need to be carefully selected and monitored during use. The cables, shielding materials, gaskets, sight glasses and so on used in various areas of nuclear fuel cycle facilities are susceptible to irradiation damage.

The irradiation of these materials can cause hardening or cracking of polymeric materials, degradation of confinement tightness or opacity of glass materials. High radiation fields can also cause embrittlement in SSCs made from inorganic materials, including mechanical or instrumentation and control components.

High radiation levels, especially in high level liquid waste tanks, cause the release of hydrogen by radiolysis. In addition to the risks arising from hydrogen's property of being a highly flammable gas, hydrogen attack can lead to ageing effects including embrittlement, blistering and cracking in susceptible materials.

High radiation levels may also lead to the degradation of organic compounds (e.g. solvents or diluents) used in the processes. Though irradiation damage to process fluids is not within the scope of the ageing management of SSCs, it may be noted that the degradation of solvents may lead to phase separation and precipitation or accumulation of material within the process equipment and piping, thus causing degradation and ageing in the SSCs.

Ageing effects caused by irradiation are significant in nuclear fuel cycle facilities that handle spent nuclear fuel and the waste and high specific activity fissile material generated therefrom. These effects are not of major concern in facilities handling natural uranium or other naturally occurring radioactive materials.

I–9. THERMAL AGEING

Thermal ageing is a non-reversible and long term damage mechanism that causes changes in the structure, composition or microstructure of a material. It is dependent on the exposed temperature, the time of exposure and the properties of the material. In nuclear fuel cycle facilities, thermal ageing occurs in equipment or piping that is involved in very high temperature operations such as sintering, reduction, calcination, melting or evaporation. In back end facilities for reprocessing and waste treatment, high temperature application equipment and piping used are for dissolvers, evaporators and vitrification melters.

A temperature above 60°C may cause the degradation of concrete by dehydration, with a corresponding loss of integrity and reduced radiological shielding effectiveness. For this reason, spent fuel storage facilities are typically designed to keep concrete temperatures below 60°C, even in accident conditions.

Thermal ageing is also an important consideration in assessing the ageing of equipment or piping made of plastic or polymeric materials. Elevated temperatures in polymers can result in hardening or a loss in tensile strength and elastic qualities. Polymer panels containing neutron absorbers can become damaged and can significantly lose neutron absorbing capacity because of elevated temperatures. Damage that would indicate loss of neutron absorption capacity may not be visually detectable, and neutron absorber components may be installed in locations where they are partly or completely out of sight. Attention needs to be paid to the proper cooling of electrical and instrumentation and control cables along with electronic components, which may be located in unventilated hot areas.

I–10. EFFECTS OF AGEING FOR DIFFERENT SERVICE CONDITIONS

Examples of the possible effects of ageing for selected service conditions associated with normal operation, anticipated operational occurrences and specific environmental conditions are provided in Tables I–1 and I–2.

TABLE I–1. EXAMPLES OF POSSIBLE EFFECTS OF AGEING FOR SELECTED SERVICE CONDITIONS ASSOCIATED WITH NORMAL OPERATION AND ANTICIPATED OPERATIONAL OCCURRENCES

Condition	Degradation mechanism	Ageing effect
Cycling of temperature, flow and/or load Flow induced vibrations	Motion	Displacement Change in position or set point Loose connections Material damage (cracks)
	Fatigue	Breakage or collapse Deformation Material damage (cracks)
	Wear	Deterioration of surface Change of dimensions
Erroneous maintenance or operation	Mechanical damage and adverse chemical conditions	Deterioration of systems Corrosion Accelerated ageing
Changes in fluid chemistry	Corrosion/galvanic cells	Release of radioactivity Reduction of strength Deposition of particles Short circuits Leakage

TABLE I–1. EXAMPLES OF POSSIBLE EFFECTS OF AGEING FOR SELECTED SERVICE CONDITIONS ASSOCIATED WITH NORMAL OPERATION AND ANTICIPATED OPERATIONAL OCCURRENCES (cont.)

Condition	Degradation mechanism	Ageing effect
	Carbonation (concrete)	Increased porosity/strength reduction Reinforcement corrosion Cracking
	Acid attack	Loss of material Scaling Strength reduction
Changes in fluid flow	Abrasion	Change in strength Material loss/thinning
	Erosion	Change in strength Loss of material
	Leaching (concrete)	Increased porosity/strength reduction Reinforcement corrosion
Radiation	Radiation damage (change in properties)	Chemical decomposition Deformation Change in ductility Swelling Change in resistivity
Soil/ foundation characteristics	Settlement	Displacement/distortion of part of buildings Misalignments Cracking
Stress (pressure)	Creep	Changes in geometry (e.g. a distortion, breakage or collapse)
Temperature	Thermal ageing (change of properties)	Change in strength Change in resistivity Change in ductility

TABLE I–2. EXAMPLES OF POSSIBLE EFFECTS OF AGEING FOR SELECTED ENVIRONMENTAL CONDITIONS

Condition	Degradation mechanism	Ageing effects
Humidity and salinity	Corrosion	Leakage Release of radioactive material Reduction in strength Short circuits
Chemical agents	Chemical reactions	Corrosion Deterioration of SSCs
Wind, dust and sand	Erosion and deposition	Change in strength Deterioration of surface Malfunction of mechanical and electrical components
Extreme low temperatures	Embrittlement	Low temperature brittle fracture Structural failure

Further information on various service conditions, associated degradation mechanisms and ageing effects are available in Safety Reports Series No. 82 (Rev. 1), Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL) [I–1], IAEA Safety Standards Series No. SSG-10, Ageing Management for Research Reactors [I–2], IAEA Nuclear Energy Series No. NP-T-3.5, Ageing Management of Concrete Structures in Nuclear Power Plants [I–3], IAEA Nuclear Energy Series No. NP-T-3.24, Handbook on Ageing Management for Nuclear Power Plants [I–4], and HSE Research Report No. 912, Management of Ageing: A Framework for Nuclear Chemical Facilities [I–5].

REFERENCES FOR ANNEX I

[I–1] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL), Safety Reports Series No. 82 (Rev. 1), IAEA, Vienna (2020).

[I–2] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management for Research Reactors, IAEA Safety Standards Series No. SSG-10, IAEA, Vienna (2010).

[I–4] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook on Ageing Management for Nuclear Power Plants, IAEA Nuclear Energy Series No. NP-T-3.24, IAEA, Vienna (2017).
[I–5] HEALTH AND SAFETY EXECUTIVE, Management of Ageing: A Framework for Nuclear Chemical Facilities, Research Rep. No. 912, HSE, UK (2012).

Annex II

AGEING MANAGEMENT DURING THE DESIGN STAGE FOR A DRY SPENT FUEL STORAGE FACILITY IN ARGENTINA

II–1. BACKGROUND

At the design stage, appropriate margins are provided in the design of SSCs important to safety to take account of the ageing and obsolescence of SSCs. Further, provisions for monitoring the ageing of SSCs that are important to the safety of the nuclear fuel cycle facility are also considered at this stage. The following sections give details of a monitoring and trending system for the detection of ageing that was envisaged during the design stage for a DSFSF in Argentina.

II–2. FACILITY DESCRIPTION

The Almacenamiento en Seco de Elementos Combustibles Quemados (ASECQ) facility is a DSFSF under construction in Lima, Buenos Aires, Argentina. The purpose of this building is to store older spent fuels from the Atucha I/II NPP after they have spent some years in the plant’s decay pools. It has the capacity to store over 2800 spent fuel elements and a design life of 40 years. It is designed as an underground silo with 316 storage units. Each storage unit can hold up to nine spent fuel elements (fuel bundles). The cooling of the decay heat is fulfilled through natural convection, backed up by an active cooling system that starts up if temperatures above 200°C are measured on the stored fuel surface.

To avoid the release of radioactive material to the environment, there are four physical barriers:

(i) Fuel element cladding;
(ii) Storage units;
(iii) Storage silo;
(iv) Building.

The structure of the silo includes the walls, floor, cover and a central column of reinforced concrete 1 m thick that works as a radiological shield and a heat insulator to allow for the normal activities of the staff inside the building. The containment function of the building is essential to avoid the release of radioactive material and provide radiation shielding. Therefore, the structural integrity of the reinforced concrete structures is expected to be maintained beyond the design life of the facility, withstanding operating conditions within the building and meteorological conditions outside it. A pictorial representation of the DSFSF is shown in Fig. II–1.

II–3. AGEING OF CONCRETE STRUCTURES

Reinforced concrete is a composite material in which carbon steel rods are embedded in a concrete structure to improve the physical properties and resistance of the civil structure to the designed service and seismic loads. Normally, the steel is in a passivated state thanks to the alkaline medium that the concrete provides. This property prevents the progressive corrosion of the rods. However, if the chemical condition changes, a corrosive process can take place in the steel, leading to two main consequences:

(i) Loss of material on the rods, which reduces the resistance of the structures;
(ii) Presence of corrosion products that can cause swelling and cracking of the concrete.

One of the main reasons for a change in the chemical condition of the concrete is carbonation. During this phenomenon, carbon dioxide (CO_2) from the atmosphere or soil slowly penetrates through the concrete’s pores, dissolves in the constrained water and reacts with the calcium hydroxide from the concrete, forming calcium carbonate ($CaCO_3$). This reaction reduces the alkaline pH value of the concrete — key to the steel passivation — from about 13 to 9, leading to the generalized depassivation of the steel rods. Carbonation is a degradation mechanism that begins on the surface of concrete structures and slowly penetrates.

The other main reason for a change in the concrete’s chemical condition is the presence of chloride ions (Cl^-). Chloride ions could be present from the construction stages (in the aggregate or water used in the concrete) or could penetrate through the pores from soil or the atmosphere. Chloride ions are not sufficient to induce the corrosion of steel by themselves; the presence of water or oxygen is also needed. Chloride ions can locally break the passivating film on the steel, at which point a pitting process begins to take place.

The ageing of concrete structures is generally monitored by non-destructive techniques such as visual inspections, rebound hammer tests or ultrasonic pulse velocity tests. However, the ageing of the reinforcing steel rods can be hard to detect, and signs of corrosion can be seen only after the phenomenon has advanced and the concrete is swollen or cracked. Further, the ageing could also take place in areas where visual inspection is not feasible.

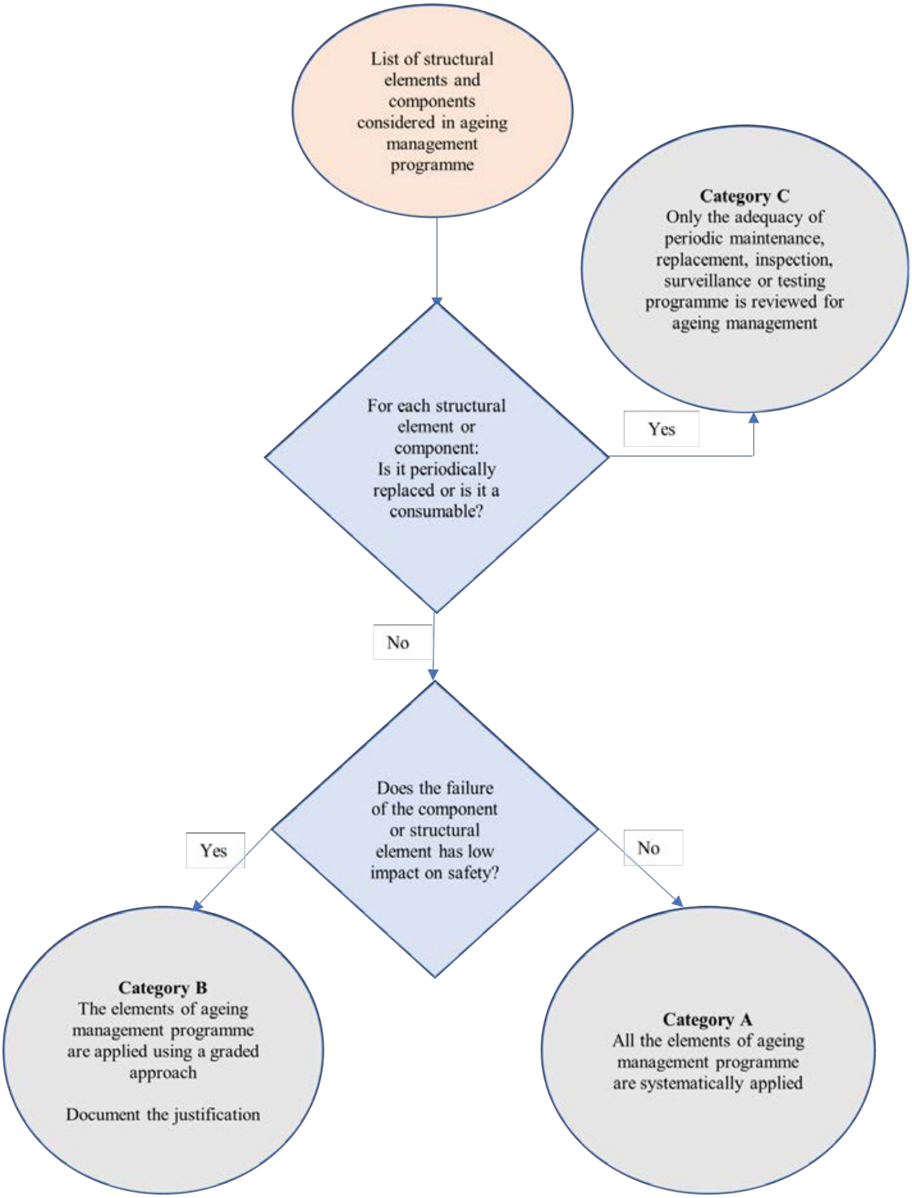

FIG. II–1. Layout of the DSFSF.

II–4. DETECTION OF AGEING

As an ageing management strategy for monitoring and trending the ageing of the reinforcement in civil structures, the installation of corrosion sensors during the construction of the facility was envisaged during the design of the DSFSF. The corrosion monitors were proposed to be installed in the silos and building structures. This activity would form part of a broader ageing management programme, intended to manage and mitigate ageing and its effects on the DSFSF's civil structures, and would be complimented by other activities, such as the application of protective coatings and paints, visual inspections and the monitoring of concrete cover thickness or carbonation progress during the operational stage.

II–5. DESIGN OF CORROSION PROBES

The probes for corrosion monitoring were developed and provided by the Corrosion Department of the Argentinian National Atomic Energy Commission. Each probe consists of a sensor that contains several electrodes: one piece of black steel as a working electrode, two electrodes of inert material, a reference electrode, a specific chloride electrode and a thermometer, all of them embedded in epoxy resin. All of these are employed to measure and characterize different electrical properties of the concrete. These sensors are embedded in the concrete structures and are wired to junction boxes mounted externally on the walls, where the data from the sensors can be periodically measured and collected. These sensors are expected to provide good accuracy and measurement reproducibility.

The properties measured by the installed probes are corrosion potential, corrosion current density, oxygen transport, electrical resistivity, chloride concentration and temperature. The corrosion potential is a thermodynamic indicator of the state of the passivating film of the steel rods near the sensors. Lower measurements of corrosion potential indicate a higher probability of deterioration of the passivating film. Measurement readings and acceptance criteria are interpreted following the ASTM C876 standard, which defines the corrosion potential of steel used in construction to determine their corrosion activity. The corrosion current density is related to the rate of corrosion: the higher the current, the higher the rate of corrosion.

The electrical resistivity and oxygen transport of the concrete are important parameters that can limit or increase the rate of corrosion of the steel. The temperature has a double effect: on the one hand, higher temperatures accelerate the rate of corrosion, while on the other hand, as the temperature increases the moisture in the concrete pores diminishes, which makes the corrosion process less likely. It is expected that trending of the temperature would allow for better understanding of the degradation mechanism of the steel rods. Further information on the development and function of the sensors may be obtained in Refs [II–1] to [II–5].

II–6. MONITORING

For the condition monitoring of the facility, six measuring locations were selected, as detailed below. Each measuring location has been provided with two redundant sensors:

(i) Two measuring locations on the external wall in the lower part of the building, 10.5 m below ground level. One close to the outermost steel rod of the wall, and one close to the innermost steel rod of the wall.
(ii) Two measuring spots on the external wall at ground level. One near the outermost steel rod of the wall, and one near the innermost steel rod of the wall.
(iii) Two measuring spots on the silo cover, at ground level, on opposite sides of the silo.

Each measuring location may be subjected to different service conditions during the service life of the facility. For instance, the outside wall may be submerged as a result of water infiltration (from soil or flooding), whereas the silo cover may be subjected to high temperatures (about 70°C) and gamma radiation from the spent fuels.

The data and measurements are expected to be collected at least three times per year and trended to detect the changes with time and seasonal variation.

II–7. CONCLUSIONS

Consideration of corrosion monitoring provisions during the design allows baseline data to be generated to characterize service conditions and their effects on structures. The proposed monitoring system permits early detection of the possible degradation of the reinforcement or concrete and allows for timely initiation of corrective measures.

REFERENCES TO ANNEX II

[II–1] FARINA, S.B., DUFFÓ, G.S., Development of an embeddable sensor to monitor the corrosion process of new and existing reinforced concrete structures, Construct. Build. Mater. **23** (2009) 2746–2751.

[II–2] DUFFÓ, G.S., et al., "Monitoring of reinforced bars corrosion: comparison among different techniques including sensors specifically designed", paper presented at Eurocorr 2011: The European Corrosion Congress, Stockholm, 2011.

[II–3] VAZQUEZ, D.R., DUFFÓ, G.S., Implementation of non-destructive techniques for the monitoring of rebar corrosion of concrete developed for nuclear application, Int. J. COMADEM **19** (2016) 33–37.

[II–4] VAZQUEZ, D.R., DUFFÓ, G.S., "Methods of monitoring reinforced concrete corrosion in formulations for nuclear facilities", Proc. NACE Corrosion 2017 — Int. Corrosion Conf. Ser. 3 (2017) 180–2188.

[II–5] VAZQUEZ, D.R., DUFFÓ, G.S., Monitoring reinforcement corrosion in concretes for nuclear facilities, Mater. Perform. **57** 3 (2018) 64–67.

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Annex III

AGEING MANAGEMENT PROGRAMME FOR A NUCLEAR FUEL FABRICATION FACILITY IN ROMANIA

III–1. BACKGROUND

The nuclear installations in Romania include operating NPPs (pressurized heavy water reactors), research reactors and other nuclear fuel cycle facilities. The operating nuclear fuel cycle facilities in Romania include a DSFSF (DICA, operating since 2003), facilities for uranium ore mining, milling and processing (Feldioara conversion factory, operating since 1978) and a nuclear fuel fabrication facility (Nuclear Fuel Plant Pitești, operating since 1983).

In January 2016, Romania's National Commission for Nuclear Activities Control issued a specific regulation (NSN-17) on ageing management for nuclear installations. NSN-17 requires the establishment of an ageing management programme in nuclear installations and addresses all the elements of an ageing management programme discussed in Section 4 of this publication. NSN-17 also specifies the requirement for reviewing and updating the ageing management programme, along with the periodic safety review of the facility.

Prior to the issue of the above regulation (NSN-17), the general requirements on ageing management for nuclear installations had been formulated in the licence conditions, as well as in the context of the regulation NSN-10 on periodic safety review, issued in 2006, and the regulation NMC-10, issued in 2003, on management systems for the operation of nuclear installations.

The following sections describe the ageing management programme at the Nuclear Fuel Plant Pitești (FCN Pitești) in Romania.

III–2. BRIEF FACILITY DESCRIPTION

FCN Pitești is a branch of National Company Nuclearelectrica S.A. Bucharest, which is a state owned company reporting to the Ministry of Economy, Energy and the Business Environment. It is situated near the town of Mioveni, 130 km northwest of Bucharest and 370 km from the Cernavoda NPP. The facility was built between 1974 and 1976 as part of the Institute for Nuclear Technologies and was commissioned in 1976.

Between 1992 and 1994, a qualification programme was implemented by the Canadian companies Atomic Energy of Canada Limited, which owns the nuclear fuel CANDU 6 type fabrication technology, and Zircatec Precision

Industries Inc. In December 1995, Atomic Energy of Canada Limited performed a final audit and, on the basis of the results already proved in practice, issued a final certificate declaring FCN Pitești a qualified and authorized CANDU 6 fuel manufacturer.

The main objective of FCN Pitești is to produce nuclear fuel of the CANDU 6 type with natural uranium (or depleted uranium) for the two units of the Cernavoda NPP. The facility processes the source material (uranium dioxide powder with natural uranium or depleted uranium) to produce sintered nuclear fuel pellets and manufacture the fuel bundles.

III–3. AGEING MANAGEMENT APPROACH

For the ageing management programme approach, the following steps have been taken:

(i) Analysis of codes, standards and guides for establishing the requirements of the ageing management programme according to the internationally recognized good practices in this field;
(ii) Establishing the strategy, organizational aspects and resources allocated to the ageing management programme;
(iii) Analysis of SSCs important to safety and identification of those SSCs that, as a result of ageing, may lead to failure of the assigned safety function (resulting in a reduced SSCs list), followed by establishing the criteria and methodology for inclusion of those SSCs in the ageing management programme.

III–4. IDENTIFICATION OF SSCS FOR AGEING MANAGEMENT

A methodology for dividing safety related SSCs into two categories (Category I and Category II) has been established. The first category, Category I, consists of the SSCs that are included in the ageing management programme, and the second category, Category II, consists of the SSCs that are not included in the ageing management programme.

The selection of SSCs for Category I is based on the following criteria:

(i) The SSCs are designed not to be replaced or are difficult to replace.
(ii) They include components whose failure can lead to the loss of the SSC’s ability to perform the assigned safety function, and which cannot be replaced or are difficult to replace.

(iii) They include components that may be affected by ageing.
(iv) Failure of the SSC has an impact on nuclear safety.

The selection of SSCs for Category II is based on the following criteria:

(i) The SSCs are easy to replace or have a short life.
(ii) They include components whose failure can lead to the loss of the SSC's ability to perform the assigned safety function, but which are easy to replace and are supplied by the spare parts system, and the effect on nuclear or radiological safety is not significant.
(iii) They do not include components that may be affected by ageing.
(iv) By default, they have a low or insignificant effect on nuclear safety.
(v) The SSCs are included in the following facility programmes:
   - The ISCIR programme[1], in which the safety assurance of pressure vessels or material handling equipment can be achieved on the basis of the authorization and periodic technical verification regime according to the requirements of the specific legislation.
   - The UCC programme[2], in which the safety assurance of all buildings or structures important for safety can be addressed by a maintenance and surveillance programme that allows the timely detection of the first signs of their degradation and the implementation of preventive or remedial actions.

A sample list of SSCs selected for the ageing management programme on the basis of the above methodology is given in Table III–1.

III–5. IDENTIFICATION OF DEGRADATION MECHANISMS

The important service conditions that contribute to ageing in the SSCs identified for inclusion in the ageing management programme are:

(i) Wet working environment;
(ii) High operating temperatures;
(iii) Vibration.

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[1] Inspecţia de Stat pentru Controlul Cazanelor, Recipientelor sub Presiune şi Instalaţiilor de Ridicat (National Authority for Control and Approvial of Boilers, Pressure Vessels and Hoisting Equipment)

[2] Urmarirea Comportarii in Timp a Constructiilor (Tracking the Behaviour of Constructions Over Time)

The main ageing effects observed in the SSCs included in the ageing management programme are:

(i) Corrosion;
(ii) Degradation of mechanical components, leading to unavailability or malfunctioning of process equipment;
(iii) Degradation of electrical and instrumentation and control components;
(iv) Degradation of sealing elements or components;
(v) Discharging batteries;
(vi) Decreased sensitivity of sensors, which can lead to unavailability of monitoring and detection systems.

III–6. DETECTION OF AGEING EFFECTS

In order to detect ageing effects in the SSCs, the following types of activities are performed:

(i) Visual examination;
(ii) Periodic testing and verification, calibration;
(iii) Measurement of contamination in different areas;
(iv) Temperature monitoring.

A sample list of activities performed, and their associated frequencies, for the detection and monitoring of the ageing of SSCs important to safety at FCN Pitești is included in Table III–2.

III–7. MINIMIZATION AND MITIGATION OF AGEING

Actions for the minimization and mitigation of ageing related degradation include the development and implementation of necessary operating conditions, preventive maintenance and the conducting of necessary periodic inspections or verifications and testing. A sample list of measures applied for the minimization and mitigation of ageing at FCN Pitești is included in Table III–3.

III–8. DOCUMENTATION

The ageing management programme document includes the following information:

- — The philosophy, strategy, objectives, organization and allocated resources of the ageing management programme, together with the way in which the ageing management programme integrates activities relevant to the ageing management of SSCs performed in the frameworks of other programmes and processes;
- — The methodology for identification and the criteria for the inclusion of the SSCs in the ageing management programme;
- — The nuclear safety analyses that use assumptions related to the lifetime of SSCs and the records of the ageing of the respective SSCs;
- — The analyses and documentation regarding ageing related degradation that has the potential to affect the nuclear safety functions of the SSCs, including analysis of the variation and the trending of the failure rates of SSCs due to ageing;
- — The important degradation mechanisms in the SSCs and their effects;
- — The availability of the data necessary for evaluating the ageing of the SSCs;
- — The effectiveness of the operation and maintenance programmes for the ageing management of the components that can be replaced;
- — The acceptance criteria and safety margins imposed for the SSCs in accordance with the design requirements;
- — The measures established for monitoring the evolution of the degradation mechanisms and for their mitigation, in particular for SSCs important to nuclear safety that cannot be replaced and the ageing of which limits the operational lifetime of the nuclear installation;
- — Information on the physical state of the SSCs, including the current safety margins, as well as any other characteristics that may limit their service lifetime;
- — The history of the inspection, surveillance, testing and maintenance of SSCs;
- — The preventive activities implemented or planned to reduce to a minimum and control the ageing of SSCs;
- — The corrective actions for preventing ageing related failure of SSCs and the establishment of acceptance criteria in relation to which the need for corrective actions is evaluated;
- — The use of research and experience exchange programmes at the national and international level, from which the licensee obtains relevant information for the optimization of the ageing management programme;

— The use of internal and external operating experience relevant to the ageing management of SSCs, including lessons learned at the international level in the field of ageing management;
— The measures established for resolving aspects related to SSC obsolescence;
— The list of codes, standards and guides used by the licensee for establishing the requirements and procedures of the ageing management programme, in accordance with good practices recognized at the international level in this field.

TABLE III–1. SAMPLE LIST OF SSCs INCLUDED IN THE AGEING MANAGEMENT PROGRAMME OF THE NUCLEAR FUEL FABRICATION FACILITY

Safety related systems	Safety function	Initiating event covered
Ventilation systems	(A) Retention of hazardous materials (chemical and radioactive)	Radioactive/chemical material releases
	(B) Plant status control and monitoring	Process failures
Gaseous effluent monitoring system	(B) Plant status control and monitoring	Process failures
Emergency power supply system	(A) Retention of hazardous materials (chemical and radioactive)	Uncontrolled radioactive material releases on loss of vent and fire–water systems
Fire–water system	(A) Retention of hazardous materials (chemical and radioactive)	Fire
Fire detection and alarm system	(B) Plant status control and monitoring	Fire
Hazardous gases detection systems (H_2 and CH_4)	(B) Plant status control and monitoring	Explosion
Sintering furnaces	(A) Retention of hazardous materials (chemical and radioactive)	Process failures

TABLE III–1. SAMPLE LIST OF SSCs INCLUDED IN THE AGEING MANAGEMENT PROGRAMME OF THE NUCLEAR FUEL FABRICATION FACILITY (cont.)

Safety related systems	Safety function	Initiating event covered
	(C) Radiological consequences mitigation (internal and external exposure)	Postulated events
Equipment for handling and transport of nuclear materials and solid radioactive waste	(C) Radiological consequences mitigation (internal and external exposure)	Uncontrolled radioactive material releases during handling/transport incidents
Equipment (tanks) for storing liquid radioactive waste	(A) Retention of hazardous materials (chemical and radioactive)	Radioactive material releases

TABLE III–2. SAMPLE LIST OF ACTIVITIES PERFORMED AND ASSOCIATED FREQUENCIES FOR DETECTION AND MONITORING OF AGEING OF SSCs IMPORTANT TO SAFETY AT FCN PITEȘTI

SSCs	Detection and monitoring	Frequency
Ventilation systems	Air piping, radioactive effluent suction, flexible anti-vibration coupling, regulating dampers, distribution grilles Verification:	
	Lack of tightness between sections	
	Pipe deformations	
	Perforated rubber cloth with anti-vibration coupling	
	Mounting brackets on the masonry	Once per year
	Adjustment valve mechanism	

TABLE III–2. SAMPLE LIST OF ACTIVITIES PERFORMED AND ASSOCIATED FREQUENCIES FOR DETECTION AND MONITORING OF AGEING OF SSCs IMPORTANT TO SAFETY AT FCN PITEȘTI (cont.)

SSCs	Detection and monitoring	Frequency
	Air distribution grid mechanism	
	Filter caissons and pre-filters Verification:	
	Tightness (gasket replacement, if applicable)	Once per year
	Weakened elements, vibrations	Once per year
	Closing mechanism for access doors	Once per year
	Microswitch according to closed door (adjust or replace, check the electrical connections)	Once per year
	Differential manometers with liquid	Every six months
	Pressure transducer with adjustable threshold	Once per year
	Fan caissons Verification:	
	Tightness (gasket replacement, if applicable)	Once per year
	Weakened elements, vibrations	Once per year
	Closing mechanism for access doors	Once per year
	Microswitch according to closed door (adjust or replace, check the electrical connections)	Once per year
	Differential pressure transducer with adjustable threshold	Once per year

TABLE III–2. SAMPLE LIST OF ACTIVITIES PERFORMED AND ASSOCIATED FREQUENCIES FOR DETECTION AND MONITORING OF AGEING OF SSCs IMPORTANT TO SAFETY AT FCN PITEȘTI (cont.)

SSCs	Detection and monitoring	Frequency
	Check and replace (if necessary) V-belt	Quarterly
	Electric fan drive assembly Verification:	
	Electrical motor insulation	Once per year
	Tightening electrical connections (check if there is local overheating, and if necessary clean or replace the terminal board, slippers)	Once per year
	Pulley condition	Once per year
	Phase current symmetry	Once per year
	Cooling palette	Once per year
	Bearing replacement	Once every 3 years
	Fan assembly Verification	
	Pulley condition	Once per year
	Propeller	Once per year
	Crank case or crank case cover	Once per year
	Bearing replacement	Once every 3 years
	Automation panel	

TABLE III–2. SAMPLE LIST OF ACTIVITIES PERFORMED AND ASSOCIATED FREQUENCIES FOR DETECTION AND MONITORING OF AGEING OF SSCs IMPORTANT TO SAFETY AT FCN PITEȘTI (cont.)

SSCs	Detection and monitoring	Frequency
	Panel cooling fans (if blocked, clean, grease or replace if burned)	Quarterly
	Check and replace (if necessary) panel air filter	Once per year
	Tightening/checking electrical connections (check if there is local overheating, and if necessary clean or replace the terminal board, slippers)	Once per year
	Circulation pump thermal agent, coolant	
	Circulation pump (check operation, replace if necessary)	Once per year
	Electrical connections	Once per year
	Thermal relay adjustment check	Once per year
	Three way valve actuators, isolation flaps	
	Electrical connections	Once per year
Gaseous effluent monitoring system	Flow check	Twice per year
	Suction pump check	Twice per year
	Filter advance check	Once per year
	Detector check	Once per year
	Checking the pressure difference	Once per year
	Analogue output check	Once per year

TABLE III–2. SAMPLE LIST OF ACTIVITIES PERFORMED AND ASSOCIATED FREQUENCIES FOR DETECTION AND MONITORING OF AGEING OF SSCs IMPORTANT TO SAFETY AT FCN PITEȘTI (cont.)

SSCs	Detection and monitoring	Frequency
	Nuclear calibration	Twice per year
Emergency power supply system	Checking/completing the fuel level	Monthly
	Checking the condition of the diesel generator electric battery	Monthly
	Starting and checking the operation of the diesel generator	Monthly
	UPS (uninterrupted power supply) source battery status check	Quarterly
Fire detection and alarm system	Check at least one button and a detector on each detection line	Quarterly
	Periodic replacement of sensors (replacement period will be determined following the results obtained from periodic checks)	Minimum 10 years

TABLE III–3. SAMPLE LIST OF MEASURES APPLIED FOR MINIMIZATION AND MITIGATION OF AGEING

SSCs	Degradation mechanism/ ageing effect	Ageing management measures
Ventilation systems	Corrosion, temperature, humidity/ mechanical wear/ thermal ageing/ degradation of sealing elements	Technical inspections/verification in accordance with specific procedure Procedure for maintenance, verification and testing Operation in accordance with technical requirements

TABLE III–3. SAMPLE LIST OF MEASURES APPLIED FOR MINIMIZATION AND MITIGATION OF AGEING (cont.)

SSCs	Degradation mechanism/ ageing effect	Ageing management measures
Sintering furnaces	Corrosion, temperature, humidity/ mechanical wear/ thermal ageing/ degradation of sealing elements	Operation according to the operating procedures Periodic maintenance according to supplier maintenance manual Periodic technical inspections/verification for: • Tightness, gas supply circuits • Tightness, pneumatic circuits • Electrical circuits • Tightness, cooling water routes • Gaskets and sealing sleeves for linear or rotating bearings
Emergency power supply system	Moisture induced corrosion, fouling and other damage	Procedure for periodic cleaning/verification and testing: • Checking/completing fuel level — monthly • Diesel generator electric battery condition check — monthly • Starting and checking the operation of the diesel generator — monthly • UPS (uninterrupted power supply) source battery status check — quarterly
Hazardous gases detection systems (H_2 and CH_4)	H_2 and CH_4 sensors; electrical connections Decreased sensitivity of sensors; oxidation of connections, thermal ageing of cables	Periodic checks/testing Periodic replacement of sensors — at least 6 years (replacement period will be determined following the results obtained from periodic checks)

Annex IV

AGEING MANAGEMENT PROGRAMME FOR A DRY SPENT FUEL STORAGE FACILITY IN UKRAINE

IV–1. BACKGROUND

The nuclear facilities in Ukraine include NPPs, research reactors and other nuclear fuel cycle facilities. The nuclear fuel cycle facilities in Ukraine (excluding NPPs and research reactors) are:

- DSFSF in operation at the Zaporizhzhya NPP site;
- Spent fuel storage facility in operation at the Chornobyl NPP site;
- Central DSFSF in the construction stage at the Chornobyl NPP site;
- Fuel fabrication facility in the design stage.

The development of the ageing management programme for nuclear fuel cycle facilities in Ukraine is based on adapting the requirements of ageing management for NPPs, considering features specific to the operation of nuclear fuel cycle facilities. Ageing management programmes developed using this approach for DSFSFs and other spent fuel storage facilities have been approved by the Ukrainian Regulatory Authority. Development of specific regulatory requirements on ageing management for nuclear fuel cycle facilities in Ukraine is in progress.

The ageing management programme adopted in the DSFSF facility at Zaporizhzhya includes the elements of the ageing management programme described in Section 4 of this publication. The important aspects of the ageing management programme of the DSFSF facility are described below.

IV–2. BRIEF FACILITY DESCRIPTION

Zaporizhzhya DSFSF Stage I (design capacity: 100 containers) was put into commercial operation in 2004, and DSFSF Stage II (design capacity: 280 containers) was commissioned in December 2011. In the DSFSF, the storage casks containing spent nuclear fuel are placed in a vertical position on a special concrete storage slab (on a base plate). Ventilated storage casks for water-water energetic reactors (VSC-VVER) are the main storage system of the DSFSF. The VSC-VVER cask consists of two components: a multi-assembly sealed basket (MSB) and an external ventilated concrete cask. The purpose of the cask is to ensure passive and dry containment for the safe storage of spent fuel. Figure IV–1 shows a schematic of a VSC-VVER cask.

IV–3. IDENTIFICATION OF SSCs FOR AGEING MANAGEMENT

Figure IV–2 illustrates the methodology adopted in the DSFSF for the selection of SSCs for ageing management. The methodology allows certain safety related SSCs (for which maintenance and repair allow the detection and mitigation of ageing effects) to be excluded from the ageing management programme. However, using a conservative approach, all the SSCs that are important to safety have been considered for the ageing management programme. The Regulatory Authority of Ukraine approved this approach for the DSFSF in operation at the Zaporizhzhya NPP site. A sample list of SSCs identified for ageing management in the DSFSF is given in Table IV–1.

IV–4. IDENTIFICATION OF DEGRADATION MECHANISMS

Corrosion, especially due to moisture ingress or oxidation, was the key degradation mechanism identified for metallic SSCs like the MSB and the spent fuel pins. For concrete structures, like the ventilated container and the foundation slab, carbonization of the concrete and corrosion of the reinforcement were the important degradation mechanisms of concern. Table IV–1 shows the identified degradation mechanisms and ageing effects for the SSCs of the DSFSF.

IV–5. DETECTION OF AGEING

To detect ageing in the SSCs, the following types of examination and testing have been envisaged in the DSFSF:

(i) Visual examination of SSCs that are accessible;
(ii) Measurement of contamination or radionuclides in the ventilation ducts, effluents and groundwater;
(iii) Temperature monitoring;
(iv) Non-destructive examination and testing of concrete.

Table IV–2 shows the sample frequencies for detection and monitoring of ageing of SSCs for the DSFSF.

IV–6. MINIMIZATION AND MITIGATION OF AGEING

The actions for the minimization and mitigation of ageing in the DSFSF include the development and implementation of necessary operating conditions and maintenance practices, and the conducting of necessary periodic inspections. Table IV–1 gives the proposed ageing management measures for minimization and mitigation of ageing in the DSFSF.

IV–7. DOCUMENTATION

The ageing management programme document for the DSFSF has the following structure:

- Introduction;
- Brief design description of the DSFSF and storage casks;
- Methodology and organization of the DSFSF management system;
- Organization of the DSFSF ageing management system;
- Requirements for planning and implementing ageing management measures;
- Requirements for monitoring of ageing effects;
- Reporting;
- Assessment of ageing management programme;
- Annexes (procedure for identification of SSCs for ageing management, list of SSCs identified for ageing management, schedule of investigations and R&D measures related to ageing of SSCs and ageing management).

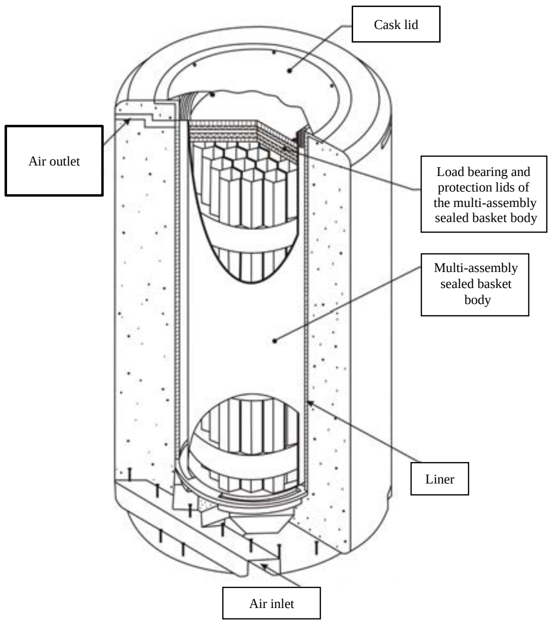

FIG. IV–1. Schematic of the VSC-VVER at DSFSF, Ukraine.

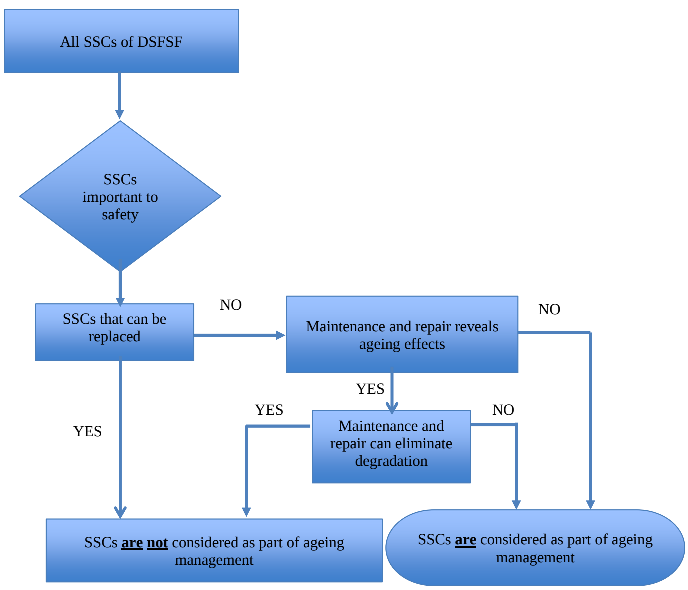

FIG. IV–2. Methodology adopted in the DSFSF for selection of SSCs for ageing management.

TABLE IV–1. SAMPLE LIST OF SSCs IDENTIFIED FOR AGEING MANAGEMENT IN THE DSFSF

System	Abbreviation	Structure/ component	Safety function	Ageing effect/ degradation mechanism	Material	Operating condition	Ageing management measures
Important SSCs that are not amenable for inspection or testing for detection of ageing effects							
Spent fuel rod	Fuel rod/ SFR	Fuel rod shell	The barrier that limits radioactive material release	Shell oxidation, corrosion due to water ingress, shell creep, shell annealing, redistribution and reorientation of hydrogen compounds	Zirconia alloy (Zr–1% Nb)	Helium T = not more than 450°C	R&D Spent fuel rod behaviour under long term operation
Multi-assembly sealed basket	MSB	MSB body	Placement, storage and cooling of spent fuel rod in helium environment Decreasing of neutron flux, preventing the release of radioactive aerosols into the environment	Corrosion, low cycle fatigue	10HSND with enamel coating KO-828M	Air T = not more than 60°C	Operation according to the operating procedures

TABLE IV–1. SAMPLE LIST OF SSCs IDENTIFIED FOR AGEING MANAGEMENT IN THE DSFSF (cont.)

System	Abbreviation	Structure/ component	Safety function	Ageing effect/ degradation mechanism	Material	Operating condition	Ageing management measures
Important SSCs that can be inspected or tested for detection of ageing effects							
Ventilated concrete container	VCC	Reinforced concrete structure	Protection of the contour of the MSB from external influences and special loads Protection of the MSC from possible deformations that can lead to depressurization of the MSB	Chips, cracks, destruction of concrete, carbonation of concrete protective layer, corrosion of reinforcement	PC 1–500 concrete, non-stressed reinforcement Class A III	Effects of weather conditions Ambient temperature range, °C:	Carrying out technical inspections in accordance with the requirements of the instructions for conducting technical surveys of MSB, VCC, VSC-VVER.

TABLE IV–1. SAMPLE LIST OF SSCs IDENTIFIED FOR AGEING MANAGEMENT IN THE DSFSF (cont.)

System	Abbreviation	Structure/ component	Safety function	Ageing effect/ degradation mechanism	Material	Operating condition	Ageing management measures
			Biological protection of personnel, the population and the environment from ionizing radiation.			Normal: minus 9 to 27 Extreme: minus 34 to 42	Instructions for maintenance and control of the state of spent nuclear fuel and ventilated concrete containers at the site of storage of spent nuclear fuel. Operation of MSC in accordance with the technical regulations.
Other SSCs							

TABLE IV–1. SAMPLE LIST OF SSCs IDENTIFIED FOR AGEING MANAGEMENT IN THE DSFSF (cont.)

System	Abbreviation	Structure/ component	Safety function	Ageing effect/ degradation mechanism	Material	Operating condition	Ageing management measures
Remote temperature control system	RTCS	Transceiver Temperature sensors TSP–1390 Communication cable Repeater	Transmission of information about the air temperature in the outlet ventilation ducts of VSC-VVER	Electrochemical corrosion, thermal ageing, loss of insulating properties of materials	Radio parts, rechargeable battery	Effects of weather conditions Ambient temperature range at SS ZNPP, °C: Normal: minus 9 to 27; Extreme: minus 34 to 42	Operating instructions for the temperature control system of air in the ventilation ducts of the containers of spent nuclear fuel
Spent fuel transportation container	SFTC	Gate and hydraulic drive mechanisms	Attenuation of radiation power from spent fuel assemblies, protection of MSB from mechanical influences	Corrosion, mechanical wear	Steel, lead	Air, boric acid solution	Operation manual

TABLE IV–1. SAMPLE LIST OF SSCs IDENTIFIED FOR AGEING MANAGEMENT IN THE DSFSF (cont.)

System	Abbreviation	Structure/ component	Safety function	Ageing effect/ degradation mechanism	Material	Operating condition	Ageing management measures
Foundation slab of the DSFSF	Storage area	Reinforced concrete structure	Safe storage of containers weighing 150 tonnes with a step of 4.5 m and cargo from a moving conveyor	Chips, cracks, destruction of concrete, carbonization of concrete of the protective layer, corrosion of reinforcement	B25W6 concrete (strength class B25, water resistance class W6, frost resistance class F75), reinforced with steel meshes on two levels, made of periodic profile reinforcement class A III	Effects of weather conditions Ambient temperature range at SS ZNPP, °C:	Acts of readiness of the site of storage of spent nuclear fuel for the VSC-VVER installation
						Normal: minus 9 to 27 Extreme: minus 34 to 42	Seasonal inspection of the state of building structures

TABLE IV–1. SAMPLE LIST OF SSCs IDENTIFIED FOR AGEING MANAGEMENT IN THE DSFSF (cont.)

System	Abbreviation	Structure/ component	Safety function	Ageing effect/ degradation mechanism	Material	Operating condition	Ageing management measures
Radiation protective structure	RPS	Reinforced concrete structure	Attenuation of radiation power from VSC–VVER	Chips, cracks, destruction of concrete, carbonization of the protective layer concrete, corrosion of reinforcement	Monolithic reinforced concrete structures 5.5 m high and 0.3 m thick	Effects of weather conditions Ambient temperature range at SS ZNPP, °C: Normal: minus 9 to 27 Extreme: minus 34 to 42	Seasonal inspection of the state of the RPS of the building structures
Absorbent inserts	AI	AI	Nuclear safety assurance with a heterogeneous absorber	Corrosion due to moisture ingress	Steel 08X18H10T, 12X18H10T	Helium T = no more than 450°C	Not required

TABLE IV–2. SAMPLE FREQUENCIES FOR DETECTION AND MONITORING OF AGEING OF SSCs FOR THE MAIN ELEMENTS AND STRUCTURES OF THE DSFSF

Component	Basis for implementation of ageing management measures	Detection and monitoring	Frequency
MSB shell	Instructions for technical inspection of MSB, VCC, VSC-VVER Technological regulations for the safe operation of a DSFSF	Technical inspection Conducting visual inspection of MSB in accessible places for: Detection of defects and damage to the outer surface of the MSB Inspection of welded joints Inspection of the state of the anticorrosion coating of the outer surface of the MSB and welded joints	Once every 4 years
		Measurement of alpha-, beta- radionuclide contamination of the lattices of the outlet ventilation ducts of VSC-VVER	Twice a year
		Measurement of the volumetric activity of radioactive gases from the outlet ventilation ducts of VSC-VVER	Twice a year
		Measurement of the volumetric activity of radioactive aerosols from the outlet ventilation ducts of VSC-VVER	Twice a year
		Determination of the activity of radionuclides in groundwater	Once a quarter
		Determination of the activity of radionuclides in wastewaters of the site	Once a quarter

TABLE IV–2. SAMPLE FREQUENCIES FOR DETECTION AND MONITORING OF AGEING OF SSCs FOR THE MAIN ELEMENTS AND STRUCTURES OF THE DSFSF (cont.)

Component	Basis for implementation of ageing management measures	Detection and monitoring	Frequency
		The value of the temperature difference at the outlet of the VSC-VVER ventilation duct and the ambient air temperature (no more than 61°C)	Temperature measurement is performed three times a day
Ventilated concrete container	Instructions for maintenance and control of the condition of spent nuclear fuel and ventilated concrete containers at the site of storage of spent nuclear fuel	Conduct non-destructive control of concrete surfaces in accordance with technical regulations for safe operation	According to the current schedules
		Perform periodic control of the corrosion state of the metal on the VCC cover	Once every 4 years
		Conduct a specialized inspection of the VCC, determining the over design lifetime and resource reassignment	Once every 4 years
		Non-contact diagnostics of possible defective areas of concrete surfaces of VCC	According to the current schedules

TABLE IV–2. SAMPLE FREQUENCIES FOR DETECTION AND MONITORING OF AGEING OF SSCs FOR THE MAIN ELEMENTS AND STRUCTURES OF THE DSFSF (cont.)

Component	Basis for implementation of ageing management measures	Detection and monitoring	Frequency
		Inspection of the external surface of the VCC, control of shapes and sizes in accessible places, observing defects and damage on the surface	According to the current schedules

LIST OF ABBREVIATIONS

DSFSF	dry spent fuel storage facility
FINAS	Fuel Incident Notification and Analysis System
GSR	General Safety Requirements
HSE	Health and Safety Executive, United Kingdom
MSB	multi-assembly sealed basket
NPP	nuclear power plant
R&D	research and development
SSCs	structures, systems and components

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The ageing of structures, systems and components is one of the major challenges faced by nuclear fuel cycle facilities worldwide. This publication is intended to provide information on methods, approaches, practices and strategies for ageing management of nuclear fuel cycle facilities. It provides practical information on the establishment of effective ageing management programmes for nuclear fuel cycle facilities in the operational stage and on ageing management considerations in different stages in the lifetime of a nuclear fuel cycle facility. It also addresses the interface of ageing management with other technical areas and programmes, including maintenance, periodic testing and inspection, equipment qualification and configuration management. Best practice examples on how Member States are addressing ageing issues in nuclear fuel cycle facilities are also provided in this publication.

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