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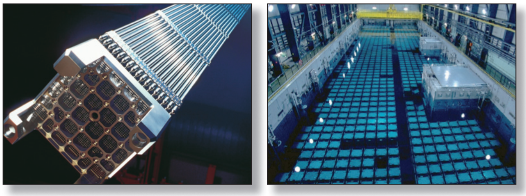
Ageing Management of Nuclear Fuel Cycle Facilities



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Ageing Management of Nuclear Fuel Cycle Facilities

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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The mission of the NEA is:

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Also available in French under the title:

Avis techniques du CSIN n° 15 – Gestion du vieillissement des installations du cycle du combustible nucléaire

Cover photos: Nuclear fuel assembly (AREVA); wet storage of spent fuel (NEI).

Foreword

The objective of the OECD Nuclear Energy Agency (NEA) Working Group on Fuel Cycle Safety (WGFCS) is to advance the understanding for both regulators and operators of relevant aspects of fuel cycle safety in member countries.

Managing the ageing of fuel cycle facilities (FCFs), as for other nuclear installations, means ensuring the availability of required safety functions throughout their service life taking into account the changes that occur with time and use. This requires addressing both physical ageing resulting in degradation of structures, systems and components (SSCs) important to safety, and the obsolescence of SSCs, i.e. their becoming out of date with the current knowledge, standards, regulations and technology (which may result in a lack of spare equipment).

On 5-7 October 2009, the NEA/WGFCS organised a workshop on ageing management of fuel cycle facilities. This workshop brought together 40 participants from 8 countries during two and half days of exchange and discussions. During the workshop conclusions, participants pointed out the need for the WGFCS to continue working on ageing management for FCFs and to prepare a dedicated technical opinion paper.

Acknowledgements

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Executive summary

The goal of ageing management is to address in a systematic way all the time-dependent parameters that can jeopardise the FCF safety during its life. This is a proactive process implemented from the facility design until its dismantling to ensure that the appropriate measures are taken to address the wear-out mechanisms of SSCs, their obsolescence compared to the current standards, and also non-technical challenges like knowledge management. It is especially crucial for the potential life extension of the facility and for deciding of its refurbishment or its shutdown and decommissioning.

In addition to these ageing management aspects common to all nuclear facilities, the ageing management of FCFs needs to cope with specific aspects like the combined nuclear and chemical hazards, uniqueness of designs, and a long operational life with numerous evolutions/additions of equipment, processes, facilities and operation. Non-technical issues of ageing management are enhanced by the size of the facilities, often located in large and complex site, and by the specific organisations set in place at the end of operational stage to face knowledge issues and legacy situations.

FCFs are characterised by their radioactive and chemical materials, in diverse physical and chemical forms, spread in interconnected vessels and equipments. Hazards are specific to the facility (e.g. criticality and/or chemical hazards) but in a general way related to potential releases of hazardous materials out of their containment. In the frame of this document, this implies that an in-depth assessment of technical ageing mechanisms that could affect the SSCs is carried out with a special focus on the physical wear i.e. corrosion and erosion of the first barrier, and plugging and deposits within it.

FCF ageing management can be eased by a set of good practices identified by benchmark of strategies and actions to cope with physical ageing, including the degradation of process. This last aspect is of particular importance for FCFs which often use chemical processes, the safety of which relies on the ability to keep the process implemented as designed (and as assessed for getting the operating licence).

Design is a fundamental stage of the FCF ageing management programme. It is used to anticipate and reduce consequences of the SSCs alteration due, in particular, to physical ageing mechanisms, and in any case, to rigorously apply the defence in depth (DiD) concept by taking into account these mechanisms. SSCs are identified with the associated requirements on their conditions and performances. These performances have to be maintained thanks to strategies that have to be prepared at the design stage.

At the FCF design stage for instance, the prevention/limitation of mechanical degradations can be achieved by proper design margins, or design and layout to allow/ease the replacement with spare parts. Preventive, corrective or mitigation measures can be implemented by specific equipment design or operating procedures against plugging and deposits. The number of SSCs for which periodic testing or maintenance is impossible (e.g. buried SSCs or located in areas with high level of radioactivity) should be limited and compensatory indirect testing measures should be anticipated during the design in order to detect rapidly degradations due to the ageing mechanisms (e.g. by chemical analysis of a non-accessible vessel to detect corrosion, I&C to calculate the volume shipper/receiver difference after each transfer to detect the potential leak of an non-accessible piping).

During operation, the conditions encountered by the SSCs should be recorded and used as an input for defining their periodic testing and maintenance, and inspection strategy for a timely detection and mitigation of ageing effect of SSCs. Specific organisational provisions (e.g. database, document that captures information from staff) should be part of the strategy during operation with particular attention paid to minor events, especially repetitive ones, that seem trivial when they occur but may be of great importance later (e.g. minor leaks and contaminations, small modifications).

At the end of the FCF operational stage, appropriate arrangements should be made to ensure that the SSCs, especially those associated to the protection of the workers against exposure of ionising radiation (ventilation and radiation protection in particular), remain available and functional to realise the decommissioning and dismantling operations.

The design and co-ordination of ageing management programme aiming at a proactive ageing management should have a special focus on knowledge management, i.e. replacement and training, documentation management and operating experience feedback (OEF) related to ageing. These various components need to be implemented over the life of a FCF, with a specific care to anticipate the needs for the future decommissioning and dismantling operations that require operation records and knowledge capture from the previous operational stage of the FCF.

The management of obsolescence is also supported by a benchmark of good practices where recommended actions are identified and classified according to the nature of the obsolescence: changes affecting the technology (including hardware and software) that may result in issues for the maintenance of SSCs, changes of current standards and regulations or obsolescence of documentation. Management of obsolescence is of special importance for FCFs as these facilities are designed for a long operation, with a safe state that may not be achieved by a facility shutdown (e.g. storage of high active liquid wastes). As a case study, the document provides examples of ageing management of I&C.

1. Introduction

1.1. Safety and ageing

The safety of nuclear installation is based on a limited number of principles and concepts.

The concept of defence in depth (DiD) is implemented for the prevention and mitigation of accidents by the use of multiple levels of protection for all relevant safety activities, whether organisational, behavioural or equipment related. Throughout the design and the operation of the facility, DiD provides multilayer protection against anticipated operational occurrences and accident conditions, including those resulting from equipment failure or human error. Its implementation leads to the identification of structures, systems and components important to safety (SSCs) which are those barriers specifically designed and operated for preventing the occurrence of initiating events and for mitigating the consequences of an accident if prevention fails

As a consequence, one important issue of ageing management is to maintain the ability of those SSCs as long as they are necessary for the safety of the facility. This is further developed in this document in sections related to "technical challenges of ageing management".

Non-technical aspects can also be impaired by ageing and as a consequence must be effectively implemented and maintained during the whole facility life. These "soft" aspects are regrouped within the "management of safety" concept related to facility organisation, management of resources including human resources, knowledge management and training, safety culture, quality assurance and documentation management, all matters that may be impacted by ageing and need periodic verification. This is further developed in this document in sections related to "non-technical" challenges of ageing management.

1.2. Fuel cycle features

Like for any other nuclear facility, the ageing management of a FCF aims at maintaining the high operational and safety levels throughout the lifetime of the facility. As such ageing management is an essential asset for achieving safety that generally gets along with production, and cost in a systematic way. Ageing management is the process to help assure the safety of the facility during its life from design to dismantling. It is of special importance for the potential life extension of the facility linked to the decision of its refurbishment or its shutdown/decommissioning. Effective ageing management programmes can have a positive impact on hazard and risk reduction in ageing facilities as well as on new facilities due, in part, to the proper anticipation of the decommissioning step and consequential minimisation of wastes production.

When compared with other nuclear facilities like nuclear power plants, the word "FCFs" covers a very large range of nuclear facilities including the conversion of uranium, enrichment, uranium and MOX fuel fabrication, spent fuel storage, de-conversion of uranium hexafluoride, spent fuel reprocessing and associated waste and effluent management facilities (e.g. HALW vitrification), and research and development facilities. Resulting from this diversity, the implementation of ageing management policy and programmes should be sized according to the potential consequences of the nuclear and chemical hazards which are often specific (due to the uniqueness of the design).

The changes of a facility (e.g. process modification) may result in potential safety impacts on other aspects of the fuel cycle and other FCFs (that can be on another site). A review of ageing should be considered accordingly.

The objective of this document is to share good practices for ageing management of nuclear fuel cycle facilities defined above. It results from an international collaboration between regulators and their technical support organisations and operators of fuel cycle facilities considering operational and regulatory experience feedback. It is designed to provide for definitions, recommendations and good practices associated with ageing management. Some case studies are also developed to illustrate the discussion.

1.3. Concept

Like any facility, FCFs experience two kinds of technical ageing:

- Physical ageing of SSCs, which results in degradation, i.e. gradual deterioration in their physical characteristics.
- Obsolescence of SSCs, i.e. their becoming out of date in comparison with current knowledge, standards and technology (that may results in a lack of spare equipment).

Evaluation of the effects of both physical ageing and obsolescence of SSCs at a FCF is a continuous process. It is re-assessed periodically in a periodic safety review or an equivalent systematic safety re-assessment programme.

FCFs are often characterised by numerous changes in their mode of operation and/or process with a strong reliance on staff that often works close to the hazardous material. In this respect, the non-technical aspects of ageing (e.g. knowledge management, documentation) need to be considered.

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1.4. Regulatory approaches

In addition to the above SSCs physical ageing and obsolescence, the periodic safety reviews assess the cumulative effects of the facility modifications, whatever related to the process, pieces of equipment, operating procedures, facility organisation, and to operating experience or technical development in the facility or elsewhere.

1.4.1. In France and Japan:[1] periodic safety review every ten years

During periodic reviews of safety, the operator must perform an appropriate set of verification, test and control of SSCs important to safety, especially those subjected to ageing effects ("conformity examination").

In the framework of the periodic safety reviews (PSR), the "ageing management programme" is assessed in order to determine the need for improvement. A structured and rigorous method is used to analyse, for SSCs, the adequacy of the measures (design, construction, operation, monitoring and maintenance) implemented to prevent the effects of ageing, to detect the potential alteration and curing at it.

Outcomes of the review of ageing management within the PSR shall be used:

- to determine whether the FCF or specific SSCs can be operated safely for a specified future period (e.g. the period between the current safety review and the next one) and the necessary safety improvements;
- to provide inputs for improvement of the periodic testing, control and maintenance programmes and for updating of the safety analysis, and for modifications of operating conditions or design.

1.4.2. UK regulatory regime and ageing management

Unlike other international regulatory regimes, the United Kingdom operates a goal setting regime for its nuclear industries and has a permissioning system that prevents an operator carrying out a task without the agreement of the regulators. Goal setting regime is where the operators of facilities are required to meet a number of safety objectives, but are allowed to utilise their own methods (processes) and equipment to achieve them.

They must however demonstrate to the regulator that these methods and equipment fulfil the requirement that they do all that is reasonably practicable to ensure the safety of the workforce and the public.

Only in the event that they demonstrate that they have done this are they given the permission to operate.

1. The first review shall be performed within 20 years after operation in Japan. A review shall be performed every ten years after the first review.

In the United Kingdom this is predominantly done via the issuing of a nuclear licence and subsequent to this additional permission where significant variations to the operation that were described within original licence occur.

Significant within these, is licence condition 15, which requires the licensee to hold a periodic and systematic review and reassessment of its safety case. The UK HSE sets the expectation that this is against modern standards and at a time period no more than ten years.

The exact time period for the review is set by specific individual arrangements between the HSE and the licensee against a particular facility or plant. Such arrangements can also include agreements between the regulator and the licensee of methods of how they will communicate.

Plant nearing the end of life might be expected to have much reduced time periods between reviews and potentially a plant may have a continuous review for instance where the facility cannot be shut down due to its requirement for facility safety.

These agreements currently ensure that facilities are judged against the standards of safety and reliability and technology at the time of the review. They seek to ensure that differences or gaps between the modern standard and the actual condition of the facility, people and processes are identified. They ensure that the licensee generates a plan to address these gaps and they then allow for the enforcement of the implementation of that plan by the regulator.

Targeted assessment is carried out on written safety cases and the associated PSRs. These are accompanied or followed by regular compliance inspections.

Compliance inspections confirm that:

- A licensee is applying the systems and processes set down in its safety case.
- Improvements are being implemented in line with the programme agreed with the regulator.
- The plant and people are degrading or improving in line with expectations. Degrading where the safety case predicts wear out or reductions in manpower and allows for it. Improving, where the PSR seeks additional reasonably practicable upgrading.

Should either the inspection or assessment show that the licensee is not meeting expectation then a graduated system of enforcement is entered into. This is graduated from the issuing of advice or a simple letter to a full prosecution. The nature of enforcement action is dependent on the gap between expectation and delivery and the degree of previous enforcement in the same area.

Thus ageing management is an integral part of the UK PSR process.

1.4.3. In the United States of America: a continuous regulatory approach

The US regulatory approach provides a continuum of assessment and review that ensures public health and safety throughout the period of facility operation. Facility safety is maintained, and aspects are improved, by a combination of the ongoing NRC regulatory process, oversight of the licensing basis, license renewal, and licensee initiatives that go beyond the regulations.

The NRC carries out many regulatory activities that, when considered together, constitute a process providing ongoing assurance that the FCFs licensing bases provide an acceptable level of safety and the effects of ageing are appropriately managed. This process includes inspections (both periodic regional inspections as well as daily oversight by the resident inspectors for some facilities), audits, investigations, evaluations of operating experience, regulatory research, and regulatory actions to resolve identified issues. The NRC's activities may result in changes to the licensing basis for the facility through promulgation of new or revised regulations, acceptance of licensee commitments to modify facility designs and procedures, and the issuance of orders or confirmatory action letters. NRC and licensees consider new safety information when it becomes available and the agency also publishes the results of operating experience analysis, research, or other appropriate analyses through generic communication documents. This process continues for plants that receive a renewed license to operate beyond the original operating license.

In the early 2000s, the NRC required certain fuel cycle facilities to complete an integrated safety analysis (ISA). By requiring FCFs to complete a comprehensive and integrated analysis, the NRC sought to improve safety through a risk-informed and performance-based regulatory approach that included: (1) the identification of performance requirements for prevention of accidents or mitigation of their consequences; (2) the performance of an ISA to identify potential accidents at the facility and the items relied on for safety; (3) the implementation of measures to ensure that the items relied on for safety are available and reliable to perform their function when needed; (4) the maintenance of the safety bases, including the reporting of changes to the NRC; and (5) the allowance for licensees to make certain changes to their safety programme and facilities without prior NRC approval.

ISA means a systematic analysis to identify facility and external hazards and their potential for initiating accident sequences, the potential accident sequences, their likelihood and consequences, and the items relied on for safety. "Integrated", in this instance, means joint consideration of, and protection from, all internal and external relevant hazard (fire, criticality, drop of loads, explosion, flood, earthquake…), particularly involving radioactive or chemical material.

Licensees are required to implement "management measures". Management measures are the functions performed by the licensee, generally on a continuing basis, that are applied to items relied on for safety, to ensure the items are available and reliable to perform their functions when needed. Management measures include configuration management, maintenance, training and qualifications, procedures, audits and assessments, incident investigations, records management, and other quality assurance elements.

The ISA is a "living" document that is routinely updated and revised to reflect new information or consider facility process changes, for example. Ageing and deterioration of systems and components is considered in periodic evaluations of potential event frequencies and may result in enhanced site programmes or "management measures".

In addition, the current inspection and oversight process collects information about licensee performance, assesses the information for its safety significance, and provides for appropriate licensee and NRC response, including corrective and enforcement actions. NRC is currently considering a revised and enhanced fuel cycle oversight process (FCOP). The NRC staff recognises that the fuel cycle industry has matured and is identifying and correcting their own problems. This recognition is essential to enable the NRC to direct its inspection resources to fuel cycle facilities with declining safety or security performance. If approved, the goal of an enhanced FCOP is to establish a more risk-informed, performance-based oversight process that provides a more objective, predictable, repeatable, and transparent assessment of licensee performance.

As in many countries, US fuel cycle facility licensees are responsible for the safety of their facilities. This responsibility is embedded in their license and in the NRC's regulatory infrastructure. Under the regulatory umbrella, licensees routinely assess new technologies, off-normal conditions, operating experience, and industry trends to make informed decisions about safety and process enhancements to their facilities.

2. Definitions and examples

2.1. Ageing management

Managing ageing of nuclear facility means ensuring that time has no consequence on the safety level of the facility throughout its service life.

This requires to maintain the safety functions by controlling the technical ageing of SSCs and to address also the non-technical human and organisational aspects stated in the introduction.

2.2. Technical ageing: wear-out and obsolescence

The table below provides a list of mechanism of technical ageing.

The initial equipment design should have anticipated the listed mechanism of physical ageing and implemented equipment or operating procedures to prevent or mitigate plugging or deposits, design and design margins to avoid or limit mechanical degradation, or design to allow or ease the replacement with spare parts.

Table 1: Technical ageing and obsolescence: examples

Technical ageing	
Main mechanisms of physical ageing	**Examples**
Process degradation	
Plugging	Plugging in pipes and transfer systems (steam ejectors)
Deposits	Deposits in vessels, pipes, process equipment
Mechanical components	
Corrosion (chemicals, hot spots), stress corrosion	Corrosion of vessels and interns, piping, welding
Irradiation	Irradiation of organic compounds (confinement tightness)
Stress fatigue due to mechanical cycles or vibrations	Fatigue of vessels and interns, piping, welding
Erosion	Erosion of hopper, chutes

Mechanical components	
Microbial influenced corrosion	Corrosion of service water system, heat exchangers diesel generators
Mechanical wear, fretting	Fretting of rotating equipment
Binding and wear	Of components within pumps and valves
Electrical and instrumentation and control components	
Insulation degradation	Degradation of cables, motor windings, transformers
Partial discharges	Discharge of batteries
Oxidation	Oxidation of relay and breaker contacts, lubricants, insulation materials associated with electrical components
Civil structures	
Ageing of concrete (chemical attack: carbonation. Effect on past deficiencies of construction quality and corrosion of embedded steel)	Ageing of concrete structure, creep due to high temperature during operation, moisture corrosion, chemical corrosion
Shrinkage and creep	Undue displacement and decrease of structural strength
Loss of material (scaling, cracking and spalling) due to freeze-thaw processes	Loss of concrete elements
Other	
Neutron absorbers	Degradation of neutron absorber for storage vessel, pits
Main mechanisms of obsolescence	**Examples**
Equipment including hardware	Lack of spare parts e.g. I&C Old design with impact on occupational exposure (especially during maintenance) e.g. design of glove boxes
Software	Loss of supplier support for the maintenance and modification of software e.g. out-of-date programming language
Deviations from current regulations	Regulatory changes e.g. standards related to fire safety, design basis earthquake
Process	Old process compared with more recent ones that eliminate one hazard e.g. dry conversion process versus wet process, centrifugation versus gas diffusion enrichment

2.3. Non-technical ageing

The table below provides a list of aspects of non-technical ageing, which should be taken into account and addressed during the facility life.

Table 2: Non-technical ageing: examples

Non-technical ageing	
Management of safety	
Knowledge management: documentation	Deficiencies in the data collection and record keeping related to ageing management. Loss of knowledge if not properly captured and updated on-time e.g. engineering diagram, safety justifications, operational feed-back…
Knowledge management: replacement and training…	Loss of operational know-how e.g. associated to industrial reorganisation or staff retirement
Leadership and organisation	Deficiencies of organisation in the management of ageing. Lack of integration between safety and quality systems and oversights e.g. deficiencies in operational safety from lack of communication, weak safety culture (learning process).

3. Ageing considerations during facility life

3.1. Introduction

Ageing management of a FCF comprises all the measures and provisions taken to ensure the facility safety during its whole life. This goal requires appropriate measures or provisions:

- Account of all the technical ageing mechanisms, i.e. physical ageing and obsolescence.
- Address of non-technical challenges.

Given the great diversity of FCFs, SSCs are identified based on a safety analysis. The SSCs include all the equipments specifically designed and operated for preventing the occurrence of initiating events, detecting them and for mitigating the radiological or chemical consequences of incident or accident for the workers, the public and the environment.

Ageing management of SSCs should be implemented proactively (with foresight and anticipation) throughout the whole facility life stages, i.e design, fabrication and construction, commissioning, operation (including maintenance or modification), decommissioning and dismantling.

This is commonly achieved through a dedicated “ageing management programme”, where needs and measures are identified and justified according to safety demonstrations, significant part of the safety analysis.

3.2. Ageing management programme

The ageing management programme starts at the design stage of the facility, when the SSCs important to safety are identified with their attached required conditions and performances. The “ageing management programme” should be operational at the start-up of the facility.

These performances have to be maintained during the ageing constraints and mechanisms, and the strategies against ageing developed during design (previous section) have to be prepared and assessed according to acceptance criteria. Their proper implementation should be verified during the fabrication/construction/ commissioning stages. During operation, the conditions encountered by the SSCs are recorded and are used as an input for defining the maintenance, periodic testing and inspection regime that provide for timely detection and mitigation of ageing effects on the SSCs.

For production facilities that have direct or indirect impact upstream and downstream facilities, the potential consequences of interaction with these related facilities have to be considered during the facility safety analysis.

3.3. Technical challenges for ageing management process

3.3.1. Strategy during design

The design of a new FCF is the fundamental stage to anticipate the alteration of SSCs due in particular to physical ageing mechanisms or to reduce their consequences and, in any case, to rigorously apply the defence in depth concept by taking into account these mechanisms when defining the safety barriers.

In the FCF design:

- A rigorous and structured method should be used to address ageing issues, taking into account all the available information. In particular, feedback from relevant experience at other facilities and data from research programme concerning ageing effects is reviewed and used by designers and suppliers. If necessary, further studies or research are to be carried out to improve the knowledge of some specific ageing issues.
- All potential ageing mechanisms for passive or active SSCs, that could affect the ability to perform the safety functions, should be identified, evaluated and taken into account. Potential combined effects should be identified. This identification considers the common cause of equipment failures (i.e. the simultaneous degradation of physical barriers and redundant components) which could result in the impairment of one or more levels of protection providing the defence in depth concept.
- Consideration should be given to the use of materials with greater resistant properties to the foreseeable physical ageing effects (e.g. materials with a high resistance to corrosion by chemicals, abrasion, thermal effects, radiation embrittlement, fatigue, environment effect…). Consideration shall be given to the combined effects of several ageing mechanisms acting simultaneously.
- To ensure the capability of SSCs to perform their safety functions, appropriate safety margins shall be provided in the design to take into account relevant ageing effects and potential ageing related degradation. This is needed especially for SSCs of which periodic testing, maintenance or replacement are difficult or impossible to implement, e.g. due to high level of radioactivity. In that case extra thickness for vessel or pipe corrosion/erosion, process temperature/pressure limits and criticality control parameters have to be implemented. The definition of the margins should also take into account the possible evolutions of the facility linked to operational requirement or safety regulations.

- It should be ensured that the design of the facility comply with the defence in depth concept, by defining appropriate safety barriers to mitigate the consequences of anticipated events (e.g. drip tray below tanks, other confinement barriers around containment equipment…). In this respect, equipment redundancies, which may not be strictly justified by the safety assessment, are considered insofar as that measure often provide more flexibility for operation and ageing management.
- The SSCs design and layout should ease decontamination, periodic testing, inspections, maintenance or replacement, in order to respect the ALARA principle during personnel intervention and to minimise the waste production. Particular consideration is given to SSCs that are difficult to test, inspect, maintain or replace. In particular, specific measure (e.g. remote intervention by robot) should be anticipated to repair or replace SSCs for which human intervention is not be foreseeable.
- The number of SSCs for which periodic testing or maintenance is impossible (especially SSCs buried or located in areas with high level of radioactivity) should be limited as much as possible. Compensatory indirect testing measures should be anticipated during the design in order to detect rapidly degradation due to ageing mechanisms (e.g. chemical analysis of a non-accessible vessel to detect corrosion, I&C to measure the volume shipper/receiver difference after each transfer to detect the potential leak of a non-accessible piping).
- The operating organisation should document the "ageing management programme" and should be able to demonstrate that ageing issues have been adequately addressed at the facility design. Particular consideration should be given to the choice of the suppliers, taking into account their management system.

3.3.2. Strategy during fabrication/construction/commissioning

The strategy during these stages includes:

- The provision of relevant information on factors affecting ageing management, including operational limits and service conditions, to the SSC manufacturers.
- Inspections to verify that the SSCs manufactured comply with the ageing safety features defined during design. In particular, attention should be paid to detect counterfeit of SSCs (e.g. quality of the materials with a high resistance to corrosion by chemicals used to manufacture valves or pipes). Data concerning manufacturing of SSCs, inspections, shipment and storage conditions shall be collected and documented.
- The proper management of wide technical documentation including QA records (history of the management of non-conformities, modifications, as-built drawings…) and safety justifications (records of the iteration between safety assessment and design) is established to identify the cause of ageing

issues during facility operation and to improve predictive models of ageing phenomena.

- Parameters that can influence ageing degradation shall be identified during commissioning (e.g. dose rate, concentration of chemical products, temperature), including acceptance criteria, and tracked during the facility lifetime.

3.3.3. Strategy during operation

The strategy during facility operation relies on the implementation of an ageing management programme defined above.

A periodic testing programme and maintenance of SSCs shall be established and implemented, in accordance with the safety case (safety report, operational limits and conditions).

A proactive approach should be used to give priority to preventive maintenance rather than curative maintenance of SSCs.

All data available concerning the alteration of SSC by ageing phenomena, including SSC manufacturers recommendations, are used to define the programme (including frequency) of maintenance and periodic testing and the corresponding procedures.

Specific organisational provisions (e.g. database, document that captures information from staff) are part of the strategy during operation and are described in the non-technical section

Attention should be paid to SSC reliability and maintenance histories, in order to detect any discrepancy with hypothesis used in the facility safety demonstration and to properly deal with them.

All measures should be taken to ensure safe operation of the facility, including housekeeping, proper management of wastes, effluents and reagents.

The effectiveness of the ageing management and periodic testing and inspection programmes can be evaluated against the check list below which aims to understand, prevent, detect, control and/or mitigate ageing effect:

- Understanding of ageing phenomena, e.g. by predictive models of relevant ageing phenomena.
- Preventive actions to minimise and control ageing degradation, e.g. service conditions and operating practices that limit potential degradation of SSCs important to safety.
- Detection of ageing effects before failure of the structure or component (proper inspection, testing and monitoring methods) and monitoring and trending of ageing effects (condition indicators and parameters monitoring).
- Acceptance criteria against which the need for corrective action is evaluated.

- Mitigating action if a component fails to meet acceptance criteria (repair and replacement actions).
- OEF and update of predictive models.
- Quality management to collect data, record practices, update models and indicators and ensure that preventive actions are appropriate and all corrective actions are effective.

The safety of facility is to be considered continually during its whole operation life. Crucial steps for long-term operation are periodic safety review (PSR) or equivalent (see above). The PSR aims at taking into account changes in safety requirements, know-how, facility environment, OEF as well as the evolution of the facility due to modifications or ageing effects.

3.3.4. Strategy during post-operational clean-out, decommissioning and dismantling

The basic principles of ageing management are the same for a facility still in operation or after its shutdown until its dismantling (operations which can last, for certain facility, a long period of time). In this respect, the above-mentioned organisational provisions for ageing management during operation should also be implemented during the decommissioning and dismantling operations: periodic testing of SSCs, maintenance, OEF management, safe operations (housekeeping, management of waste…, periodic safety review…).

The possible alteration or failures of SSCs, due to ageing effects is to be considered in the safety analysis of the decommissioning and dismantling operations. This analysis takes into account the strategic plan for these operations (e.g. order and duration of the operations) and the corresponding safety and radiation protection of the workers. The "ageing management programme" of SSCs important to safety shall be updated accordingly and periodically until the end of their operations.

Appropriate arrangements should be made to ensure that the SSCs, especially those associated to the protection of the workers against exposure of ionising radiation (ventilation and radiation protection in particular), remain available and functional to realise the decommissioning and dismantling operations.

3.4. Non-technical challenges

FCF ageing management includes non-technical aspects as organisational and human factors, data collection and record keeping, review of the management of ageing – and requires associated necessary resources (human resources, financial resources, tools and equipment, and external resources).

3.4.1. Management of safety

3.4.1.1. Leadership and organisation

The comprehensive nature of ageing management requires the assignment of a specific person designated within the operating organisation to co-ordinate the ageing management implementation, collect and consider the potential lessons learnt from OEF coming from other facilities.

This may require the support outside the operating organisation:

- The participants of the operating organisation should include experts from operations, maintenance, engineering, equipment qualification, design and research and development, according to the complexity of ageing issues.
- External organisations (e.g. owners' groups and research, design and manufacturing organisations,) should be requested to provide expert services on specific topics, e.g. condition assessments, research and standards development.

The effectiveness of the FCF ageing management regarding non-technical aspects should be reviewed and assessed periodically, for example during the periodic safety reviews.

3.4.1.2. Knowledge management: replacement and training

The operating organisation should prevent for the possible loss of staff qualification, skills and know-how regarding current operations, maintenance and engineering. In this case, depending on the state of the facility:

- A list of key-functions and profiles (staff qualifications, skills, know-how) should be established and periodically reviewed.
- Recruitments of staff should be managed according to this list, according to written procedures to offset any loss.
- The adequate qualifications of staff should be maintained by training, education, tutoring or other appropriate means.
- A particular attention regarding qualifications, skills, know-how… should be paid when dealing with subcontractors.

The operating organisation should provide for training on the ageing of SSC for staff involved in operations, maintenance and engineering, to enable them to make an informed and positive contribution to the management of ageing.

The training topics shall concern particularly:

- The awareness and understanding of concepts and practices for ageing management.
- The availability and use of correct procedures, tools and materials for a given job.

- OEF both generic and specific to the facility, to learn from relevant events related to ageing.
- The use of databases on SSC reliability and maintenance history.
- The results of reviews, inspections, assessments and improvements done in the frame of the ageing management programme.

3.4.1.3. Knowledge management: documentation

The documentation regarding the facility's life should be kept up to date. This requires that organisational directives are established regarding the preparation and modification of documents, the collection of data and records (database) in order to keep and make available comprehensive and accurate information on facility, regarding baseline, operation and maintenance histories.

Representatives of the operations, maintenance and engineering units should be involved in the design of the database, in order to facilitate obtaining the desired quality and quantity of ageing related data from facility operations, maintenance and engineering.

The data collected and the records kept should include all information relevant to ageing management, e.g.:

- Reference (baseline) data on the design (design specifications, manufacturer's data – e.g. expected time-life of equipments), fabrication, and construction of the plant or SSC and conditions at the beginning of the service life, including results of equipment qualification tests, commissioning tests, and mappings of environmental conditions during commissioning.
- Collection of safety reports and associated safety documentation related to the justification (safety analysis, margins).
- Data on the *operating history* of the plant (e.g. shift reports and records), design modifications, service conditions for SSC (including transient data), event reports, and data on the testing of availability and failure of SSC (e.g. emerging of ageing phenomena), results of in-service inspections and material surveillance of equipments and structures.
- Data on the *maintenance history*, including data on the monitoring of the operation condition and maintenance of components and structures, assessments of ageing related failures or significant degradation of SSC, including results of root cause analyses.
- Records of SSC ageing evaluations and condition assessments.
- Records of internal and external OEF, and research results.

Data should be entered in the database by maintenance and operations personnel, and the data entry should include an appropriate quality control mechanism. Provisions should be implemented to capture information from individuals. Particular attention should be paid to minor events, especially repetitive ones that seem trivial when they occur but may be of great importance later (e.g. minor leaks and contaminations, small modifications).

The data stored should remain available over long period of time. In this respect, procedures should be established that will ensure that the relevant database is backed up, that the resulting data storage media are suitably handled and stored and that the relevant data storage media remain readable. Procedures should also be established regarding the updating and maintenance of the database.

3.4.1.4. Funding for ageing management

Cost for structured and long-standing ageing management should be estimated and funded.

4. Physical ageing – Examples of good practices

SSCs ageing can generally be divided into 3 main categories associated with 3 different strategies:

Category	Example	Strategy
SSCs can be easily replaced		Ageing is dealt with during maintenance, preferably predictive (avoiding of equipment failure) or use periodic procedure for early detection of failure.
SSCs are not designed for being replaced	e.g. civil structures and non-accessible equipment	Ageing management programme (with identification of life limiting features).
SSCs with rapid obsolescence	e.g. I&C	Measures for securing spare parts.

The following table summarises these conditions and their effects, and suggests actions that should be considered for managing physical ageing.

Conditions	Ageing effects	Ageing management actions
Degradation of process	Degradation of transfer systems (pipes, steam ejectors, air-lift). Unavailability of vessels, pipes, process equipment. Degradation of nuclear criticality mass safety control (estimation of deposits).	Ensure systematic identification of deposits, and degradation of plugging. Provide complete and accurate procedure of nuclear criticality safety control (mass estimation of deposits). Provide spare parts. Prepare a modification project for future replacement of SSCs. Provide documentation to support SSCs maintenance and replacement.

Conditions	Ageing effects	Ageing management actions
Degradation of mechanical components (corrosion, stress corrosion, irradiation, fatigue, erosion, microbial corrosion)	Unavailability of vessels, pipes, process equipment. Degradation of safety functions. (confinement, radiation protection, criticality, cooling, …).	Ensure systematic identification of corrosion, leakage, and degradation of confinement of process equipment. Anticipate margins in the design (extra thickness of corrosion). Prepare a project of intervention for a possible repair of the equipment (robots for an intervention in inaccessible cell). Anticipate future replacement of important process equipment in the design (intervention cell). Prepare a modification project for future replacement of SSCs.
Degradation of electrical and I&C components (insulation degradation, oxidation)	Degradation of high voltage insulator quality (aggressive environment associated with the presence of salt deposits).	Periodic checks. New design (shielding, time limitation under irradiation, remote intervention).
Degradation of civil structures, ageing of concrete (chemical attack, elevated temperature, corrosion of embedded steel)	Degradation of concrete structure.	Ensure systematic identification of degradation of concrete structure.

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5. Physical ageing – Case studies

5.1. Stress fatigue due to mechanical cycles or vibrations

Fatigue is a phenomenon leading to fracture under repeated or fluctuating stresses having a maximum value less than the tensile strength of the material. Fatigue fractures are progressive, and grow under the action of the fluctuating stress.

Fatigue due to vibratory and cyclic thermal loads is defined as the structural degradation that can occur from repeated stress/strain cycles caused by fluctuating loads (e.g. from vibratory loads) and temperatures, giving rise to thermal loads. After repeated cyclic loading of sufficient magnitude, micro-structural damage may accumulate, leading to macroscopic crack initiation at the most vulnerable regions. Subsequent mechanical or thermal cyclic loading may lead to growth of the initiated crack. Vibration may result in component cyclic fatigue, as well as in cutting or wear. Vibration is generally induced by external equipment operation. It may also result from flow resonance or movement of pumps or valves in fluid systems. Crack initiation and growth resistance is governed by factors including stress range, mean stress, loading frequency, surface condition.

The operating experience review identified a number of examples where vibration-induced fatigue caused cracking of plant components.

One example is the incident occurred on 21 April 2005 in the Thermal Oxide Reprocessing Plant (THORP) in United Kingdom.

A camera inspection of a feed clarification cell revealed that 83 000 litres of dissolver solution had leaked from a broken pipe into the cell sump. Investigators determined that the dissolver solution had been leaking into the cell for many months, possibly since July 2004. It is believed the pipe, which provided feed to an accountancy vessel (tank), suffered a major break on or around 15 January 2005.

The feed pipe to the accountancy vessel failed as a result of fatigue that resulted from relative movement of the vessel and the feed pipe.

5.2. Formation of ammonium nitrate in a gaseous effluent pipe of the Karlsruhe WAK fuel reprocessing pilot plant

In 1994, the Karlsruhe WAK fuel reprocessing pilot plant was being dismantled. During the dismantling of the process ventilation system of the facility responsible for U/Pu separation, a white powder deposit was discovered between the condenser and the liquid eliminator. Analyses found that the powder was made up of ammonium nitrate.

Dismantling work in these pipelines was stopped until the ammonium nitrate had been washed off by rinsing. Approximately 9 kg of the powder were removed.

This event was covered by FINAS sheet No. 64. In this sheet, it was indicated that the deposits accumulated over the years of the facility's operation (200 tonnes of fuel were processed from the plant). According to information recently provided by GRS, the formation of ammonium nitrate could be linked to the mixture of gaseous nitric acid and ammonia derived from the non-explosive decomposition of hydrazoic acid (HN_3). This very volatile acid is generated in small quantities by the decomposition of hydrazine used in the U/Pu separation process.

5.3. Explosion of an off-gas scrubber in the scrap recovery at the SIEMENS uranium fuel element fabrication plant in Hanau

On 12 December 1990, at the fuel fabrication plant for uranium fuel elements in Hanau, Germany, an explosion occurred in a scrubber. The spray scrubber for off-gas cleaning was part of the installations for uranium recycling and treatment of liquid waste streams. The lower part of the scrubber column built of steel was ripped and demolished, the bottom was thrown down and the upper part built of PVC was broken into many pieces. The housing of the loop pump was smashed into small missiles. The adjacent storage tanks, piping and switch cabinets were deformed by the pressure wave. Some storage tanks were penetrated by missiles and also the roof of the hall got some small holes. Two workers were injured, one of them severely. This event was rated 2 on the INES scale.

From the investigations conducted, it appears that the off-gas cleaning installation had to treat, during normal operation, gases or vapours of different chemical nature from different systems: nitrous gazes emitted by dissolvers for recycling of uranium oxide, ammonia, organic compounds or fluorides emitted in particular by furnace for calcination of the diuranate ammonium filter cake and for drying clarification mud. This led to the presence in the scrubber tank, of an ammonium nitrate solution with parts of fluoride and organic compounds.

Due to a failure of the liquid level control, the ammonium nitrate concentration in the scrubber liquid increased because of evaporation of the liquid generating probably the formation of slurry or crystallisation. The explosion might have been initiated by the loop pump running at a too high temperature. The typical residue samples, accumulated over time, taken from several places in the scrubber wreck and in the loop contained ammonium nitrate up to 50% (weight) and about 10 % fluoride as well as about 1% nitrite. The fluoride and the uranium content as well as the organic compounds might have had a catalytic effect.

6. Management of obsolescence – Examples of good practices

The following table summarises conditions and their effects, and suggests actions that should be considered for managing obsolescence.

Conditions	Ageing effects	Management actions
Changes in technology (process, design standards, equipment including hardware, software)	Incompatibility between old and new equipment. Unavailability of suppliers. Shortage or lack of spare parts.	Ensure systematic identification of useful service life and anticipated obsolescence. Prepare a modification project for future replacement of obsolete SSCs. Provide spare parts for planned service life or identify alternative suppliers. Share data with other industries. Provide complete and accurate documentation to support SSCs maintenance and replacement.
Changes in management of safety (documentation becoming out of date)	Lack of the information needed for safe operation.	Establish an effective integrated management system, including configuration management.
Changes in standards and regulations	Outdated knowledge of practices, standards and regulations. Deviation from current standards and regulations.	Ensure compliance with current standards and regulations. Consider the modification of SSCs important to safety, as required.

7. Obsolescence of SSCs – Case studies

7.1. Criticality I&C – Tokai CAAS

The first criticality accident alarm system (CAAS) has been installed in the Tokai reprocessing plant (TRP) in Japan in 1973, which was an imported system. It was replaced once in 1984 with a new system which was developed in Japan. The new system had an excellent operation record without any serious trouble including any false alarm for more than 25 years. Since major parts of the system, however, have been obsolete in recent years, the system ended its life time.

On the other hand, the safety base of the TRP has not changed, and still requires CAAS as a safety function. The latest CAAS has been developed to satisfy the requirements and to solve the obsolescence issue. Its reliability and cost effectiveness have been also improved by employing the following design features.

A detector of the latest system is composed of a plastic scintillator coupled with a photomultiplier tube that is placed into a cadmium-lined polyethylene moderator, and is capable of responding to both neutron and gamma-rays in proportion to total absorbed doses of those radiations. This eliminates the necessity of a detector using fissile material. Signal interface of the new detector is compatible with the existing gamma-sensitive detector, which contributes to standardisation in the necessary maintenance programmes. Owing to the latest computation analysis method of radiation, deployment of the detectors has been optimised, which enables number of detectors to be reduced.

A function test of the detector and its signal processing unit was conducted using the pulse-type reactor TRACY, and their performance was successfully demonstrated. The latest CAAS has been in service in TRP since October 2009.

7.2. I&C ageing management – The case of AREVA NC reprocessing site

I&C ageing management includes physical ageing but the main issue is the obsolescence (both hardware and software).

In the frame of the La Hague projects, AREVA NC made the decision to control the means needed for the hardware production and the software upgrade, i.e. to get the ownership of systems design documents, to keep the technical expertise on basic components like operating systems and electronic circuit boards.

For reprocessing plants like other industry sectors e.g. in the energy production or aircraft construction, the long-term availability of electronic circuit boards and components is a challenging issue as the market life of electronic components is shorter than ten years.

With other major French industry AREVA built up a committee dedicated to the obsolescence of electronic components and their repair to reach the same quality level. For components not any more available on the market, a common platform was developed for reverse engineering, re-fabrication of components and their graft inside the initial and older technology environment.

Internal training has been in place since 2002 from the lessons learnt inside the facilities to maintain the knowledge and keep the control of the whole I&C architecture.

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8. Conclusions

The importance of a rigorous and systematic management of ageing for ensuring the FCF safety is shared worldwide by the operators, the national safety authorities and their technical support organisations. This was confirmed during the October 2009 OECD/NEA workshop that identified the benefits of defining and sharing recommendations and best practices to address both technical and non-technical issues of FCF ageing.

Compared with other nuclear facilities, FCFs ageing management needs to address FCF specificities, like the nature of hazards that are commonly nuclear and chemical, the chemical processes that can also be submitted to time degradations, the uniqueness of designs, and the frequent evolutions of equipment design and/or facility operation.

This document identified a set of good practices thanks to a benchmark of strategies and good practices coping with physical ageing and obsolescence from the facility design until its decommissioning.

FCF design is the fundamental stage for anticipating the SSCs alterations and for reducing the consequences of these physical ageing. The defence in depth concept should be rigorously kept applied with a due account of these mechanisms. For new facilities, the need is highlighted to develop specific programme sized according to the facility risks and to implement it from this early stage. During the FCF operational stage, the major recommendation is to implement proactive maintenance with organisational provisions to capture and keep track of the operation and maintenance history of the facility.

The management of obsolescence is classified according to the nature of the obsolescence: changes affecting the technology (including hardware and software) that may result in issues for the maintenance of SSCs, changes of current standards and regulations or obsolescence of documentation. Management of obsolescence is of special importance for FCFs as these facilities are designed for a long operation, with a safe state that may not be achieved by a facility shutdown.

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List of abbreviations

ALARA	As low as reasonably achievable
CAAS	Criticality accident alarm system
CSNI	Committee on the Safety of Nuclear Installations (OECD/NEA)
DiD	Defence in depth
FCF	Fuel cycle facility
FCOP	Fuel cycle oversight process
FINAS	IAEA/NEA fuel incident notification and analysis system
GRS	*Gesellschaft für Anlagen und Reaktorsicherheit* (Germany)
HALW	High active liquid waste
HSE	Health and safety executive (United Kingdom)
I&C	Instrumentation and control
IAEA	International Atomic Energy Agency
INES	International nuclear events scale
IRSN	*Institut de radioprotection et de sûreté nucléaire* (France)
ISA	Integrated safety analysis
JNES	Japan Nuclear Energy Safety Organisation

MOX	Mixed oxide fuel
NEA	Nuclear Energy Agency (OECD)
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission (United States of America)
OECD	Organisation for Economic Co-operation and Development
OEF	Operating experience feedback
ONR	Office for Nuclear Regulation (United Kingdom)
PSR	Periodic safety review
QA	Quality assurance
SSCs	Structures, systems, and components important to safety
THORP	Thermal oxide reprocessing plant (United Kingdom)
TRP	Tokai reprocessing plant
WGFCS	Working Group on Fuel Cycle Safety (OECD/NEA/CSNI)

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Managing the ageing of fuel cycle facilities (FCFs) means, as for other nuclear installations, ensuring the availability of required safety functions throughout their service life while taking into account the changes that occur with time and use. This technical opinion paper identifies a set of good practices by benchmarking strategies and good practices on coping with physical ageing and obsolescence from the facility design stage until decommissioning. It should be of particular interest to nuclear safety regulators, fuel cycle facilities operators and fuel cycle researchers.

OECD Nuclear Energy Agency
12, boulevard des Îles
92130 Issy-les-Moulineaux, France
Tel.: +33 (0)1 45 24 10 15
nea@oecd-nea.org **www.oecd-nea.org**

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