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Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL)

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AGEING MANAGEMENT FOR NUCLEAR POWER PLANTS: INTERNATIONAL GENERIC AGEING LESSONS LEARNED (IGALL)

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FOREWORD

With a growing number of nuclear power plants exceeding 30 years of operation, a number of IAEA Member States have, in line with economic and energy demands, and environmental concerns, started to consider the long term operation of nuclear power plants beyond the period of operation originally anticipated in their design. This publication provides detailed information on plant level and specific (or individual) ageing management programmes and methods (e.g. other plant programmes, time limited ageing analyses), to manage existing and potential ageing effects and degradation mechanisms of structures, systems and components over the full duration of the intended lifetime (including long term operation period).

Specific ageing management programmes assist operating organizations and regulatory bodies by providing the technical basis for and practical guidance on managing the ageing of mechanical, electrical, and instrumentation and control components, and civil structures in the scope of ageing management. This publication is also intended to provide a common, internationally recognized basis of what constitutes an effective plant level ageing management programme and a knowledge base on ageing management for the design of new nuclear power plants or design reviews. It also contains information on a roadmap with available information on the development, implementation and management of ageing management programmes. The ageing management programmes are developed and applied to maintain the design basis conditions of structures, systems and components that require ageing management over the intended period of operation of a nuclear power plant. This publication documents a collection of proven ageing management programmes for structures, systems and components developed and implemented in various types of nuclear power plant.

In addition, structures, systems and components whose design life is time limited by design assumptions linked to the operating term are evaluated to ensure that the original design assumptions (also called time limited ageing analyses) remain valid or can be projected until the end of the intended operation. Otherwise, the structures, systems and components can be included in the scope of an appropriate ageing management programme and, therefore, the ageing effects will be adequately managed.

To ensure that an ageing management programme continues to be effective throughout the design life of a structure, system or component, plant specific and industry operating experience; corrective actions; structure, system and component replacement or refurbishment; and relevant research programmes are evaluated to improve the ageing management programme, as necessary.

This publication provides information on ageing management in a comprehensive and systematic way such that operating organizations can develop and implement effective ageing management programmes and time limited ageing analyses that enhance safety in accordance with a Member State's regulatory requirements.

This publication is an updated and revised version of Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL), published in 2020. It complements IAEA Safety Standards Series Nos SSR-2/2 (Rev. 1), Safety of Nuclear Power Plants: Commissioning and Operation, and SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants.

The IAEA is grateful to all who contributed to the drafting and review of this publication. The IAEA officers responsible for this publication were G. Petofi, M. Marchena, R. Krivanek and K. Mäkelä of the Division of Nuclear Installation Safety.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Data on operating experience and relevant research can be collected and retained for use as input for the management of plant ageing. Paragraph 5.51 of IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design [1], states:

> "The design for a nuclear power plant shall take due account of ageing and wear out effects in all operational states for which a component is credited, including testing, maintenance, maintenance outages, plant states during a postulated initiating event and plant states following a postulated initiating event."

Requirement 14 of IAEA Safety Standards Series No. SSR-2/2 (Rev. 1), Safety of Nuclear Power Plants: Commissioning and Operation [2], states:

> "**The operating organization shall ensure that an effective ageing management programme is implemented to ensure that required safety functions of systems, structures and components are fulfilled over the entire operating lifetime of the plant.**"

Systematic ageing management provides for the capability of safety functions throughout the service life of the plant and decommissioning, taking into account the changes that occur with time and use. IAEA Safety Standards Series No. SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants [3] stipulates:

> "1.2. ...This requires addressing both the effects of physical ageing of SSCs [structures, systems and components], resulting in degradation of their performance characteristics, and the non-physical ageing (obsolescence) of SSCs (i.e. their becoming out of date in comparison with current knowledge, codes, standards and regulations, and technology).
>
> ....
>
> "2.6. Effective ageing management throughout the lifetime of SSCs requires the use of a systematic approach to managing the effects of ageing that provides a framework for coordinating all activities relating to the

understanding, prevention, detection, monitoring and mitigation of ageing effects on the plant's structures and components…."

This includes maintenance, in-service inspection, testing and surveillance, as well as operations, technical support programmes (including analysis of any ageing effects and degradation mechanisms) and external programmes such as research and development (see also IAEA Safety Standards Series Nos SSG-74, Maintenance, Testing, Surveillance and Inspection in Nuclear Power Plants [4], and SSG-25, Periodic Safety Review for Nuclear Power Plants [5]).

In addition to SSG-48 [3], a number of IAEA publications provide specific guidance and information (see Refs [6–23]) for selected major nuclear power plant structures and components, such as reactor vessels, reactor internals, piping, steam generators and containment.

The number of IAEA Member States which give high priority to continuing the operation of nuclear power plants beyond the time period originally anticipated in the design (typically 30–40 years) has steadily increased. Recognizing the need to assist Member States in dealing with the unique challenges associated with long term operation (LTO), the IAEA conducted the Extrabudgetary Programme on Safety Aspects of Long Term Operation of Water Moderated Reactors from 2003 to 2006, the outcome of which was published in Refs [3, 24], which also focus on ageing management. Although SSG-48 [3] provides recommendations on the methodology, key attributes and implementation of effective ageing management programmes (AMPs) for mechanical, electrical, instrumentation and control components, and civil structures in the scope of ageing management (hereinafter 'in-scope SSCs'), it does not provide comprehensive information on specific degradation mechanisms of SSCs or related AMPs and time limited ageing analyses (TLAAs).

In addition to safety related publications, the IAEA has also issued publications on the engineering, technological and scientific aspects of ageing management (see Refs [25–30]). To complement the existing guidance and technical information, a need was identified to establish a process to collectively and systematically document and analyse research results and operating experience. The resulting effort addresses various types of water moderated reactor. The process facilitates the exchange of technical information on ageing management among participating Member States. The results provide guidance on what constitutes an acceptable AMP for specific structures and components, and on ageing effects and degradation mechanisms, as well as tools for assessing existing plant programmes.

The United States Nuclear Regulatory Commission has developed a consistent approach to ageing management in connection with licence renewal for operating plants (see Refs [31–36]). At the request of the IAEA, it provided

Refs [33–34] for the 2015 version of this publication and Refs [35–36] for the 2020 version. This version of the publication was developed through the IAEA Extrabudgetary Programme on International Generic Ageing Lessons Learned in 2018–2022.

The present publication updates the information previously provided in Safety Report Series No. 82 (Rev. 1), which it supersedes.[1]

1.2. OBJECTIVE

The objective of this publication is to provide a technical basis and practical guidance based on proven practices on managing the ageing of in-scope SSCs of nuclear power plants to support the application of the IAEA safety standards on design (SSR-2/1 (Rev. 1) [1]), on commissioning and operation (SSR-2/2 (Rev. 1) [2]), ageing management and LTO (SSG-48 [3]) and periodic safety review (PSR) (SSG-25 [5]). With regard to in-scope SSCs, this publication includes the following:

— A generic sample of ageing management review (AMR) tables and related definitions;
— A collection of proven AMPs;
— A collection of typical TLAAs;
— A description of other ageing management related activities.

The information in this publication is based on approaches developed for and implemented in various types of water moderated reactor in participating Member States and it will be periodically updated. This publication serves as a roadmap with available information on ageing management and provides a common, internationally recognized basis on what constitutes an effective AMP and TLAA for operation of existing plants, as well as a knowledge base on ageing management for design of new plants, design reviews and PSRs.

In terms of regulatory oversight of ageing management, Ref. [37] provides more information for nuclear safety authorities, while this publication contains a collection of proven regulatory practices.

This publication is intended to be used by ageing management experts of operating organizations of nuclear power plants, technical support organizations and regulatory bodies for nuclear safety.

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[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).

Guidance and recommendations provided here in relation to identified good practices represent expert opinion but are not made on the basis of a consensus of all Member States.

1.3. SCOPE

This publication addresses ageing management of both active and passive structures and components for water moderated reactors that can affect, directly or indirectly, the safe operation of the plant and that are susceptible to ageing. The information provided is relevant for plants in operation, for plants considering LTO, as well as for new plants and new designs. It is important to implement ageing management from the start of operation and to make adequate provisions to facilitate effective ageing management during the original design, fabrication, transport, construction, commissioning, operation, LTO and decommissioning of the plant.

In this publication, passive structures and components are defined as those structures and components that perform their intended functions without moving parts or a change in configuration or properties. This includes those that do not display a change in state. Although this publication focuses on the management of physical ageing, the obsolescence of in-scope SSCs is to be managed proactively throughout their service life. Aspects of technological obsolescence have already been taken into consideration in the AMPs (i.e. the AMPs provided in this publication reflect the current state of the art in managing these mechanisms). New insights are to be addressed in future updates of the AMPs.

More general aspects of technological obsolescence are to be addressed within a programme for the management of obsolescence, which is to be established by the operating organization in accordance with SSG-48 [3]. A description of a generic technological obsolescence programme is provided in the TOP401 Technological Obsolescence Programme.[2]

Conceptual aspects of obsolescence, such as consistency with current knowledge and standards, can be evaluated within the framework of a PSR (see safety factors 1–7 of SSG-25 [5]) or as part of ongoing regulatory processes, and are not discussed in this publication.

This publication is not intended to facilitate comprehensive identification of structures and components for ageing management. In particular, it does not address the identification of structures and components (scope setting) for LTO and it is not intended to be used as a checklist or as scope setting guidance, which is described in SSG-48 [3]. More information on practical implementation of

[2] See https://gnssn.iaea.org/NSNI/PoS/IGALL/SitePages/Home.aspx

scope setting can be found in Ref. [38]. The inclusion of a certain SSC, AMP or TLAA does not mean that this particular SSC, AMP or TLAA is within the scope of LTO for all nuclear power plants. Conversely, the absence of an SSC, AMP or TLAA in this publication does not mean that this particular SSC, AMP or TLAA is excluded from the scope of LTO for any plant.

The information provided in the AMR tables is not applicable to every plant type, and even for a specific reactor type, the information might not be applicable due to design, construction and operational measures. The information provided represents proven practices of Member States participating in the International Generic Ageing Lessons Learned (IGALL) programme. These proven practices might not be applicable to every nuclear power plant or Member State. The definitions of the terms used, provided in Section 8 and Appendix V, are selected definitions and might not include all SSCs and other items as applicable to a particular nuclear power plant.

1.4. STRUCTURE

Section 2 summarizes information on AMRs and provides a roadmap to the AMR tables. Section 3 provides typical content of a plant level AMP. Section 4 presents basic concepts of individual AMPs, describes the nine generic attributes of an effective AMP and provides details for each of the attributes. Section 5 provides information for the evaluation process of the effectiveness of the plant level AMP and individual AMPs. Section 6 provides general information on TLAAs. Section 7 provides general information on other programmes and analyses which can be used to manage ageing. Section 8 provides definitions for the terms used in this publication.

The appendices are based on input from participating Member States. Appendix I provides a list of proven AMPs, and Appendices II and III list TLAAs and other programmes, respectively. Appendix IV lists the proven regulatory practices in the oversight of ageing management. Appendix V provides definitions of terms for structures and components, materials, environments, ageing effects and degradation mechanisms to facilitate consistent use of terms. Appendix VI provides grouping of civil structures, except for containment. Appendix VII provides examples of performance indicators for plant level AMP, while Appendix VIII provides examples of performance indicators for individual AMPs.

The AMR tables and the information referred to in Appendices I–III are provided in the IGALL database, which comprises more than 2000 line items in the AMR tables, 116 AMPs, 36 TLAAs, and a description of 4 other ageing management related activities as of the end of 2022.[3]

2. AGEING MANAGEMENT REVIEW

Scope setting is an essential prerequisite for AMR. The in-scope SSCs subject to AMR are identified on a plant specific basis through a scope setting process, as described in SSR-2/2 (Rev. 1) [2] and SSG-48 [3]. As in-scope SSCs typically present a large number of items, they are usually divided into commodity groups as recommended in para. 5.20 of SSG-48 [3], and further discussed in section 3.4 of Ref. [38]. Nevertheless, some in-scope SSCs can be managed independently due to their safety importance, complexity or uniqueness.

The AMR is a process to identify relevant ageing effects and degradation mechanisms for SSCs and provides a basis for implementation of effective ageing management over the intended period of operation. The AMR process involves, but is not limited to, identifying the following elements:

— Structure and component;
— Critical location or part;
— Material;
— Environment;
— Ageing effect and degradation mechanism;
— Ageing management programme (AMP);
— Time limited ageing analysis (TLAA).

For structures and components that are identified as being subject to an AMR in general or in the scope of LTO, it is required to demonstrate that the effects of ageing will be adequately managed to ensure that intended safety functions of SSCs are fulfilled over the entire operating lifetime of the plant (see Requirements 14 and 16 of SSR-2/2 (Rev. 1) [2] and 10 CFR 54.21(a)(3) [31]).

Paragraph 5.26 of SSG-48 [3] states that "[a]n ageing management review should be performed for each in-scope structure or component or commodity group of structures or components and should consist of the following essential elements…." These essential elements are presented in the subsections that follow.

[3] See the IGALL database for the most up to date information, available at https://gnssn.iaea.org/NSNI/PoS/IGALL/SitePages/Home.aspx

2.1. ASSESSMENT OF THE CURRENT CONDITION OF STRUCTURES AND COMPONENTS

The assessment of the current condition of the structures and components is the initial step of an AMR. It comprises the collection and analysis of all available data for each in-scope structure and component or commodity group of structures and components such as baseline information; operational history data; environment, maintenance, surveillance and in-service inspection history data; results of ageing management activities and external operating experience data. More details about essential data are provided in section 2.3 of Ref. [38]. Collected data are then analysed and properly managed as described in section 2.2 of Ref. [38].

Assessment of the current condition can also include one-time inspections or diagnostic tests of in-scope structures and components that could provide for better understanding of the conditions of in-scope structures and components and could lead to decisions on repair, replacement or refurbishment of an in-scope structure or component or to enhancement of ageing management activities.

As the condition assessment of in-scope structures and components leads to better knowledge about their materials, environments and current conditions, it can reveal a need to adjust the commodity groups to ensure the representativeness of each commodity group member for further steps of the AMR.

In accordance with SSG-25 [5], the current condition of the structures and components can also be assessed as part of the PSR, which is normally conducted in ten-year intervals. It is therefore crucial to determine the actual condition of these SSCs in order to determine whether they are capable of maintaining the intended safety function throughout the LTO period.

2.2. IDENTIFICATION OF AGEING EFFECTS AND DEGRADATION MECHANISMS

Once the condition assessment is completed, identification of existing and potential ageing effects and degradation mechanisms for in-scope SSCs is conducted. Then all existing ageing effects and related degradation mechanisms (i.e. those that have already occurred at the plant) are assigned to the in-scope structures, components or commodity groups.

Afterwards, all potential ageing effects and related degradation mechanisms are assigned to the in-scope structures, components or commodity groups. Each potential degradation mechanism is assessed in all relevant in-scope structures, components or commodity groups for the intended period of the plant operation. All available information is used for this examination, including available external operating experience and research and development results. The IGALL AMR tables are useful sources of information to identify potential ageing effects and degradation mechanisms for in-scope SSCs, however IGALL can never substitute a thorough assessment conducted by the given plant.

If it is concluded that a potential ageing effect can occur during the intended period of the plant operation, it is further managed as an existing (relevant) ageing effect. If it is concluded that the potential ageing effect cannot occur during the intended period of the plant operation, then justification is provided why this potential ageing effect can be excluded.

2.3. IDENTIFICATION OF THE APPROPRIATE PROGRAMME FOR AGEING MANAGEMENT

For each combination of in-scope structure, component or commodity group, material, environment and ageing effect, the relevant existing AMPs and other plant programmes are identified. Existing AMPs and other plant programmes, which will be credited as programmes to manage applicable ageing effects, are evaluated for consistency with the nine attributes of an effective ageing management programme (see table 2 of SSG-48 [3] and Section 4 of this report). TLAAs relevant for in-scope structures, components and commodity groups are also identified (TLAAs are earlier identified, and their validity demonstrated as recommended in paras 5.64–5.69 of SSG-48 [3]).

If existing AMPs, plant programmes or TLAAs are not found to be sufficient to adequately manage all applicable ageing effects, an enhancement to the existing AMPs, plant programmes and TLAAs may be necessary, and/or the development of new AMPs, plant programmes or TLAAs or other actions (e.g. replacement, repair, operational regime change) may need to be implemented.

The IGALL AMR tables can be useful sources of information to identify proven AMPs and TLAAs to manage ageing effects and degradation mechanisms of in-scope SSCs.

2.4. REPORTING OF THE AGEING MANAGEMENT REVIEW

Information on documentation of AMR methodology and results is provided in section 6.6 of Ref. [38].

The IGALL AMR tables were developed on a generic basis using available operating experience and research and development results from Member States to identify ageing effects and degradation mechanisms that require ageing management for each combination of structure or component, critical location or part, material and environment. Participating Member States provided information, which was discussed and consolidated by the IGALL programme working groups. Since the AMR tables comprise results provided by Member States, it cannot be guaranteed that each combination of structure or component, critical location or part, material, environment, and ageing effect and degradation mechanism has been included for all nuclear power plant designs.

The AMR tables identify proven AMPs and TLAAs for each combination of structure or component, material, environment, and ageing effect and degradation mechanism. In this publication, documents available in the IGALL programme are identified as 'AMR', 'AMP' and 'TLAA', and plant specific documentation on AMR, AMP, and TLAA is titled as 'plant specific AMR', 'plant specific AMP' and 'plant specific TLAA', respectively.

The AMR approach described here uses numerous terms to identify structures and components, materials, environments, ageing effects and degradation mechanisms. For each of these five categories used in the AMR tables, the AMPs and the TLAAs, the definitions of the most commonly used terms are provided in Section 5 and Appendix V.

The AMPs used to address the ageing effects requiring management are identified in the AMP column of the AMR tables. The structure of the AMPs is aligned with the nine generic attributes of an effective AMP as defined in SSG-48 [3]. A general description of AMPs, including the nine generic attributes, is provided in Section 4. The list of AMPs for mechanical components, electrical and instrumentation and control (I&C components), and civil structures is provided in Appendix I. The most up to date versions of AMPs, which are based on consolidated input from Member States, are provided in the IGALL database.

The AMR table identifies more than one AMP for many of the identified combinations of system, structure or component, critical location or part, material, environment, and ageing effect and degradation mechanism. In some cases, more AMPs are offered as possible solutions; in other cases, one of the listed AMPs is a preventive programme (e.g. AMP103 Water Chemistry) and is used in combination with a conditioning monitoring programme (e.g. AMP102 In-service Inspection/Periodic Inspection). When multiple condition monitoring programmes are identified, the user can implement any of the programmes the user determines to be suitable for the plant.

The use of TLAAs in the 'Time limited ageing analysis (TLAA)' column of the AMR tables indicates that one or more specific TLAAs could be used to analyse the identified degradation with respect to projected operational time. It is emphasized that identification of TLAAs depends on national regulatory requirements and might not apply to all plants. A general description of TLAAs is given in Section 4. The list of TLAAs for mechanical components, electrical and I&C components, and civil structures is provided in Appendix II. The most up to date versions of TLAAs, which are based on individual input from participating Member States, are provided in the IGALL database.

The AMR table identifies more than one TLAA for many of the identified combinations of system, structure or component, critical location or part, material, environment, and ageing effect and degradation mechanism. Since TLAAs are generally plant specific analyses in the plant's current licensing basis (CLB), the appropriate TLAA for the plant is self-evident. If there is no analysis identified in the plant CLB, the cited TLAAs can be used by the plant as guidance to develop an appropriate safety analysis.

An AMR is implemented on a plant specific basis using established procedures and methods in line with the national regulatory requirements [39]. The AMR tables may be used as an additional basis to supplement the plant specific AMR (for development or review). The AMR tables in the IGALL database contain the following information (see Table 1):

— Table number: AMR table number in the IGALL database as described in Table 2.
— IGALL number: The sequential number of the line item (or row) in the AMR table assigned to each area and numbered as described in Table 2. A combination of table number and IGALL number creates a unique ID number for each line item.
— System: The systems to which the structure or component subject to AMR belongs. For electrical and I&C plant equipment, this column only indicates whether the equipment concerned is subject to equipment qualification or not.
— Structure/component: The structure or component subject to AMR, listed in alphabetical order in Appendix V (see Table 5).
— Critical location/part: The location or part within a given structure or component that is susceptible to the degradation mechanism.
— Material: The material of construction, listed in alphabetical order in Appendix V (see Table 6).
— Environment: The environment to which the structure or component is exposed. Internal or external environments are indicated as applicable, listed in alphabetical order in Appendix V (see Table 7). Applicable environmental stressors (e.g. temperature, radiation level, concentration of chemicals) are identified in the AMR tables in the IGALL database.
— Ageing effect/degradation mechanism: The applicable ageing effects and degradation mechanisms. Ageing effects and degradation mechanisms are listed in alphabetical order in Appendix V (see Tables 8 and 9, respectively). The ageing effect/degradation mechanism entries are 'No ageing effects identified' for some of the combinations of system, structure/component,

TABLE 1. EXAMPLE OF AGEING MANAGEMENT REVIEW TABLE LINES

Table No.	IGALL No.	System	Structure/ component	Critical location/part	Material	Environment	Ageing effect/ degradation mechanism	Ageing management programme (AMP)	Time limited ageing analysis (TLAA)	Design
101	1	Reactor pressure vessel, internals, reactor coolant system	Piping	Class 1 piping component	Stainless steel, steel with stainless steel cladding	Reactor coolant >250°C	Cracking due to stress corrosion cracking	AMP102 In-service Inspection/ Periodic Inspection, AMP156 Main Coolant Piping	TLAA103 Crack Growth Analyses for Flaws Detected in Service	PWR
101	8	Reactor pressure vessel, internals, reactor coolant system	Main circulation loop component	External surface	Steel	Air with borated water leakage	Loss of material due to boric acid corrosion	AMP110 PWR Boric Acid Corrosion	None identified	PWR

TABLE 1. EXAMPLE OF AGEING MANAGEMENT REVIEW TABLE LINES (cont.)

Table No.	IGALL No.	System	Structure/ component	Critical location/part	Material	Environment	Ageing effect/ degradation mechanism	Ageing management programme (AMP)	Time limited ageing analysis (TLAA)	Design
101	42	Reactor pressure vessel, internals, reactor coolant system	Reactor pressure vessel	Nozzle: inlet, outlet, safety injection	Low alloy steel with stainless steel or nickel-alloy cladding	Reactor coolant >250°C	Loss of fracture toughness due to thermal ageing	None	TLAA116 Thermal Ageing of Low Alloy Steels	PWR
104	76	Engineered safety features	Piping	Piping component	Copper alloy (≤15 % Zn and ≤8 % Al)	Air with borated water leakage	No ageing effect identified	None	None identified	PWR

TABLE 1. EXAMPLE OF AGEING MANAGEMENT REVIEW TABLE LINES (cont.)

Table No.	IGALL No.	System	Structure/ component	Critical location/part	Material	Environment	Ageing effect/ degradation mechanism	Ageing management programme (AMP)	Time limited ageing analysis (TLAA)	Design
107	1	Primary containment	Penetration	Bellow, sleeve	Dissimilar metal weld, stainless steel, steel	Air — indoor uncontrolled, air — outdoor	Cumulative fatigue damage due to fatigue	AMP101 Low-cycle Fatigue Monitoring, AMP146 CANDU/ PHWR Inspection Programmes, AMP147 Containment Bellows	TLAA101 Low-Cycle Fatigue Usage	BWR, CANDU/ PHWR, PWR

critical location/part, material and environment. In these cases, neither prior evaluations of the combinations of system, structure/component, critical location/part, material and environment or operating experience nor research and development results have identified ageing effects requiring management at the time they were created. Plant specific use of these items confirms that these conclusions are valid for the plant.

- Ageing management programme: The AMP used to manage the ageing effects. AMPs are addressed in Section 4 and are listed in Appendix I.
- Time limited ageing analysis: The TLAA used to manage ageing effects. TLAAs are addressed in Section 4 and are listed in Appendix II.
- Design: Pressurized water reactor (PWR) (including water cooled water moderated power reactor, WWER), boiling water reactor (BWR), Canada deuterium–uranium (CANDU) reactor/pressurized heavy water reactor (PHWR).

The latest version of IGALL AMR tables is provided in the IGALL database on the IAEA IGALL public web site (https://gnssn.iaea.org/NSNI/PoS/IGALL/SitePages/Home.aspx).

TABLE 2. NUMBERING OF AMR TABLES

Area	Structures and components	Table No.
Mechanical	PWR class 1	101
	BWR class 1	102
	CANDU/PHWR class 1	103
	PWR non-class 1	104
	BWR non-class 1	105
	CANDU/PHWR non-class 1	106
	Generic cross-cutting[a]	107
	Generic non-class 1[b]	108

TABLE 2. NUMBERING OF AMR TABLES (cont.)

Area	Structures and components	Table No.
Electrical and I&C	Electrical components subject to equipment qualification	201
	Electrical components not subject to equipment qualification	202
	I&C components subject to equipment qualification	203
	I&C components not subject to equipment qualification	204
Civil structures and components	Containment structures	301
	Civil structures except containment[c]	302, 303
	Anchors and supports for equipment, piping and components	304
	Civil structures in delayed construction condition[d]	305

[a] May relate to mechanical, electrical and I&C components or civil structures for all classes applicable to all designs.

[b] Mechanical non-class 1 components applicable to all designs.

[c] Grouping of these structures is described in Appendix VI.

[d] Civil structures whose construction has been interrupted at any stage prior to the beginning of the electromechanical assembly, regardless of the reason of interruption.

Each plant performs a plant specific AMR. An example of implementation of the plant specific AMR process, input information and specific guidance is given in Fig. 1. The figure also shows how IGALL and other IAEA guidance can be used during an AMR. A plant can use the AMR to achieve the following:

(a) Identify potential ageing effects: The approach is to review in-scope SSCs and to identify potential ageing effects and degradation mechanisms. These can be compared with the AMR table to identify any missing ageing effects and degradation mechanisms applicable to the SSCs.

(b) Close gaps between a plant’s existing programmes and IGALL: AMR tables can be used to determine whether new AMPs or TLAAs need to be developed. AMPs and TLAAs can be used if existing programmes need to be modified.

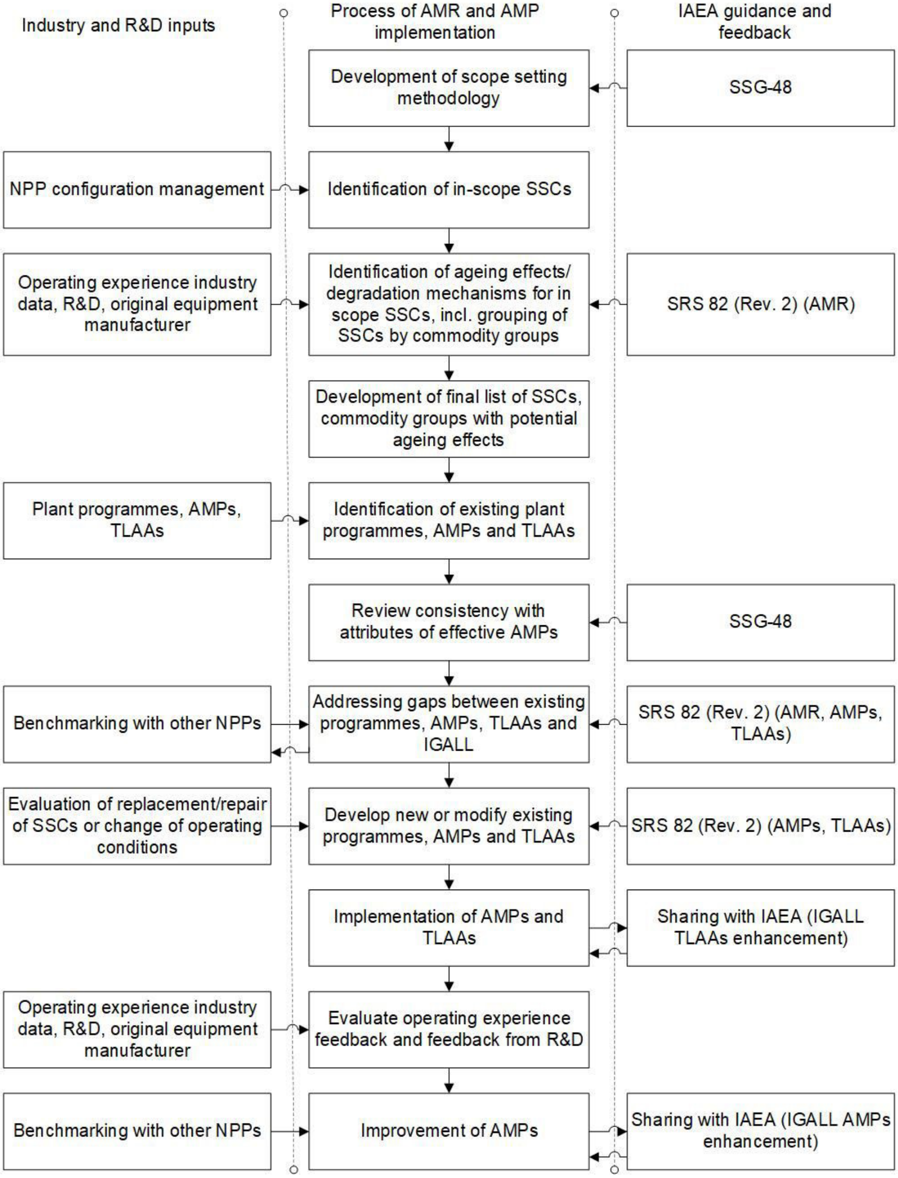

FIG. 1. Implementation of the plant specific AMR process, input information and specific guidance.

TABLE 3. DESIGNATION OF THE NOTE COLUMN IN THE AMR TABLE

Note	Description
A	Consistent with the structure or component, material, environment, ageing effect and degradation mechanism and AMP listed for IGALL line item. All nine attributes of the plant specific AMP are consistent with the AMP description.
B	Consistent with the structure or component, material, environment, ageing effect and degradation mechanism and AMP listed for IGALL line item. Plant specific AMP has exceptions to the nine attributes of the AMP.
C	Consistent with the structure or component, material, environment, ageing effect and degradation mechanism listed for IGALL line item, but a different plant specific AMP is implemented.
D	The structure or component, material, environment or ageing effect and degradation mechanism listed in AMR tables is not covered by the plant specific AMR.
E	The structure or component, material or environment does not apply to the plant.

For self-assessment or comparison with this publication, the consistency of a plant specific AMR and plant specific AMPs against the AMR and proven AMPs can be summarized using the AMR table format with two additional columns. The first additional column can provide space for the results of the review. A designation can be added to the note column (see Table 3).

For line items with notes B–E, additional discussion can be provided for each line item by adding the rationale in the second additional column. The review for consistency with the AMR tables may also identify some line items that require a TLAA. This may lead to identification of inconsistencies between plant specific TLAAs and IGALL TLAAs. For these line items, it would be helpful to include specific discussion in the text of the plant review report. Member States may choose to use a methodology other than IGALL to demonstrate compliance with the intent of Requirements 14 and 16 of SSR-2/2 (Rev. 1) [2].

3. PLANT LEVEL AGEING MANAGEMENT PROGRAMME

Paragraph 2.16 of SSG-48 [3] states:

> "[i]n practice, ageing effects and degradation mechanisms are studied and managed at the level of the structure or component. However, the ageing management programmes for individual structures or components may be integrated into an ageing management programme at the system and/or plant level."

Proven experience of some Member States has shown that a plant level AMP provides a suitable approach to implement effective ageing management. A plant level AMP is used to encompass all relevant activities in the nuclear power plant conducted in order to maintain the intended functions of in-scope SSCs for the intended period of operation. The purpose of a plant level AMP is to ensure coordination of the ageing management related activities in the plant to meet the applicable requirements established in para. 4.50 of SSR-2/2 (Rev. 1) [2]. The plant level AMP comprises the following elements (see Fig. 2):

(1) Introduction, objectives: Characteristics of the facility at unit, plant or corporate level; description of plant level AMP, including scope, objectives and the approach followed for ageing management.
(2) Organization: Arrangements, including roles and responsibilities of the line organization, and the adequacy of resources (e.g. human resources, financial resources, tools, equipment) and external support organizations.
(3) Requirements: Overview of national and international requirements, regulations, guidance, codes and standards to be met or adopted by the plant for ageing management.
(4) Coordination: Relevant programmes and activities among operation, maintenance and engineering units of the nuclear power plant; designers and manufacturers; management of the operating organization; and external technical support organizations.
(5) Scope setting: Description of the processes for scope setting such as the classification method used for setting the scope of SSCs and

updates — including reference to the relevant plant documents and databases — and a graded approach based on safety classification[4].

(6) AMR: Description of the process for conducting the AMR, including developing the structure or component commodity groups, undertaking the condition assessment, identifying the potential ageing effects and degradation mechanisms, identifying and revalidating TLAAs, identifying the appropriate programmes for ageing management and reporting ageing management review results as well as defining the frequency of the AMR evaluation [see footnote 4].
(7) AMPs, TLAAs, other plant programmes: Description of existing and new plant activities (including development of new AMPs and TLAAs as needed) to satisfy the requirements listed in item 3 of this list (e.g. AMPs and other plant programmes or procedures, including inspection, testing, surveillance, maintenance, preservation of equipment qualification, and management of obsolescence). This also includes the links between the individual AMPs and other relevant plant programmes and activities and how these interactions are defined, documented and implemented.
(8) Data collection and record keeping: Description of how ageing management related information is collected, recorded, retained and made available for ageing management purposes, and how this information meets the applicable requirements [see footnote 4].
(9) Operating experience feedback and research and development: Description of how internal and external operating experience and research and development results are collected and evaluated, and how this information is routinely used to enhance the ageing management activities, including plant modifications, if any.
(10) Implementation of AMPs: Description of how the plant ensures that the AMPs and other plant programmes are implemented (e.g. quality assurance procedures, audits, assessments, indicators for programmes and activities, regular reports).
(11) Documentation: Description of how ageing management is documented [see footnote 4] in the plant licensing documents such as the safety analysis report (SAR), PSR and other CLB documents describing the plant level AMP, the individual AMPs and the TLAAs.
(12) Evaluation of effectiveness: Description of how the effectiveness of the plant level AMP is evaluated, including evaluation of the effectiveness

[4] Detailed guidance on data management, scope setting and record keeping for ageing management and LTO and review of plant programmes is provided in Safety Reports Series No. 106, Ageing Management and Long Term Operation of Nuclear Power Plants: Data Management, Scope Setting, Review of Plant Programmes, Documentation [38].

of individual AMPs and other plant programmes (e.g. review and improvement of AMPs, assessment, indicators, periodic reports, monitoring and trend analysis, corrective action programme, operating experience; see footnote 4). Detailed guidance on evaluating the effectiveness of the plant level AMP and individual AMPs is provided in Section 6.

(13) Traceability: Description of technical traceability (e.g. documents are auditable and retrievable) of activities performed within the plant level AMP for internal or external reviews and audits which assess ageing management.

The plant level ageing management programme and its relations to other plant activities and programmes are represented in Fig. 2.

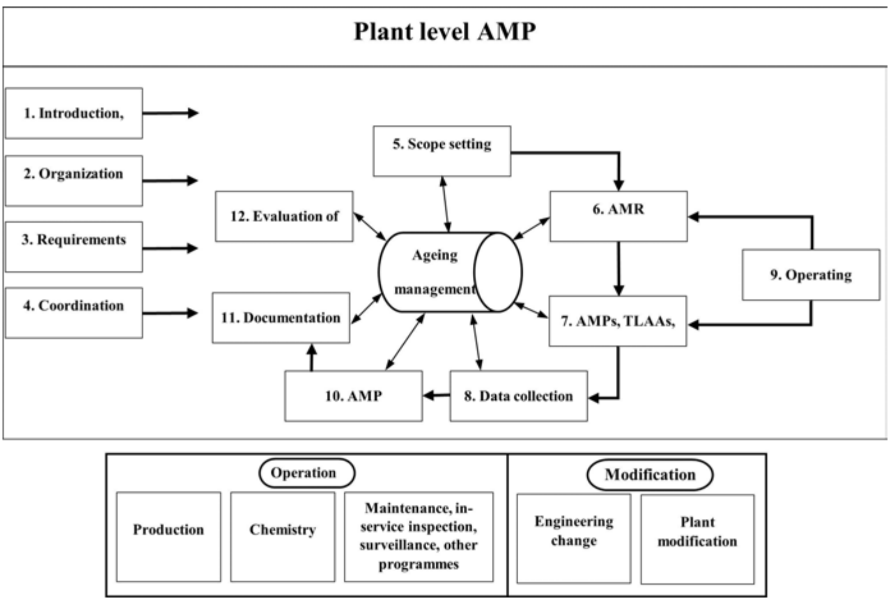

FIG. 2. Representation of a typical plant level AMP and its relations to other plant activities and programmes.

4. AGEING MANAGEMENT PROGRAMMES

An individual AMP is a set of plant activities relating to the prevention, detection, monitoring and mitigation of a specific ageing effect on a structure, component or group of components based on an understanding of the ageing process. Plant activities include maintenance, in-service inspection, testing and surveillance, as well as technical support programmes. Paragraph 5.54 of SSG-48 [3] states:

> "The effectiveness of ageing management programmes should be periodically evaluated in the light of current knowledge and feedback from the programme and the performance indicators and should be updated and adjusted as appropriate. Relevant knowledge includes information on the operation of the structure or component, surveillance and maintenance histories, information from the results of research and development, and operating experience from other nuclear facilities."

Ageing management of SSCs is to be implemented proactively (with foresight and anticipation) throughout the lifetime of the plant; that is, in design, fabrication and construction, commissioning, operation (including LTO and extended shutdown) and decommissioning [3]. Many decisions relating to ageing management are made early in the process, during the phases of design, construction and commissioning.

Many nuclear power plants have been designed for 30–40 years of operation. There is evidence that ageing in some cases has been underestimated during the original design, construction and commissioning or has not been accurately taken into account during operation. It is also recognized that the ageing of plants needs to be assessed, and that an effective management strategy needs to be developed in a timely manner, to ensure the necessary technical basis for maintaining safety margins throughout the operation of the plant. The several ways to accomplish ageing management covered in this publication include the following individual AMP types:

- Degradation mechanism specific AMPs (e.g. flow accelerated corrosion, stress corrosion cracking, thermal ageing);
- Structure or component specific AMPs (e.g. reactor coolant pumps, control rod drive housing);
- General AMPs (e.g. in-service inspection, chemistry).

As described in SSG-48 [3], effective ageing management for an SSC includes maintenance, in-service inspection, testing and surveillance, with a goal of maintaining the reliability of SSCs to ensure the capability of in-scope SSCs to perform the intended safety functions throughout their design life. Maintenance of components typically involves implementation of recommended maintenance schedules from the vendor of each component [4]. Maintenance activities generally involve preventive and corrective activities, consistent with a specified schedule, to keep structures and components in good operating condition.

In-service inspection or similar AMPs generally involve condition monitoring that leads to follow-up activities, such as repair or replacement, if adverse conditions of equipment are identified. In addition, various tests and surveillance procedures that are regularly performed in accordance with existing requirements can provide benefits for AMPs to ensure the reliability of SSCs.

The approach used to establish ageing management priorities — specifically the balancing and integration of AMPs and maintenance, in-service inspection, testing and surveillance — depends on the regulatory requirements in each Member State and also on operators' targets for plant load factors and outage duration. In some Member States, the focus of ageing management for LTO is on passive structures and components only, since the reliability of active structures and components is addressed by current requirements in the maintenance regulations (see requirements for monitoring the effectiveness of maintenance at nuclear power plants in Ref. [40]), which provide a performance based approach to ensure component reliability and include maintenance, testing and surveillance. In other Member States, ageing management deals with both active and passive structures and components.

Although this publication is concerned with the development and implementation of AMPs and does not provide specific guidance for maintenance, in-service inspection, testing and surveillance, these programmes can continue to be implemented and augmented, if needed, as a necessary complement to the implementation of AMPs to ensure robust ageing management for SSCs.

It is important that plant specific AMPs, like all other plant programmes and processes, be documented and prioritized in the quality management system and that they be included in the SAR of the plant [41]. The list of proven AMPs for mechanical components, electrical and I&C components, and civil structures is provided in Appendix I. The latest collection of full AMPs, which are based on input from participating Member States, is provided in the IGALL database on the IAEA IGALL public web site. Each IGALL AMP description comprises three main parts, 'Programme Description', 'Evaluation and Technical Basis' and 'References'. The 'Programme Description' presents a description of the programme purpose and objectives. 'References' are technical documents such as IAEA Safety Standards and technical publications, international organizations' guides and technical publications, international and national codes, standards, regulatory requirements and guides. Each reference is referred to in the AMP text at least once. References are publicly available documents which means that they are available for free or for a fee. References can be made available in any language, not only in English.

The ‘Evaluation and Technical Basis’ part of each IGALL AMP is generally structured according to the nine generic attributes of an effective AMP, against which each plant specific AMP is evaluated (see table 2 of SSG-48 [3]). The particular AMPs, however, do not necessarily contain equally comprehensive information for each attribute as there are different types, including condition monitoring, performance monitoring, prevention or mitigation. The following structure, along with the nine attributes of an effective AMP, is typically used for documenting plant specific AMPs:

(1) Scope of the AMP based on understanding ageing;
(2) Preventive actions to minimize and control ageing effects;
(3) Detection of ageing effects;
(4) Monitoring and trend analysis of ageing effects;
(5) Mitigation of ageing effects;
(6) Acceptance criteria;
(7) Corrective actions;
(8) Operating experience feedback and feedback of research and development results;
(9) Quality management.

4.1. SCOPE OF THE AGEING MANAGEMENT PROGRAMME BASED ON UNDERSTANDING AGEING

The scope of an effective programme includes structures (including structural elements) and components subject to ageing management, and an understanding of ageing phenomena (e.g. significant degradation mechanisms, susceptible sites), and is based on the following:

(a) Structure or component materials, service conditions, stressors, degradation sites, degradation mechanisms and ageing effects;
(b) Structure or component condition indicators and acceptance criteria;
(c) Quantitative or qualitative predictive models of relevant ageing phenomena.

4.2. PREVENTIVE ACTIONS TO MINIMIZE AND CONTROL AGEING EFFECTS

This attribute includes the following actions:

(a) Specification of preventive actions: These actions are defined as those that are necessary to prevent or minimize the initiation of degradation:
  (i) The actions for preventive programmes are described as to how they contribute to preventing ageing effects;
  (ii) Condition or performance monitoring programmes that do not rely on preventive actions need not be provided;
  (iii) Condition or performance monitoring programmes that rely on preventive actions are specified (e.g. maintenance of water chemistry or use of appropriate lubrication).

(b) Determination of service conditions (i.e. environmental conditions, operating conditions) to be maintained and operating practices aimed at precluding potential degradation of the structure or component: For preventive programmes, the parameters monitored will be the specific parameters being controlled to achieve prevention of ageing effects. An example is the dissolved oxygen level in the coolant that is being controlled in a water chemistry programme to prevent pipe corrosion.

4.3. DETECTION OF AGEING EFFECTS

This attribute includes the following:

(a) Specification of parameters to be monitored or inspected:
  (i) This attribute identifies the ageing effects that the programme manages and provides a link between the parameters to be monitored and how the monitoring will ensure adequate ageing management.
  (ii) In an effective condition monitoring programme, the parameter monitored or inspected will be capable of detecting the presence and extent of ageing effects (e.g. measurements of wall thickness and detection and sizing of cracks).
  (iii) In an effective performance monitoring programme, a link is established between the degradation of the intended function or functions of the particular structure or component and the parameters being monitored. An example of linking the degradation of the intended function of a passive component with the performance being monitored is linking the fouling of heat exchanger tubes with the heat

transfer function. This could be monitored by periodic changes in heat balances. Since this example deals only with one intended function of the tubes (heat transfer), additional programmes may be necessary to manage other intended functions of the tubes (i.e. pressure boundary). Thus, an effective performance monitoring programme ensures that the structures and components can perform their intended functions by using a combination of performance monitoring and evaluation of changes in performance characteristics that can be the result of degradation mechanisms (if performance falls outside acceptable limits according to the acceptance criteria).

(iv) In an effective preventive or mitigative programme, the parameters monitored are the specific parameters being controlled to achieve prevention or mitigation of ageing effects. An example is the coolant oxygen level that is being controlled in a water chemistry programme to mitigate pipe cracking.

(b) Effective technology (e.g. inspection, testing, monitoring methods) for detecting ageing effects before failure of the structure or component:

(i) Detection of ageing effects is required before there is a loss of the intended function or functions of the structure or component. In an effective programme, the parameters to be monitored or inspected are appropriate to ensure that the intended function or functions of the structure or component will be adequately maintained under all CLB design conditions. Thus, the discussion on an effective programme to detect ageing effects addresses: how the programme element would be capable of detecting or identifying the occurrence of an ageing effect prior to a loss of the intended function or functions of the structure or component; or for prevention or mitigation programmes, how the programme would be capable of preventing or mitigating the occurrence of an ageing effect prior to a loss of the intended function or functions of the structure or component. The discussion provides information that links the parameters to be monitored or inspected to the ageing effects being managed.

(ii) Nuclear power plant safety is based on defence in depth principles (e.g. redundancy, diversity). A degraded or failed component reduces the reliability of the system, might challenge safety systems and contributes to elevated plant risk. Thus, in an effective programme, the effects of ageing on a structure or component are managed to ensure its availability to perform its intended functions as designed. In this way, all system level intended functions consistent with the plant CLB, including defence in depth, are maintained.

(iii) For condition monitoring programmes, the method or technique (e.g. visual, volumetric, surface inspection), frequency and timing of new, one-time inspections may be linked to plant specific or industry wide operating experience. In an effective programme, the discussion provides justification, including codes and standards referenced, that the technique and frequency are adequate to detect the ageing effects before a loss of the intended function of a structure or component. A programme based solely on detecting structure and component failures is not considered an effective AMP. For a condition monitoring programme, when sampling is used to represent a larger population of structures and components, the basis for the inspection population and sample size is provided. The inspection population is based on such aspects of the structures and components as similarity in materials of construction, fabrication, procurement, design, installation, operating environment or ageing effects. The sample size is based on such aspects of the structures and components as the specific ageing effect, location, existing technical information, system and structure design, materials of construction, service environment or previous failure history. The samples are biased towards locations most susceptible to the specific ageing effect of concern in the period of extended operation. Provisions on expanding the sample size when degradation is detected in the initial sample are also included.

(iv) In an effective performance monitoring programme, the detection of an ageing effects programme attribute establishes the methods that will be used to monitor performance. In addition, the detection of an ageing effects programme attribute also establishes and justifies the frequency with which these performance monitoring activities will be implemented.

(v) In an effective prevention or mitigation programme, the detection of an ageing effects programme attribute establishes the methods that the programme will use to monitor the preventive or mitigative parameters that the programme controls and justifies the frequency with which these monitoring activities are performed.

4.4. MONITORING OF AND ANALYSIS OF TRENDS FOR AGEING EFFECTS

This attribute includes the following:

(a) Condition indicators and parameters that are monitored. Activities for monitoring and analysis of trends are described, and they provide a prediction of the extent of degradation and thus enable the implementation of timely corrective or mitigative actions. Plant specific and industry wide operating experience may be considered in evaluating the appropriateness of the technique and frequency.
(b) Description of when, where and how programme data are collected (i.e. all aspects of activities to collect data as part of the programme).
(c) Data to be collected to facilitate the assessment of structure or component ageing.
(d) Assessment methods used for data analysis and analysis of trends. A description of how the collected data are evaluated is provided and may also include analysis of trends (i.e. a comparison of the current monitoring results with previous monitoring results to make predictions for the future). The description includes an evaluation of the results against the acceptance criteria, and a prediction with regard to the rate of degradation, to confirm that the next scheduled inspection will occur before a loss of the intended function of the structure or component. Although ageing indicators may be quantitative or qualitative, ageing indicators are quantified, to the extent possible, to allow the analysis of trends. The parameter or indicator that is being assessed for analysing trends is described. The methodology for analysing the inspection or test results against the acceptance criteria is described.

4.5. MITIGATION OF AGEING EFFECTS

This attribute includes the following:

(a) Actions that mitigate further degradation when degradation has been observed but the condition of the structure or component is still within the limits of the acceptance criteria.
(b) Operation, maintenance, repair and replacement actions to mitigate detected ageing effects and/or degradation of the structure or component. The activities are described for programmes which mitigate ageing degradation.

An example is the coolant dissolved oxygen level that is being controlled in a water chemistry programme to mitigate pipe corrosion.

4.6. ACCEPTANCE CRITERIA

This attribute includes acceptance criteria against which the need for corrective action is evaluated:

(a) The quantitative or qualitative acceptance criteria of the programme, and their bases, are described. The acceptance criteria against which the need for corrective actions is evaluated ensure that the intended function or functions of the structure or component are consistently maintained under all CLB conditions. The programme includes a methodology for analysing the results against applicable acceptance criteria. For example, carbon steel pipe wall thinning might occur under certain conditions as a result of flow accelerated corrosion. An effective AMP for flow accelerated corrosion might consist of periodically measuring the pipe wall thickness and comparing that with a specific minimum wall thickness acceptance criterion. Corrective action, such as piping replacement, is taken before the acceptance criterion is exceeded, and this acceptance criterion is appropriate to ensure that the thinned piping would be able to carry CLB design loads (i.e. deadweight, seismic and other loads). This acceptance criterion provides for the implementation of timely corrective action before the loss of intended function under these CLB design loads.

(b) When condition based qualification of a structure or component for design basis accident conditions is implemented, the acceptable degradation limit for the pre-accident condition needs to be established. The additional degradation expected to occur during or following any accident sequence, including that which can be attributed to changes in the operating environment or duty, is to be known and taken into account when establishing acceptance criteria.

(c) The acceptance criteria for an effective AMP are shown, either as specific numerical values or as a discussion of the process for calculating specific numerical values to define conditional acceptance criteria and ensure that the intended function or functions of the structure or component will be maintained under all CLB design conditions. Information from available references may be cited.

(d) It is not necessary to justify any acceptance criteria taken directly from the design basis information included in the SAR, the plant technical specifications or other codes and standards incorporated by reference into the applicable regulations; they are a part of the CLB. Nor is it necessary to justify the acceptance criteria that have been established in a methodology that is accepted or endorsed by the regulatory body, such as those that are determined in regulatory body approved or endorsed topical reports or endorsed codes and standards. It is also not necessary to discuss CLB design loads if the acceptance criteria do not permit degradation because a structure or component without degradation continues to function as originally designed. Acceptance criteria that do permit degradation are based on maintaining the intended functions under all CLB design loads.

4.7. CORRECTIVE ACTIONS

This attribute includes corrective actions if a structure or component fails to meet the acceptance criteria:

(a) Actions to be taken when the acceptance criteria are not met are described in appropriate detail or referenced in source documents. Corrective actions, including root cause analysis and prevention of recurrence, are implemented in a timely manner.

(b) If corrective actions permit analysis without repair or replacement, the analysis ensures that the intended function or functions of the structure or component are maintained consistent with the CLB.

(c) Corrective actions are prioritized and scheduled as a part of the plant's AMPs according to their safety importance.

(d) For safety related components, a plant quality assurance programme confirms that the corrective actions are performed in accordance with applicable code requirements or regulatory body approved standards. In the United States of America, for example, for a plant specific condition monitoring programme that is based on American Society of Mechanical Engineers Section XI requirements, the implementation of appendix B to 10 CFR Part 50 [40] ensures that the corrective actions are performed in accordance with applicable code requirements or regulatory body approved code cases.

4.8. OPERATING EXPERIENCE FEEDBACK AND FEEDBACK OF RESEARCH AND DEVELOPMENT RESULTS

This attribute includes the following:

(a) A mechanism that ensures timely feedback of operating experience and research and development results (if applicable), and provides objective evidence that they are taken into account in the plant specific AMP:
   (i) Consideration is given to plant specific and industry operating experience from all Member States and international organizations relating to each of the AMPs. Reviews of operating experience by the operator can identify areas where the plant specific AMPs are to be enhanced or new programmes developed. The plant operator commits to a review of plant specific and industry operating experience on a periodic basis to confirm the effectiveness of its AMPs or indicate a need to develop new plant specific AMPs.
   (ii) Operating experience with existing programmes is discussed. The operating experience of existing plant specific AMPs, including past corrective actions resulting in programme enhancements or additional programmes, is considered. A past failure of a component or structure would not necessarily invalidate a plant specific AMP because the feedback from operating experience is supposed to have resulted in appropriate programme enhancements or new programmes, if needed. This information can show where an existing programme has succeeded and where (or if) it has failed in intercepting ageing degradation in a timely manner.
   (iii) For new plant specific AMPs that have yet to be implemented and have therefore not generated any operating experience, other relevant plant specific operating experience or generic operating experience in the industry that is relevant to the AMP's attributes is to be considered. Thus, to ensure the effectiveness of a new plant programme, the plant operator considers the impact of relevant operating experience that results from the past implementation of its existing plant specific AMPs, and the impact of relevant generic operating experience, when developing the programme attributes. Therefore, operating experience applicable to new programmes will be discussed.
   (iv) International and domestic research and development activities relevant to the plant specific AMP are identified. Findings and results from these activities are evaluated to determine the need either to revise the existing plant specific AMPs or to develop new plant specific AMPs, as appropriate.

(v) Consideration is given to the effectiveness of AMPs. To measure their effectiveness, appropriate indicators are developed and assessed on a regular basis. Operating experience is used to define and improve definition and calculation of the indicators. Alternatively, AMP effectiveness indicators can be applied to identify AMPs that are not performing adequately and need to be enhanced.

(b) The result of the process provides objective evidence to support the conclusion that the effects of ageing will be managed adequately so that the intended function or functions of the structure or component are maintained during the entire period of operation.

4.9. QUALITY MANAGEMENT

This attribute includes the following:

(a) Administrative controls: A plant specific quality assurance programme is applied that documents the implementation of the plant specific AMPs, actions and procedures to guarantee fulfilment of the safety and performance goals of the plant operator and provide a formal review and approval process. The AMPs are developed and implemented according to relevant codes, standards and regulatory requirements.

(b) SAR supplements: SAR supplements include a summary description of each AMP, including the scope of SSCs and ageing effects, and an overview of the main results of the AMP (e.g. actual conditions of managed SSCs based on AMP results, safety margins of managed SSCs). Reference to relevant documents can be a suitable approach for reporting AMP results. The SAR supplement is consistent with paras 3.13.16–3.13.17 of SSG-61 [41]. Thus, any informal programmes relied upon to manage ageing will be administratively controlled and included in the supplement of the SAR.

(c) Performance indicators: Where possible, performance indicators are developed and used by the operating organization to evaluate the effectiveness of AMPs. The effectiveness of prevention and mitigation programmes is verified periodically. For example, in managing internal corrosion of piping, a mitigation programme (e.g. water chemistry) may be used to minimize susceptibility to corrosion. However, it may also be necessary to have a condition monitoring programme (e.g. ultrasonic inspection) to verify that corrosion is indeed insignificant. Performance indicators can be either quantitative (those that can be objectively measured) or qualitative (measure change over time against specific, predetermined criteria but do not involve enumeration).

(d) Confirmation (verification) process: A confirmation process is applied for ensuring that:
   (i) Preventive actions are adequate, prioritized correctly, have been completed and are effective.
   (ii) When corrective actions are necessary, root cause analysis has been performed, and there are follow-up activities to confirm that the corrective actions have been completed and are effective, and recurrence will be prevented.

   The confirmation process is addressed in accordance with IAEA Safety Standards Series No. GS-G-3.1, Application of the Management System for Facilities and Activities [42] (see paras 6.76–6.77 for preventive actions and paras 6.66–6.75 for corrective actions), and has to be in line with the national regulations and the plant specific preventive action programme and corrective action programme.

(e) Record keeping, data collection, management and approval practices: A data collection and record keeping system is necessary to support effective plant ageing management activities. Section 2 of Ref. [38] provides good practices on data collection and record keeping for ageing management, including AMPs.

5. EVALUATION OF EFFECTIVENESS OF PLANT LEVEL AGEING MANAGEMENT PROGRAMME AND INDIVIDUAL AGEING MANAGEMENT PROGRAMMES

Paragraph 5.49 of SSG-48 [3] states that “Performance indicators representing the effectiveness of the ageing management programmes should be developed along with the development of the ageing management programmes (see para. 5.56 [of Ref. [3]])”. Paragraph 5.54 of SSG-48 [3] states:

> “The effectiveness of ageing management programmes should be periodically evaluated in the light of current knowledge and feedback from the programme and the performance indicators and should be updated and adjusted as appropriate. Relevant knowledge includes information on the operation of the structure or component, surveillance and maintenance

histories, information from the results of research and development, and operating experience from other nuclear facilities."

The purpose of this section is to provide information for the process of evaluating the effectiveness of plant level and individual AMPs with an aim to ensure their continuous improvement. The results of this evaluation process may be used to demonstrate AMP effectiveness and to support safe plant operation by nuclear power plant decision makers, for LTO assessments or in a PSR.

The self-assessment approach of AMP effectiveness is part of this process and is integrated with existing utility self-assessment procedures and processes. Programme strengths and weaknesses are documented in accordance with existing procedures. An ineffective plant level AMP or individual AMP attributes are addressed using the corrective action programme (CAP).

The following sections provide guidance for evaluation of the effectiveness of AMPs for long term and short term intervals.

5.1. EVALUATION OF EFFECTIVENESS FOR LONG TERM INTERVALS

The activities typically taken into account for evaluating the effectiveness of plant level and individual AMPs in the long term are described in this section. The various review activities address different aspects of the AMPs' effectiveness. The following important factors are to be considered while evaluating the effectiveness of ageing management:

- Ageing management integrates other activities such as the effective cooperation of the plant divisions responsible for the individual plant programmes and technical areas within the management system and throughout the organization.
- Ageing management is an interdisciplinary activity, involving many technical areas, some of which need very specific technical knowledge, skills and experience. The plants provide qualified experts involved in ageing management to ensure the role of an 'intelligent customer' for services purchased from external technical support organizations.
- The most effective AMPs are proactive, anticipating and responding to ageing related issues rather than reacting to failures of SSCs.

5.1.1. Periodic safety review

Within the PSR, the cumulative effects of ageing on the safety of nuclear power plants, the effectiveness of AMPs and the need for improvements to AMPs, as well as technological obsolescence, are all covered and reviewed in safety factor 4 (ageing) in accordance with SSG-25 [5], and this takes place typically every 10 years. Other equivalent safety assessments can also be conducted at regular intervals depending on the national regulations.

A review of the ageing management process is part of the PSR. It typically addresses compliance with the latest national and international codes, standards and requirements, the scope of the SSCs covered by ageing management, and an in-depth review of the actual condition of in-scope SSCs, including assessment of ageing related data collected during the past to assess the effects of ageing on plant safety. The review also covers a consistency check of ageing related data and databases, ageing related knowledge management and human resources.

The review involves an assessment of the attributes of an effective ageing management programme for individual AMPs and a revalidation of TLAAs, where appropriate.

All these review components during a PSR are taken into account to evaluate the effectiveness and comprehensiveness of plant programmes and practices used to support ageing management throughout the plant's service life. Analysis of positive and negative findings, including their safety significance and identification of new ageing effects and degradation mechanisms, can be considered to measure the effectiveness of AMPs. Following PSR corrective actions are determined to improve the effectiveness of individual AMPs and the plant level AMP. Such corrective actions may include, for example, enhancing monitoring, inspection or surveillance technology, increasing inspection volume and changing the random sampling selection.

5.1.2. Regulatory body review

The regulatory body oversees the ageing management activities of nuclear power plants throughout their lifetime stages from design to release from regulatory control [37]. Regulatory functions, such as authorization, inspection, review and assessment and enforcement are discharged for the oversight of ageing management. The purpose of the regulatory oversight activities is to ensure, confirm and re-establish compliance with national regulations and standards, and check against international best practices.

The main contributions of the regulatory body in evaluating the effectiveness of plant level and individual AMPs can be summarized as follows:

- Evaluation of compliance of ageing management activities, including safety assessments, AMPs and TLAAs;
- Assessment of effectiveness of pre-existing plant programmes;
- Assessment of completeness of the scope setting;
- Evaluation of adequacy of SSC maintenance, modifications, refurbishment, replacement or safety improvements to respond to ageing related issues;
- Confirmation that all ageing related issues are addressed, including assessment and management of new ageing effects and/or degradation mechanisms;
- Evaluation of ageing related corrective actions, including implementation of the schedule proposed by the operating organization and follow-up on the status of implementing this schedule;
- Evaluation of ageing related performance indicators;
- Evaluation of the process and results of the operating experience feedback;
- Confirmation that due priority is given to initiation, planning and implementation of long term research related to ageing management;
- Evaluation of how knowledge management supports the long term implementation of ageing management activities;
- Checking that appropriate resources (including human resources) are deployed by the plant on ageing management activities;
- Interviewing the plant management and plant personnel implementing the ageing management process;
- Evaluation of the ageing management related procedures and documents within the plant's management system;
- Discussion of ageing management results with plant experts, as appropriate;
- Desktop reviews of submitted individual AMPs focused on technical aspects and attributes for an effective AMP;
- Experience and research results of other regulatory bodies provided through experience exchange between regulatory bodies;
- Application of a graded approach in the evaluation of the plant level ageing management activities of the licensee.

The regulatory body focuses attention on determining how well ageing is managed; thus the relevant outputs of the regulatory oversight activities are to be used to evaluate the effectiveness of plant level and individual AMPs.

5.1.3. Peer reviews

The effectiveness of ageing management can be evaluated by peer reviews and missions. Peer reviews reveal areas for improvement of safety, so the plants can pursue, achieve and demonstrate effectiveness in their ageing management.

The Safety Aspects of Long Term Operation (SALTO) peer review is a comprehensive IAEA service focused on ageing management and LTO of nuclear power plants, and complements Operational Safety Review Team (OSART) reviews. It evaluates plant programmes and performance on the basis of the relevant IAEA Safety Standards and the combined expertise of an international review team. It assesses the status of ageing management and the preparedness for LTO and provides recommendations and suggestions for improvement based on the identified gaps as compared to the IAEA Safety Standards. SALTO peer reviews are conducted in accordance with the guidelines presented in Ref. [43].

The main contribution of SALTO peer reviews in evaluating the effectiveness of plant level AMP and individual AMPs is a comprehensive review of the following:

— Regulations and requirements for ageing management and LTO;
— Ageing management process and organizational arrangements;
— AMR methodology and implementation;
— AMPs development, implementation and improvement;
— TLAA identification and revalidation;
— Documentation for ageing management;
— Process for internal and/or external operating experience and research and development results feedback;
— Knowledge and competence management for ageing management.

OSART missions can include an LTO review area, which covers the review of ageing management and preparation for LTO. The scope and outcome of the review is similar to that of SALTO missions, but the depth of the review is reduced.

There are also other peer reviews focused on ageing management. For example, the first Topical Peer Review (launched in 2017 by the European Nuclear Safety Regulator's Group (ENSREG)) had the objective to evaluate the consistency of AMPs in European countries with international requirements on ageing management. The review results can be used by concerned Member States to improve the effectiveness of the AMPs of nuclear power plants.

In some Member States external organizations are relied on or invited by the plant to peer review all or some of the plant level ageing management activities. The frequency of peer reviews may be adjusted to the plant's needs.

In the United States of America, the utilities perform domestic peer reviews of the effectiveness of the AMPs, in accordance with NEI 14-12 [44].

5.1.4. Benchmarking with other nuclear power plants and international practices (e.g. IGALL)

Benchmarking with other plants’ practices facilitates the improvement of a plant level AMP as well as of individual AMPs.

Several cooperation networks — organized on the international level on the basis of the reactor type, manufacturer or region (e.g. CANDU owners group, PWR and BWR owners group, WWER, KWU/Siemens, EDF, CGN, EPRI, NORDIC forum) or on the national level (where a fleet of plants exists) — provide appropriate platforms for benchmarking ageing related issues. International workshops also provide an opportunity to effectively initiate or perform benchmarking in terms of ageing management.

Comparing the implementation of the AMR process with other plants and with the AMR process proposed in IGALL promotes the improvement of the AMR process. The comparison can serve to identify new or potential degradation mechanisms and ageing effects, and to identify other SSCs or degradation mechanisms to be considered in the plant level AMP. It is also a tool for identifying new TLAAs; comparing equivalent TLAAs of different Member States allows for their improvement.

Experience in implementing AMPs and international practices is shared to assess the effectiveness of ageing management and develop corrective measures.

5.1.5. Periodical assessment of ageing management elements

Identification and revalidation of TLAAs

The identification and revalidation of TLAAs is assessed typically every 5 to 10 years or as required by national regulations. The purpose of the assessment activities is to confirm that all the time limited ageing parameters are properly managed for the intended period of operation. The process of identification and revalidation provides inputs to a periodic AMR.

The following aspects contribute to the evaluation of effectiveness of plant level and individual AMPs and are to be assessed when identifying and revalidating TLAAs:

— The scope of the TLAAs covers all components and corresponding degradation mechanisms associated with a time dependent parameter in the design basis analyses.

- Actual input data, applied conditions and limits, analysis methods and calculation models are adequate.
- New information (internal and external operating experience feedback) has been taken into account.
- The recommendations for safe operation are implemented in the corrective action programme.
- The modifications resulting from the revalidation of TLAAs are implemented, for example in operating regimes, SSC repairs and refurbishment.

Ageing management review

As described in Section 2, the AMR process includes identifying ageing effects and degradation mechanisms and identifying a need to develop new programmes and/or enhance existing programmes that manage these ageing effects so that each in-scope structure, component or commodity group performs its intended function. To determine the ageing effects requiring management, the plant considers and addresses the materials, environments and stressors that are associated with each structure, component or commodity group under review.

In addition to the consideration of materials, environment and stressors, the plant considers and addresses internal and external operating experience and existing engineering evaluations in order to identify the ageing effects requiring management for the structure or component subject to an AMR. The ageing effects requiring management are those that have been identified using the considerations described above, and that adversely affect the structure and component such that the intended function(s) cannot be maintained consistent with the CLB for the period of extended operation.

The AMR is updated typically every 5 to 10 years, or as required by national regulations. The objective of the AMR is to demonstrate the suitability of the ageing management process and the associated documentation (i.e. TLAAs, AMPs). The AMR verifies that effective ageing management is implemented to ensure that the safety functions of SSCs are fulfilled over the entire lifetime of the plant. On the basis of the results of the AMR for LTO, the existing plant programmes, AMPs and TLAAs used for ageing management are reviewed and updated to ensure that they will remain effective to manage the effects identified for the planned period of LTO.

The main contributions of the AMR in the evaluation of the effectiveness of the plant level AMP and individual AMPs are:

- To demonstrate that ageing effects and degradation mechanisms of in-scope SSCs are properly managed;
- To identify ageing effects which are not adequately managed;

— To evaluate the adequacy of the AMPs and TLAAs.

5.2. EVALUATION OF EFFECTIVENESS FOR SHORT TERM INTERVALS

In the short term (typical period of 1 to 5 years), nuclear power plant personnel may use the information provided in this section as a self-assessment tool when evaluating the effectiveness of an AMP. It is suggested that AMP effectiveness is periodically evaluated as part of existing operating experience and managed in the CAP. Results of existing and ongoing operating experience reviews and CAP results are part of the AMP review and improvement process. The tools and processes typically used to evaluate the effectiveness of plant level and individual AMPs in the short term are described in this section.

5.2.1. PLAN–DO–CHECK–ACT approach

The effectiveness of plant level and individual AMPs is typically maintained and improved by applying the PLAN-DO-CHECK-ACT approach, as a process of continuous improvement described in fig. 1 of SSG-48 [3]. Methods and actions to assess and improve the effectiveness of AMPs are planned, implemented, evaluated and modified as needed within this approach. The PLAN-DO-CHECK-ACT approach is well integrated in the relevant plant procedures and processes.

An example of applying this approach is assessing the effectiveness of the measures for detecting and managing relevant degradation mechanisms at regular intervals. The length of these intervals can be chosen in accordance with the expected ageing behaviour. This assessment may be based on a comparison of the specified and the actual conditions or on trend analyses. If the assessment of the effectiveness shows that the measures taken did not yield the expected result, these measures can be optimized or supplemented.

As part of the CHECK step, a checklist can be developed and used to evaluate plant level and individual AMPs. Checklists for a plant level AMP can use the elements listed in Section 3, while checklists for individual AMPs can use the generic attributes of an effective AMP (e.g. questions can be adjusted to the attributes: whether all inspections, monitoring activities or maintenance actions were done, whether new operating experience was found, whether any work permits affected the given AMP).

5.2.2. Internal and external operating experience, and research and development feedback

A systematic search, selection and analysis of operating experience with the subsequent implementation of acceptable experience by developing, implementing and evaluating corrective actions and the international operating experience feedback system as a whole contributes to the evaluation and further improvement of AMP effectiveness.

The effectiveness of AMPs is periodically evaluated on the basis of current knowledge and feedback from the programme and the performance indicators, and the AMPs are updated as appropriate. Periodic assessments such as programme implementation reports and focused self-assessments can contribute to the basis for determining when AMPs may need adjustment. Relevant knowledge includes information on the operation of the structure or component, histories of surveillance and maintenance activities, information from the results of research and development, and operating experience from other nuclear facilities and international organizations. A comprehensive review of operating experience relating to ageing management can trigger updates to the AMPs in order for the AMPs to be adequate to effectively manage ageing.

An indication of the effectiveness of the adequate management of ageing effects is that a loss of intended function does not occur due to ageing. To achieve this objective, the information from the following sources can be used to inform the need for improving the effectiveness of plant level and individual AMPs:

- Implementation of plant level and individual AMPs;
- Self-assessments of plant level and individual AMPs;
- Relevant external (e.g. IAEA Incident Reporting System (IRS), World Association of Nuclear Operators (WANO), bilateral relations, seminars) and internal operating experience which is shared within the organization;
- Research and development results (e.g. Electric Power Research Institute (EPRI), Nuclear Generation II & III Alliance (NUGENIA), Materials Ageing Institute (MAI)).

The number of cases when operating experience feedback was used to avoid the occurrence of an ageing effect or a loss of function due to an ageing effect can be considered in the determination and evaluation of performance indicators.

In the overall process of reviewing operating experience, ageing related information is identified, analysed and fed back to the ageing management process in a traceable manner with the involvement of ageing management experts with adequate expertise. The objectives of reviewing operating experience for ageing management are to check for new ageing effects, to identify a new component or location experiencing an already identified ageing effect and to improve the effectiveness of preventive, monitoring, mitigative and corrective actions foreseen in the AMPs. Monitoring the internal and external operating experience and research and development is key to updating AMPs and other plant programmes, and their implementation, in order to improve their effectiveness, as appropriate.

5.2.3. Performance indicators

Even a comprehensive, well-planned AMP might not be effective if not properly implemented. The implementation of an AMP can be evaluated using the results it produces during its implementation; for example, operating or maintenance experience, past corrective actions, root cause analyses, monitoring results, analysing trends in the evaluations, or health reports. These documents provide objective means to identify areas that might necessitate the implementation of improvements.

To evaluate the effectiveness of the AMPs, the operating organization develops and uses performance indicators. Examples of typical performance indicators are listed in SSG-48, para. 5.56 [3].

Plant level AMP

Performance indicators are used to evaluate the effectiveness of the AMP. Performance indicators used for the plant level AMP could be quantitative or qualitative. Plant level AMP indicators are typically evaluated on a yearly basis.

Qualitative indicators can be developed to evaluate any element of the plant level AMP. The qualitative performance indicators of a plant level AMP can include the workload, resource planning, progress of implementation of the AMP, cost planning and evaluation of results of the AMP, quality assurance and general condition of SSCs.

Examples of quantitative performance indicators of a plant level AMP are the overall operational time of safety systems, the overall number of failures of qualified components, the chemistry index, the number of orders and reissued orders for corrective maintenance, the number of regulatory findings, the ratio of implemented and planned ageing management actions. Appendix VII provides further examples of performance indicators for a plant level AMP.

Individual AMPs

In addition, some performance indicators can evaluate the correspondence of technical parameters of individual components to the acceptance criteria. The performance indicators can be specific for each individual AMP depending on the type and intended function of the SSC (e.g. number of steam generator plugged tubes, wall thickness, critical temperature of embrittlement, mechanical properties, conductivity, leak rates of containment, level of prestress). Performance indicators for individual AMPs are typically evaluated on a quarterly to yearly basis.

System health and reliability indices may also be used as performance indicators. The most obvious indicators are those directly related to the failure of the SSC caused by ageing or to the decreased availability of the SSC caused by ageing, and those that require the modification or development of AMPs.

If an AMP has an interface with other AMP(s), the effectiveness of the programmes needs to be evaluated together. In this case, the evaluation examines how the objective of the main programme is met.

Appendix VIII provides examples of performance indicators for the individual AMPs. These examples are based on the examples provided by the Member States. Examples are divided into general indicators that could be used for any individual AMPs and as specific indicators for some AMPs.

5.2.4. Performance criteria by attribute (maintaining the nine attributes of individual AMPs)

Existing AMPs and other plant programmes are evaluated for continued consistency with the nine attributes to determine if they are effective in detecting, monitoring and preventing or mitigating ageing effects and degradation mechanisms in the structures or components for which the programme is credited. If an existing AMP or other plant programme is not sufficiently effective, then the existing programme is improved or modified or a new programme is developed, consistent with the nine attributes. Below are some suggested performance criteria for each of the nine attributes based on NEI 14-12 [44]:

1. *Scope of the AMP based on understanding ageing*

The scope of the AMP identifies the specific structures and components that are managed by the AMP, as follows:

- Procedures and work orders contain appropriate components;
- For programmes that involve sample selection, the sample bases are applied consistently with the specifications outlined in the AMP;
- Implementing procedures and work orders are clearly tied to AMP findings (if applicable);
- Additions or deletions to the programme scope are properly addressed.

2. *Preventive actions to minimize and control ageing effects*

Preventive actions prevent the applicable ageing effects, as follows:

- Identified programme enhancements are defined in implementing procedures;
- Specific actions or commitments are verified, and changes, if any, are approved in accordance with the appropriate procedures;
- Preventive measures are appropriate for the applicable degradation mechanisms.

3. *Detection of ageing effects*

Detection of ageing effects occurs with sufficient time to implement preventive actions before there is a loss of structure- or component-intended function. This includes aspects such as the technique used (i.e. visual, volumetric, surface exam), frequency, sample size, data collection, and timing of new or one-time inspections to ensure timely detection of ageing, as follows:

- Inspections and examinations are conducted at specified intervals as required by the relevant standards or national regulations;
- Ageing effects are identified, and actions are implemented before loss of the intended function;
- Samples are biased toward locations most susceptible to the ageing effect of concern, and the sample size is expanded when degradation is detected in the initial sample;
- Any unexpected results are evaluated, and programme adjustments are made, as necessary;
- Operating experience is considered in evaluating the appropriateness of technique, frequency and adoption of new (enhanced) techniques as they become available.

4. *Monitoring and analysing trends of ageing effects*

Monitoring and analysing trends contribute to the prediction of the extent of degradation, and support the implementation of timely corrective or mitigative actions, as follows:

- Links between the monitored parameter and the respective ageing effect are explained;

- Justification is provided (including reference to codes and standards) that the technique and frequency are adequate to detect ageing effects in a timely manner;
- Justification of the selected sample size and sampling technique is given if sampling is applied (the sample needs to be representative considering the construction, fabrication, procurement, design, installation, operating environment and ageing effects of the SSCs for which the sample is taken);
- Data collection, evaluation against acceptance criteria and trend analyses for prediction of the extent of degradation are described;
- Ageing effects are monitored and analysed to identify trends so that no loss of intended function occurs;
- Results are used to establish a rate of degradation in order to confirm that the timing of the next scheduled inspection will occur before a loss of the intended function;
- Inspection frequencies are adjusted, as necessary;
- The implementing procedures identify the parameters monitored by the programme;
- An AMP based solely on detecting failure without adequate preventive, mitigative or corrective actions cannot be considered as effective.

5. Mitigating ageing effects

Actions mitigate the applicable ageing effects, as specified below:

- The parameters monitored include those parameters being controlled to achieve mitigation of ageing effects;
- When any evidence of an ageing effect or mechanism is observed, the extent of the condition is documented;
- Implementing activities are completed as scheduled and not deferred without adequate technical justification.

6. Acceptance criteria

Acceptance criteria, against which the need for corrective action will be evaluated, ensure that the structure or component-intended function(s) are maintained, as specified below:

- The basis of the acceptance criteria is explained unless it is determined in the design or other CLB documents;

- The implementing procedures contain acceptance criteria for the parameters monitored or inspected;
- The rate of change and margin to loss of function is evaluated against acceptance criteria;
- Acceptance criteria are revised or updated as necessary if unexpected or new degradation mechanisms occur; this triggers actions to reveal the extent of the degraded condition.

7. *Corrective actions*

The following actions, including cause evaluation and prevention of recurrence, need to be implemented in a timely manner:

- Condition reports are generated when the programme results fail to meet the acceptance criteria and upon detection of unexpected significant ageing degradation;
- Cause evaluations are performed in accordance with the plant procedures;
- The extent of degraded condition is fully revealed (i.e. the evaluation is extended to areas beyond where the problem was identified);
- Prognosis of further degradation is used to implement timely actions;
- Additional preventive actions, monitoring and inspections are identified and applied, as necessary.

8. *Operating experience feedback and feedback of research and development results*

Following the implementation of the AMP, industry operating experience and plant operating history, including corrective actions, are used to inform and update the AMPs:

- Industry operating experience is evaluated, and programme updates are made, as necessary;
- Plant-specific operating experience is used to update programmes, as necessary.

9. *Quality management*

Administrative controls provide a formal review and approval process, and the confirmation process ensures that preventive actions are adequate and corrective actions have been completed and are effective. Administrative controls include the following:

— Recommendations or deficiencies from external assessments are addressed.
— Commitments are managed in accordance with site procedures.
— Changes in commitments are flagged and administrative controls are employed.
— Documentation is verified in accordance with existing procedures.
— Evaluations are conducted when unexpected conditions of significant ageing effects are discovered. The evaluations address the expected conditions, rates, future inspections, and consideration of the impact on intended functions.
— Self-assessments are conducted, and programme improvements are applied, as necessary.
— Recommendations or deficiencies from external assessments are addressed.

6. TIME LIMITED AGEING ANALYSES

TLAAs are plant specific safety analyses that consider time and ageing and involve in-scope SSCs. TLAAs are analyses that meet all six criteria defined in para. 5.64 of SSG-48 [3]. This publication includes, among the list of typical TLAAs, other safety analyses that do not meet the criteria, but they may still be contained or incorporated by reference in the CLB because of having been newly developed in Member States to demonstrate readiness for LTO. The list of TLAAs in this publication might not address all plant specific analyses that need to be considered to demonstrate readiness for LTO, and not each listed TLAA applies to all plants.

Paragraph 7.28 of SSG-48 [3] states that "[t]ime limited ageing analyses should be reviewed to determine the continued acceptability of the analysed structure or component for the planned period of long term operation". Paragraph 7.18 of SSG-48 [3] states that the programme for LTO should include a:

"(d) Demonstration that the time limited ageing analyses have been revalidated and that the evaluation includes: ...Revalidation of each identified time limited ageing analysis in accordance with the recommendations provided in para. 7.28 to demonstrate that the intended function(s) of the structure or component will be maintained throughout the planned period of long term operation in a manner that is consistent with the current licensing basis."

Revalidation of an identified TLAA means assessing an identified ageing effect (time dependent degradation due to normal service conditions) and developing certain plant specific safety analyses based on an explicitly specified component life (e.g. fatigue calculations, pressurized thermal shock analysis, equipment qualification of electrical and I&C cables [45], concrete containment tendon prestress analysis). Paragraph 2.23 of SSG-48 [3] states:

> "Time limited ageing analyses involve two types of parameters. The first parameter is the time dependent variable used in the analysis. Examples of this parameter are the neutron fluence, the operating time or the number of thermal cycles a structure or component undergoes. The second parameter is the ageing effect associated with the first parameter, which could be the neutron embrittlement of vessel material, the cumulative fatigue usage factor or the thermal embrittlement of cast austenitic stainless steel, respectively. Both parameters should be evaluated and compared with a regulatory limit or criterion to determine the acceptability of the structure or component for continued service."

Evaluation of plant specific TLAAs can assume or analyse a given value of the time dependent parameter; for example, through a calculation of the neutron fluence for a certain operating period. This value of neutron fluence could then be used to evaluate certain analysis parameters, such as the adjusted reference temperature (e.g. T_k, RT_{NDT}) or the Charpy upper-shelf energy level. The purpose of a TLAA is to compare a calculated value of the analysis parameter to a regulatory limit or criterion, so that the acceptability of the component for continued service can be determined.

For LTO, plant specific TLAAs are reviewed to determine the continued acceptability of the analysed component or structure for the LTO period. In this case, the time dependent parameter is determined from a re-evaluation or analysis of plant operating history, which is projected to the end of the LTO period to define the value that applies to or bounds the expected value of the parameter at the end of the LTO period. This new value for the time dependent parameter is then used to re-evaluate the analysis parameter applicable to the LTO period. Paragraph 5.68 of SSG-48 [3] states:

"If the time limited ageing analyses cannot be found acceptable using the criteria in para. 5.67, then corrective actions should be implemented. Depending on the specific analysis, corrective actions could include:

(a) Refinement of the analysis to remove excess conservatism;
(b) Implementation of further actions in operations, maintenance or the ageing management programme;
(c) Modification, repair or replacement of the structure or component."

The plant's SAR can be supplemented to include a summary description of the plant specific TLAAs concerned and their evaluation for the LTO period. Generic TLAAs typically include the following [33]:

— Reactor vessel neutron embrittlement;
— Metal fatigue;
— Equipment qualification;
— Concrete containment tendon prestress;
— In-service local metal containment corrosion analyses.

Examples of potential plant specific TLAAs include the following [33]:

— Intergranular separation in the heat affected zone of reactor vessel low alloy steel under austenitic stainless steel cladding;
— Low temperature overpressure protection analyses;
— Fatigue analysis for the main steam supply lines to the turbine driven auxiliary feedwater pumps;
— Fatigue analysis for the reactor coolant pump flywheel;
— Fatigue analysis for the polar crane;
— Flow induced vibration endurance limit for the reactor vessel internals;
— Transient cycle count assumptions for the reactor vessel internals;
— Reduction of ductility and fracture toughness for the reactor vessel internals;
— Leak before break;
— Fatigue analysis for the containment liner plate;
— Containment penetration pressurization cycles;
— Metal corrosion allowance;
— High energy line break postulation based on fatigue cumulative usage factor;
— In-service flaw growth analyses that demonstrate structure stability for the current operating term.

Analyses that are not regarded as TLAAs include population projections and cost–benefit analyses for plant modifications. A sample process for identifying potential plant specific TLAAs and a basis for disposition are provided in Table 4 [32].

Lists of typical TLAAs for mechanical components, electrical and I&C components, and civil structures are provided in Appendix II. The latest collection of full TLAAs, which are based on input from participating Member States, is provided in the IGALL database on the IAEA IGALL public web site.

TABLE 4. EXAMPLES OF DISPOSITION OF POTENTIAL PLANT SPECIFIC TIME LIMITED AGEING ANALYSES

Example	Disposition
Regulatory correspondence requests a utility to justify that unacceptable cumulative wear did not occur during the design life of control rods.	Does not qualify as a TLAA because the design life of control rods is less than the plant operating life and therefore, does not meet criterion 3 of the TLAA definition in para. 5.64 of SSG-48 [3].
Maximum wind speed of 161 km/h is expected to occur once per 50 years.	Not a TLAA because it does not involve an ageing effect.
Correspondence from the utility to the regulatory body states that the membrane on the containment basement is certified by the vendor to last for the current operating term.	The membrane was not credited in any safety evaluation, and therefore the analysis is not considered a TLAA. This example does not meet criterion 4 of the TLAA definition in para. 5.64 of SSG-48 [3].
Fatigue usage factor for the pressurizer surge line is determined not to be an issue for the current licence period in response to regulatory notices.	This example is a TLAA because it meets all six criteria of the TLAA definition in para. 5.64 of SSG-48 [3]. The plant's fatigue design basis relies on assumptions defined by the current operating term, and it is important that they be revalidated for the LTO period.
Containment tendon lift-off forces are calculated for the current operating term of the plant. These data are used during technical specification surveillance to compare measured and predicted lift-off forces.	This example is a TLAA because it meets all six criteria of the TLAA definition in para. 5.64 of SSG-48 [3]. The lift-off force curves are currently limited to values appropriate for the current operating term, and it is important that they be revalidated for the LTO period to perform the technical specification surveillance.

Each TLAA description comprises three main parts: ‘TLAA description’, ‘TLAA acceptance by criteria (a), (b) and (c)’ (see para. 5.67 of SSG-48 [3]) and ‘References’. The ‘TLAA description’ describes the TLAA’s purpose, objectives, and identification of time dependent parameter and analysis parameter.

‘References’ are technical documents such as IAEA Safety Standards and technical publications, international organizations’ guides and technical publications, international and national codes, standards, regulatory requirements and guides. Each reference is cited in the TLAA at least once. References are publicly available documents which means that they are available for free or for a fee. References are available in any language, not only in English.

7. OTHER AGEING MANAGEMENT RELATED ACTIVITIES

Besides AMPs and TLAAs (see Sections 4 and 6) and plant programmes [38], other programmes or activities can also be of essential support for ageing management, including addressing not only physical but also non-physical ageing aspects. These programmes or activities have the following attributes:

- Are not referred to in the AMR;
- Are not connected to a typical TLAA;
- Are not fully described nor implemented in accordance with the nine generic attributes of an effective AMP;
- Do not fully meet the six criteria of a TLAA.

These other programmes or activities are not necessarily consistent with the guidelines or information provided in SSG-48 [3] or Ref. [38]; however, avoiding any contradiction is desired. Application of the relevant attributes of an effective AMP or suitable criteria of a typical TLAA may provide for better development and effective implementation of these other programmes or activities.

The practice of several Member States identified some important differences among ageing management related activities described in this section and IGALL AMPs and TLAAs, such as the following:

- Other ageing management related activities typically provide more general level guidance on proven ways of managing ageing than that provided in IGALL AMPs and TLAAs;

— The scope of the SSCs is defined on a high level (a list of managed SSCs is plant specific);
— Other ageing management related activities provide information on ageing effects (or obsolescence in case of TOP401) which are managed but they do not explicitly define combinations of ageing effect, structure or component, material and environment, which means that IGALL AMR line items cannot be created.

Examples of other programmes and activities described in this section are the following: management of non-physical ageing (TOP401 Technological Obsolescence Programme), approaches to managing ageing of spare parts while they are in storage (SPP402 Spare Parts Storage Programme), approaches to managing ageing during suspended operation (SOP403 Preservation of SSCs During Suspended Operation Programme) and addressing a lack of supporting ageing related analyses (ORP404 Components with Operational Restrictions that Have No Documented Safety Analysis).

Technological obsolescence is typically managed within a dedicated programme, which is established by the operating organization according to sections 2 and 6 of SSG-48 [3]. A description of a generic technological obsolescence programme is provided in IGALL TOP401 Technological Obsolescence Programme. This programme is not intended to manage ageing effects (i.e. physical ageing) but rather non-physical ageing (also called technological obsolescence).

Spare parts for components within the ageing management programme scope are made available partially through adequate storage arrangements that consider environmental conditions and through maintaining the condition of the spare parts. A generic SPP402 Spare Parts Storage Programme summarizes the considerations for in-storage ageing management (as recommended in para. 3.28 of SSG-48 [3]) and for maintenance on the basis of shelf life storage requirements mainly defined by suppliers.

Nuclear power plants can experience suspended operation (i.e. an extended outage of one to several years with the ultimate intention to restart). Typical reasons for such suspended operation are natural disasters, planned refurbishments, major equipment failures, major events or new or modified regulatory requirements. During a suspended operation, ageing management is considered in order to preserve the safety functions (see paras 3.37–3.40 of SSG-48 [3]). Many SSCs may experience operating and environmental conditions different from their normal operating state leading to different degradation mechanisms or ageing effects. Examples of such conditions are reduced or stagnant flow conditions, chemistry changes in process piping, changed ventilation, temperatures (due to the absence of component self-heating) and ambient air qualities (e.g. due to increased dust generation). SOP403 Preservation of SSCs During Suspended Operation Programme provides a proactive ageing management strategy to preserve the SSCs during the period of suspended operation and additional measures for restarting a unit.

In some cases, plant technical specifications have operational restrictions, but the plant designer has not provided the plant operator with a full design basis, including safety analyses that provide the bases for restrictions. For such cases, ORP404 Components with Operational Restrictions that Have No Documented Safety Analysis is one approach through which the plant operator could develop a new TLAA (see paras 4.13, 4.15 and 5.65 of SSG-48 [3]) to evaluate the operational restriction or to develop or enhance the AMP. These cases are plant specific and can involve various structures and components, and support management of various combinations of ageing effects, structures and components, materials and environment.

A list of documents describing other ageing management related activities is provided in Appendix III. The updated collection of proven practices of participating Member States is provided in the IGALL database on the IAEA IGALL public web site.

8. DEFINITIONS

It is important to ensure that a structure or component under question has similar characteristics (i.e. material, environment, ageing effect, degradation mechanism) to the items described in this publication before adopting the guidance provided for the subject item. For consistent use, the definitions of the most commonly used terms are provided in this section and in Tables 5–9, in Appendix V. The format and content of the AMR tables described in Section 2 have been developed to provide a generalization of terms used in this publication. The line items are made more generic and less prescriptive. For example, the phrase ‘piping, piping components, piping elements’ is used to replace various combinations of the terms ‘piping’, ‘fittings’, ‘tubing’, ‘flow elements or indicators’, ‘demineralizer’, ‘nozzles’, ‘orifices’, ‘flex hoses’, ‘pump casing and bowl’, ‘safe ends’, ‘sight glasses’, ‘spray head’, ‘strainers’, ‘thermowells’ and ‘valve body and bonnet’. Further associated with this simplification is the need to define what these simplified terms mean and how and where they are used.

Table 5 defines structures and components used in the nuclear industry. It is important to carefully compare the structures and components used in different reactor types and the structures and components used in the tables before reaching any conclusion. In the treatment of external or internal surfaces it is important to consider that surface conditions of SSCs are monitored through visual examinations and leakage inspections to determine the existence of external and internal corrosion or deterioration. For some environments, such as ‘air, indoor controlled’, ‘air, indoor uncontrolled’, ‘air, outdoor’, ‘condensation’ or ‘air, indoor uncontrolled >35°C’, the component description needs to identify whether the surface is external. This information is important because it indicates the applicability of direct visual observation of the surface for ageing management. For the remaining environments, this distinction need not be made, since the environment is to be internal to the barrier.

Table 6 defines many generalized materials used in the nuclear industry. Different manufacturers might not produce the same material composition. It is important to carefully compare the materials used with the materials in the table before reaching any conclusions.

Table 7 defines many of the standardized environments used. Some technical criteria, such as temperature thresholds for ageing effects in common use by the industry, are added to further clarify the applicability of the results.

Table 8 provides definitions of ageing effects, and Table 9 contains definitions of degradation mechanisms. In this publication, an ageing effect is a phenomenon that could lead to a loss of function of a component or structure. An ageing effect is a consequence of one or more degradation mechanisms affecting a component or structure, such as pipe wall thinning due to erosion, or loss of fracture toughness due to neutron irradiation and thermal ageing. In this publication, degradation mechanisms are terms that describe the fundamental processes by which ageing degradation occurs (e.g. boric acid corrosion, ohmic heating, settlement).

NOTE ON THE APPENDICES

The content of the appendices of this publication is consistent with the IGALL results approved by the end of 2022. The actual version of the appendices, consistently updated as the new IGALL results are published, can be found on the IGALL public web site.

Appendix I

LIST OF AGEING MANAGEMENT PROGRAMMES

This appendix provides a list of proven individual AMPs based on input from participating Member States. The most up to date versions of AMPs can be found in the IGALL database.

I.1. AGEING MANAGEMENT PROGRAMMES FOR MECHANICAL COMPONENTS

AMP101	Low Cycle Fatigue Monitoring
AMP102	In-service Inspection/Periodic Inspection
AMP103	Water Chemistry
AMP104	Reactor Head Closure Stud Bolting
AMP105	BWR Vessel ID Attachment Welds
AMP106	BWR Feedwater Nozzle
AMP107	BWR Stress Corrosion Cracking in Coolant Pressure Boundary Components
AMP108	BWR Penetrations
AMP109	BWR Reactor Pressure Vessel Internals
AMP110	PWR Boric Acid Corrosion
AMP111	PWR Cracking of Nickel Alloy Reactor Coolant Pressure Boundary Components
AMP112	Thermal Ageing Embrittlement of Cast Austenitic Stainless Steel
AMP113	PWR Reactor Pressure Vessel Internals
AMP114	Flow Accelerated Corrosion and Erosion
AMP115	Bolting Integrity
AMP116	Steam Generators
AMP117	Closed Treated Water Systems
AMP118	Reactor Pressure Vessel Surveillance
AMP119	One-time Inspection
AMP120	Selective Leaching
AMP121	One-time Inspection of Class 1 Small Bore Piping
AMP122	PWR Flux Thimble Tube Inspection
AMP123	BWR Control Rod Drive Return Line Nozzle

AMP124	Open Cycle Cooling Water System
AMP125	Buried and Underground Piping and Tanks
AMP126	Boraflex Monitoring
AMP127	Inspection of Overhead Heavy Load and Light Load (Related to Refuelling) Handling Systems
AMP128	Compressed Air Monitoring
AMP129	BWR Reactor Water Cleanup System
AMP130	Fire Protection
AMP131	Fire Water System
AMP132	Above Ground Metallic Tanks
AMP133	Fuel Oil Chemistry
AMP134	External Surfaces Monitoring of Mechanical Components
AMP135	Inspection of Internal Surfaces in Miscellaneous Piping and Ducting Components
AMP136	Lubricating Oil Analysis
AMP137	Monitoring of Neutron-absorbing Materials other than Boraflex
AMP138	Reactor Coolant Pump
AMP139	CANDU/PHWR Fuel Coolant Channels
AMP140	CANDU/PHWR Feeder Piping
AMP141	CANDU/PHWR Reactor Assembly
AMP142	CANDU/PHWR Fuel Handling
AMP143	Safety-Related Valves
AMP144	Safety-Related Pumps
AMP145	CANDU/PHWR Moderator and Moderator Purification Heat Exchangers
AMP146	CANDU/PHWR Inspection Programmes
AMP147	Containment Bellows
AMP148	CANDU/PHWR Reactor Shutdown Systems
AMP149	CANDU/PHWR Heavy Water Management
AMP150	CANDU/PHWR Annulus Gas System
AMP151	CANDU/PHWR Primary Heat Transport Instrument Tubing
AMP152	WWER Reactor Pressure Vessel Surveillance
AMP153	WWER Main Gate Valves
AMP154	PWR Pressurizer
AMP155	PWR Residual Heat Removal Heat Exchangers
AMP156	PWR Main Coolant Piping
AMP157	Internal Coatings and Linings
AMP158	Passive Hydrogen Recombiners
AMP159	PWR Emergency Core Cooling System Hydro-accumulators

AMP160	Neutron Fluence Monitoring
AMP161	High Cycle Fatigue Monitoring
AMP162	PWR Reactor Pressure Vessel
AMP163	Dissimilar Metal Welds
AMP164	Outdoor Piping, Tanks and Structures
AMP165	Essential Chillers
AMP166	Dry Storage Cask System

I.2. AGEING MANAGEMENT PROGRAMMES FOR ELECTRICAL AND INSTRUMENTATION AND CONTROL COMPONENTS

AMP201	Electrical Insulation for Electrical Cables and Connections Not Subject to Equipment Qualification Requirements
AMP202	Electrical Insulation for Electrical Cables and Connections Not Subject to Equipment Qualification Requirements Used in Instrumentation Circuits
AMP203	Electrical Insulation for Inaccessible Instrumentation and Control and Low and Medium Voltage Power Cables Not Subject to Equipment Qualification Requirements
AMP204	Metal Enclosed Bus Not Subject to Equipment Qualification Requirements
AMP205	Fuse Holders Not Subject to Equipment Qualification Requirements
AMP206	Electrical Cable Connections Not Subject to Equipment Qualification Requirements
AMP207	(not used)
AMP208	High-voltage Insulators and Connections, Transmission Conductors and Connections
AMP209	(not used)
AMP210	Condition Monitoring of Electrical and I&C Cables Subject to Equipment Qualification Requirements
AMP211	Oil-immersed Power Transformers Not Subject to Equipment Qualification Requirements
AMP212	Electrical Enclosures Not Subject to Equipment Qualification Requirements
AMP213	Whiskers and Capacitors with Liquid Electrolyte
AMP214	Electrical Insulation of Rotating Electrical Machines and Actuators Not Subject to Equipment Qualification Requirements
AMP215	Switchgears/Breakers/Distribution Panels/Contactors/Protection Relays/Relays Not Subject to Equipment Qualification Requirements
AMP216	Lead Batteries Not Subject to Equipment Qualification Requirements

AMP217	Sensors and Transmitters Not Subject to Equipment Qualification Requirements
AMP218	Electronic Equipment Not Subject to Equipment Qualification Requirements
AMP219	Fuses Not Subject to Equipment Qualification Requirements
AMP220	Lightning Protection, Grounding Grid and Surge Arresters Not Subject to Equipment Qualification Requirements
AMP221	Equipment Qualification Preservation and Re-assessment
AMP222	Fibre Optic Cables and Connections Not Subject to Equipment Qualification Requirements
AMP223	Electrical Insulation for Medium Voltage Shielded Cables and Connections Not Subject to Equipment Qualification Requirements
AMP224	Electrical Motors Not Subject to Equipment Qualification Requirements
AMP225	Condition Monitoring of Electrical Penetration Assemblies Subject to Equipment Qualification Requirements
AMP226	Fans Used in I&C and Power Electronics Cabinets
AMP227	Low-voltage Coils of Control Rod Drive System Not Subject to Equipment Qualification Requirements
AMP228	Capacitor Voltage Transformers Not Subject to Equipment Qualification Requirements
AMP229	Power Transformer Tap-changers Not Subject to Equipment Qualification Requirements
AMP230	Generators for Emergency Diesel Generator Systems Not Subject to Equipment Qualification Requirements
AMP231	Isolated Phase Bus Not Subject to Equipment Qualification Requirements

I.3. AGEING MANAGEMENT PROGRAMMES FOR CIVIL STRUCTURES

AMP301	In-service Inspection for Containment Steel Elements
AMP302	In-service Inspection for Concrete Containment
AMP303	Safety Class 1, 2 and 3 Piping and Metal Containment Components Supports
AMP304	Containment Leak Rate Testing
AMP305	Masonry Walls
AMP306	(not used, superseded by AMPs 318 and 319)
AMP307	Water Control Structures
AMP308	Protective Coating Monitoring and Maintenance Programme
AMP309	Non-metallic Liner

AMP310	Ground Movement due to Expansive Soils
AMP311	Containment Monitoring System
AMP312	Concrete Expansion Detection and Monitoring System
AMP313	Containment Prestressing System
AMP314	Seismic Isolation
AMP315	Spent Fuel Pool
AMP316	Subsurface Engineered Backfill Materials
AMP317	Settlement of Structures
AMP318	Concrete Structures Monitoring
AMP319	Non-concrete Structures Monitoring
AMP320	Vibration and Cyclic Loads on Civil Structures
AMP321	Monitoring of Concrete Structures During Delayed Construction
AMP322	Preservation of Non-concrete Structures During Delayed Construction
AMP323	Spent Fuel Dry Storage Concrete Structures
AMP324	Inaccessible Areas

Appendix II

LIST OF TIME LIMITED AGEING ANALYSES

This appendix provides a list of typical TLAAs based on input from participating Member States. The most up to date versions of TLAAs are provided in the IGALL database.

II.1. TIME LIMITED AGEING ANALYSES FOR MECHANICAL COMPONENTS

TLAA101	Low Cycle Fatigue Usage
TLAA102	Reactor Pressure Vessel Neutron Embrittlement
TLAA103	Crack Growth Analyses for Postulated Flaws or Flaws Detected in Service
TLAA104	Corrosion Allowances
TLAA105	CANDU/PHWR Fuel Channel Creep
TLAA106	Environmentally Assisted Fatigue
TLAA107	High Cycle Fatigue for Steam Generator Tubes
TLAA108	Fatigue of Cranes
TLAA109	PWR Reactor Pressure Vessel Internals Swelling
TLAA110	Thermal Ageing of Cast Austenitic Stainless Steels
TLAA111	CANDU/PHWR Hydrogen Embrittlement and Delayed Hydride Cracking in Pressure Tubes
TLAA112	Main Circulation Pump Flywheel
TLAA113	(not used)
TLAA114	(not used)
TLAA115	Fatigue and Thermal Ageing Analysis of Manufacturing Flaws and Flow Tolerance
TLAA116	Thermal Ageing of Low Alloy Steels
TLAA117	Under Clad Cracking
TLAA118	(not used, the TLAA was changed to ORP404)
TLAA119	High Cycle Thermal Fatigue
TLAA120	PWR Reactor Pressure Vessel Internals Vibrations
TLAA121	IASCC Fluence Limit for Stainless Steel
TLAA122	Thermal Ageing of Martensitic Stainless Steels

TLAA123	CANDU/PHWR Calandria Internals Vibrations
TLAA124	PWR Reactor Pressure Vessel Internals Irradiation and Thermal Embrittlement
TLAA125	Irradiation of Reactor Vessel Steel Supports
TLAA126	Pressure-temperature Limits and Low Temperature Overpressure Protection
TLAA127	Fatigue Waiver Evaluations
TLAA128	Re-flood Thermal Shock of the Reactor Pressure Vessel — Boiling Water Reactor
TLAA129	BWR Main Steam Line Flow Restrictors Erosion Analysis
TLAA130	Re-flood Thermal Shock of the Core Shroud — Boiling Water Reactor

II.2. TIME LIMITED AGEING ANALYSES FOR ELECTRICAL AND INSTRUMENTATION AND CONTROL COMPONENTS

TLAA201	Equipment Qualification of Electrical and I&C Equipment

II.3. TIME LIMITED AGEING ANALYSES FOR CIVIL STRUCTURES

TLAA301	Concrete Containment Tendon Prestress
TLAA302	Effects of Creep and Shrinkage on Performance of Concrete Structures
TLAA303	Cumulative Fatigue Damage of Containment Liners and Penetrations
TLAA304	Foundation Displacement due to Expansive Supporting Material
TLAA305	Irradiation of Concrete Biological Shield Structures

Appendix III

LIST OF OTHER AGEING MANAGEMENT RELATED ACTIVITIES

This appendix provides a list of other ageing management related activities based on input from participating Member States. The most up to date versions of other ageing management related activities can be found in the IGALL database.

TOP401	Technological Obsolescence Programme
SPP402	Spare Parts Storage Programme
SOP403	Preservation of SSCs during Suspended Operation Programme
ORP404	Components with Operational Restrictions that Have no Documented Safety Analysis
PAMC405	Programme for Active Mechanical Components

Appendix IV

LIST OF PROVEN REGULATORY PRACTICES IN THE OVERSIGHT OF AGEING MANAGEMENT

This appendix provides a list of publications in the IGALL database addressing proven regulatory practices.

RRP501	Regulatory Review Practice
SIP502	Standard Inspection Practices
RPE503	Regulatory Practices in Oversight of Ageing Management Programme Effectiveness
RPR504	Regulatory Practices in Oversight of Time Limited Ageing Analyses of the Reactor Pressure Vessel Pressurized Thermal Shock
RPC505	Regulatory Practices in Oversight of the Containment and Its Structural Elements

Appendix V

DEFINITIONS OF STRUCTURES AND COMPONENTS, MATERIALS, ENVIRONMENTS, AND AGEING EFFECTS AND DEGRADATION MECHANISMS

Many of the definitions listed in this appendix are based on Ref. [34].

TABLE 5. STRUCTURES AND COMPONENTS

Term	Definition as used in ageing management review tables
Anchorages	Used to join components to the structure.
Aseismic devices	Bearings that are able to isolate a component or a building from vibration due to earthquakes.
Bleed condenser	In CANDU or PHWR reactors, under high pressure conditions in the main heat transport circuit, pressure relief is via flow into the bleed condenser (also known as the degasser condenser). Pressure in the bleed condenser is regulated by condensing the heavy water steam with cooling flow through a reflux tube bundle and a spray flow.
Bolting	Structural bolting, closure bolting or all other bolting. Bolted closures are necessary for the pressure boundary of the components being joined or closed. Closure bolting in high pressure or high temperature systems is defined as that in which the pressure exceeds a certain level, for example 2 MPa (1.896 MPa in USA), or in which the temperature exceeds a certain level, for example 100°C (93°C in USA). Closure bolting is used to join pressure boundaries or when a mechanical seal is required.
Cable connection (cable splice, connector, terminal block)	Accessories used for proper insulation of cable connections at either end of the cable run or accessories used to join together two or more conductors (e.g. connectors, terminal blocks, termination kits, splices).

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in ageing management review tables
Cable connection (metallic parts)	Devices used to mechanically join the conductors of two or more cables together for terminations or splices. They can be either a fusion connection or a pressure connection. Fusion connections include soldering, brazing or welding one conductor to another (such as for connection ground braids to a cable shield). Pressure connections are used in most cases and include compression type (conductors inserted into a lug and crimped) or mechanical type (bare conductors joined together by clamping down with a bolt or set screw).
Cable (I&C)	The class of low-voltage cables that support instrument logic and control functions for both AC and DC circuits. Instrument cables carry low-level analogue or digital signals. Low-level analogue signals are variable voltage or currents from instrumentation systems. Low-level digital signals are coded voltage signals from analogue-to-digital converters or digital computers. Instrument cable is not limited to instrument circuits but is also used in security systems, page-party communications, fire detection and other systems. Conductor sizes for instrument cable are typically 18 or 16 AWG (American wire gauge; 18 or 16 AWG comply with 0.75 or 1.5 mm^2). Included in this category are shielded pairs or triads with copper tape or fine parallel wire shields. Coaxial and triaxial cables and thermocouple extension wire are also included in the instrument cable category. Control cables are those applied at relatively low current levels or used for intermittent operation to change the operating status of a utilization device of the plant auxiliary (or safety) systems. They interconnect protective relays, control switches, push buttons, and contacts from various devices (such as connections for interlocks and outputs from auxiliary relays). Control cables are generally multiconductor. Control cables are typically 14 or 12 AWG (1.5 or 2.5 mm^2) and are usually rated at a minimum of 600 volts.
Calandria vault	A structure of reinforced concrete. The inner surface of the water-filled calandria vault is lined with carbon steel to provide a leaktight seal for containment of the shield cooling system demineralized light water.
Calandria vessel	Contains the heavy water moderator and reflector; is a horizontal, cylindrical, single-walled shell enclosed at each end by calandria tube sheets and spanned horizontally by calandria tubes.
Chimney made of fibre reinforced polymer	Comprises composite material in which both polymer and fibres are included.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in ageing management review tables
Containment	Structures and associated components that perform a confinement function, namely preventing or controlling the release of radioactive substances and their dispersion in the environment. The containment refers, depending on the design, to a concrete or steel structure, and/or associated parts such as liners and penetrations. Together the structure and parts separate the confinement atmosphere from the outside environment.
Electrical enclosures	Passive mechanical supporting components of active electrical and I&C equipment that are mounted onto or inside electrical enclosures. An enclosure is a surrounding case or housing used to protect the contained conductors and prevent personnel from accidently making contact with live parts.
Electrical penetration assembly	Electrical penetration assemblies provide passage of electric conductors through a single aperture in the nuclear containment structure, while providing a pressure retaining boundary between the inside and outside of the containment structure.
Encapsulation components	Airtight enclosures that function as a secondary containment boundary to completely enclose containment sump lines and isolation valves. Encapsulation components and features (in systems such as the emergency core cooling system, containment spray system, containment isolation system and refuelling water storage tank) can include encapsulation vessels, piping and valves.
End fittings	The out-of-core extensions of pressure tubes. The end fittings provide a flow path for the primary coolant between the pressure tube and the rest of the CANDU primary heat transport system by having a bolted connection to carbon steel inlet feeders and outlet feeders.
End shield	Each end shield consists of a horizontal cylindrical shell enclosed by two tube sheets and spanned horizontally by lattice tubes. The inboard tube sheet, called the calandria tube sheet, is common to the end shield and the calandria vessel, except on some of the very early plants. The outboard tube sheet faces one of the fuelling machines and is, therefore, called the fuelling tube sheet. One end shield is welded to each end of the calandria vessel.
Expansion joint	An expansion joint is a mid-structure separation designed to relieve stress on building materials caused by structural movements induced by thermal expansion and contraction.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in ageing management review tables
External surfaces	The external surfaces of structures and components, such as tanks, which are not specifically listed elsewhere.
Feeders	In CANDU or PHWR systems, small diameter piping configured with a combination of bends and straight pipe runs that carry reactor coolant to and/or from the end fittings of each fuel channel to the inlet or outlet headers of the primary heat transport system.
Fibre optic cables	A cable, containing one or more optical fibres, where the cable elements provide protection to the optical fibre(s) from stress during installation and from the environment once installed.
Fuel coolant channels	In CANDU or PHWR systems, a horizontal array of zirconium tubing containing the reactor fuel and primary heat transport coolant through the calandria vessel. The fuel coolant channel consists of the pressure tube, annulus spacers, end fittings and their associated hardware.
Fuelling machine	The CANDU system employs a unique, on-power refuelling system. Two identical fuelling machines rise from a fuelling duct under the reactor and latch onto opposite ends of a designated fuel channel. Each machine is operated remotely from the control room. With both machines latched on and brought up to system pressure, the ends of the fuel channel are opened, and new fuel is exchanged for used fuel — one machine discharges new fuel and the other accepts used fuel. Major components or related parts of the fuelling machine include the fuelling machine bridges, carriages, machine heads, catenaries, guide column ball screw assembly, fuel transfer ports and shielding doors. A PHWR design with vertical fuel orientation has a single fuelling machine. This machine is able to handle two spent fuel elements and fresh fuel at the same time to perform fuel management.
Guide tubes	Used for the reactivity control units to penetrate the calandria vessel, passing between the calandria tubes, and screwing into locators on the inside of the calandria vessel.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in ageing management review tables
Heat exchanger components	A device that transfers heat from one fluid to another without the fluids coming into contact with each other. This includes air handling units and other devices that cool or heat fluids. Heat exchanger components include air handling unit cooling and heating coils, piping, shell, tube sheets, tubes, valves and bolting. Although tubes are the primary heat transfer components, heat exchanger internals, including tube sheets and fins, contribute to heat transfer and may be affected by the reduction of heat transfer due to fouling.
High voltage insulators	An insulator is an insulating material in a configuration designed to physically support a conductor and separate the conductor electrically from other conductors or objects. High voltage insulators are those insulators used to support and insulate high voltage electrical components in switchyards, switching stations and transmission lines.
HVAC duct	Heating, ventilation and air-conditioning (HVAC) duct and its components. Examples include ductwork, ductwork fittings, access doors, closure bolts, equipment frames and housing, housing supports (including housings for valves), dampers (including louvres and gravity dampers), mesh, filters and fire dampers, and ventilation fans (including exhaust fans, intake fans, purge fans). In some cases, this also includes HVAC closure bolts or HVAC piping.
Jet impingement shield	The impact of jet impingement on various types of piping and component insulations is considered in nuclear power plants. Jet impingement shield withstands the effects of jet impingement loading, resonant and non-resonant, blast loading and the like. Essential SSCs that cannot be demonstrated to meet code requirements under jet impingement loading can be protected by a jet shield.
Masonry walls	Construction parts made of concrete blocks or bricks. The masonry wall can be reinforced by rebars. Stability might be necessary to prevent interaction with SSCs, for fire area separation or for other safety reasons.
Metal enclosed bus	Term used in electrical and industry standards (Institute of Electrical and Electronics Engineers and American National Standards Institute) for electrical buses installed on electrically insulated supports, constructed with all phase conductors enclosed in a metal enclosure.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in ageing management review tables
Pipe whip restraint	Pipe whip restraints are used in nuclear power plants to protect nearby safety related systems and components against the effect of a high energy piping break that results in a pipe whip.
Piping, piping components	A category that includes features of the piping system within the scope of the AMR; specific features included in this category may vary in different countries. Examples include piping, fittings, tubing, flow elements and indicators, demineralizers, nozzles, orifices, flex hoses, pump casings and bowls, safe ends, spray heads, strainers, thermowells, and valve bodies and bonnets. For reactor coolant pressure boundary components that are subject to cumulative fatigue damage, this category also can include flanges, nozzles and safe ends, penetrations, instrument connections, vessel heads, shells, welds, weld inlays and weld overlays, stub tubes, and miscellaneous Class 1 components (e.g. pressure housings). Buried piping is in direct contact with soil or concrete (e.g. a wall penetration). Underground piping is below grade but is contained within a tunnel or vault such that it is in contact with air and located where access for inspection is restricted.
Power cable (low voltage)	Feed plant distribution equipment and motors rated 600 volts or less.
Power cable (medium voltage)	Feed plant distribution systems and large motors rated greater than 600 volts up to 15 kilovolts. Medium voltage power cables can be single conductor, triplexed (three single conductors twisted together), or three conductors under a single jacket. Cables rated less than 5 kilovolts can be shielded or non-shielded, while cables rated 8 kilovolts up to 15 kilovolts require a shield.
Pressure housings	Refers only to pressure housing for the control rod drive mechanisms (for PWR reactor vessels).
Pressure tubes and calandria tubes	Pressure tubes, which contain the high pressure, high temperature coolant, form part of the fuel channel assembly and are isolated from the cold, low pressure moderator by the carbon dioxide filled annulus spacer between the pressure tubes and calandria tubes of the CANDU or PHWR.
Prestressed cables and rods of retaining wall	Designed to support the retaining wall and to limit its deformation.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in ageing management review tables
Primary heat transport system	The reactor coolant pressure boundary of the CANDU or PHWR. Primary heat transport system boundary components include the fuel coolant channels, steam generators, primary heat transport system pumps, inlet headers, outlet headers, feeders and interconnecting piping.
Reactor assembly (CANDU/ PHWR)	The CANDU or PHWR reactor assembly components include: calandria vessel, end shield, shield tank (or water filled, steel-lined calandria vault), guide tubes and fuel coolant channels.
Reactor coolant pressure boundary components	Components include reactor pressure vessel, piping, piping components, piping elements, flanges, nozzles and safe ends, pressurizer vessel, heater sheaths and sleeves, penetrations and thermal sleeves.
Seals, gaskets, and moisture barrier (caulking, flashing and other sealants)	Elastomer components used as sealants or as gaskets, including metal reinforced sealing materials.
Shield tank	A welded carbon steel vessel with double end walls. The shield tank contains demineralized water, steel slabs and steel balls to provide biological shutdown shielding.
Spillway	A structure located inside the river dedicated to maintaining a minimum water level so that the pumping system is fed with sufficient water under all circumstances.
Steel and stainless steel elements (liner, liner anchors, integral attachments)	Steel and stainless steel liners used in the suppression pool, spent fuel pool, reactor pool and fuel transfer channel.
Steel components (civil structures)	Steel components that are attached to or reside within structures but are not part of the load bearing building structures, and include mechanical and electrical component supports, and other members, which include metal partition walls, pipe whip restraints, pipe and conduit supports, jet barriers, missile shields, crane rails, flood curbs, flood and fire doors, electrical and instrumentation enclosures, cable trays and fire hose racks.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in ageing management review tables
Structural steel	Steel members that comprise the load bearing building structures. It consists of structural members such as beams, girders (including crane path girders), joists, trusses, frames, columns, posts, girts, base plates, bearing plates, braces, splice assemblies, connections, stairs and platforms, decking, grating, bolts, washers and nuts, welds, studs, shims, and other steel items.
Switchyard bus	The uninsulated, unenclosed, rigid electrical conductor or pipe used in switchyards and switching stations to connect two or more elements of an electrical power circuit, such as active disconnect switches and passive transmission conductors.
Tanks	Large reservoirs used as hold-up volumes for liquids or gases. Tanks may have an internal liquid or vapour space and may be partially buried or in close proximity to soils or concrete that may experience general corrosion as the ageing effect at the soil or concrete interface. Tanks are treated separately from piping due to their potential need for different AMPs. Buried tanks are in direct contact with soil or concrete (e.g. a wall penetration). Underground tanks are below grade but are contained within a tunnel or vault such that they are in contact with air and are located where access for inspection is restricted.
Threaded fasteners	Threaded fasteners include joint components such as bolts, studs, nuts, washers, screws, anchorage to concrete, member faying surfaces (i.e. mating surfaces of bolted parts) and the exposed surfaces of cast-in-place or grouted steel and the entire length of concrete expansion anchors, above and below the concrete line.
Transmission conductors	Uninsulated, stranded electrical cables used in switchyards, switching stations and transmission lines to connect two or more elements of an electrical power circuit, such as active disconnect switches, power circuit breakers, transformers and passive switchyard buses.
Trash rack / Screen	A trash rack or screen is a metal structure capable of intercepting debris in a coolant flow system while maintaining a sufficient coolant flow rate. A trash rack for an emergency core cooling system of a nuclear power plant is comprised of at least one wire-mesh upright screen for filtering debris from water flowing in the cooling system.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in ageing management review tables
Vacuum building	A concrete containment structure in some CANDU reactors, operated at a pressure below atmospheric pressure during normal operation that, under accident conditions, serves to control pressure within the containment system.
Vibration isolation elements	Non-steel supports used to support components prone to vibration.
Water control structures	Integral parts of the systems that provide plant cooling water and residual heat removal.
Water stop	A water stop is an embedment in the concrete that obstructs the passage of water through the joint.

TABLE 6. MATERIALS

Term	Definition as used in ageing management review tables
ACSR	Aluminium conductor steel reinforced transmission conductor.
Aluminium	Aluminium alloys have low density and excellent corrosion resistance in the absence of halides and in the neutral pH-range only.
Boraflex	Composed of 46% silica, 4% polydimethyl siloxane polymer and 50% boron carbide. It is a neutron absorbing material used as a neutron absorber in spent fuel storage racks. Degradation of Boraflex panels under gamma radiation can lead to loss of the ability to absorb neutrons in spent fuel storage pools (e.g. AMP126 Boraflex Monitoring).
Boral®	Material consisting of aluminium and boron carbide sandwiched between aluminium. Boral® refers to patented aluminium–boron master alloys; these alloys can contain up to 10% boron as AlB12 intermetallics.
Boron steel	Steel with ^{10}B content ranging from one to several per cent. Boron steel absorbs neutrons and hence is often used to make control rods to help to control neutron flux.
Cast austenitic stainless steel (CASS)	A family of steels, including CF-3, CF-8, CF-3M and CF-8M, that have been widely used in water moderated reactors. These CASS alloys are similar to wrought grade types 304L, 304, 316L and 316, except that CASS typically contains 5–25% ferrite. CASS is susceptible to loss of fracture toughness due to thermal and neutron irradiation embrittlement.
Cementitious coating	Passive fire protection features installed on structures and components may vary and are selected based on their performance in the event of a fire. One such material is the cementitious coating, which is a lightweight cement product infused with an insulating aggregate of exfoliated vermiculite that is passive during normal conditions but is able to withstand extreme temperatures. Commercially available and widely used cementitious coatings include but are not limited to Pyrocrete, BIO™ K-10 Mortar and Cafecote.
Coating material	A thin layer of material applied by various processes for the purpose of corrosion prevention, resistance to high-temperature scaling, wear resistance, lubrication or other purposes. A good example is paint.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in ageing management review tables
Concrete and cementitious material	When used generally, a category of concrete applies to concrete in many different configurations (e.g. block, cylindrical) and to prestressed or reinforced concrete. Cementitious material can be defined as any material having cementing properties, which contributes to the formation of hydrated calcium silicate compounds. The following have cementitious properties: Portland cement, blended hydraulic cement, fly ash, ground granulated blast furnace slag, silica fume, calcined clay, metakaolin, calcined shale and rice husk ash. This category may include asbestos cement, although such compounds may not be in use any more due to adverse health implications.
Contact material	Used for electrical contacts and usually made of materials with good contact resistance (e.g. gold, silver).
Copper alloy (>15% Zn or >8% Al)	Critical alloying elements are above certain thresholds that make it susceptible to ageing effects. Copper–zinc alloys >15% zinc are susceptible to stress corrosion cracking (SCC), selective leaching (except for inhibited brass), and pitting and crevice corrosion. Additional copper alloys might be susceptible, such as aluminium bronze >8% aluminium. The elements that are most commonly alloyed with copper are zinc (brass), tin (bronze), nickel, silicon, aluminium (aluminium bronze), cadmium and beryllium. Additional copper alloys might be susceptible to ageing effects above the threshold for the critical alloying element.
Copper alloy (≤15% Zn and ≤8% Al)	This category applies to those copper alloys whose critical alloying elements are less than the thresholds that keep the alloy from being susceptible to ageing effects. For example, copper, copper nickel, brass, bronze ≤15% zinc (Zn), and aluminium bronze ≤8% aluminium (Al) are resistant to stress corrosion cracking, selective leaching, and pitting and crevice corrosion. They may be identified simply as ‘copper alloy’ when these degradation mechanisms are not at issue.
Ductile iron	Contains spherical graphite nodules, as opposed to graphite flakes for grey cast iron, resulting in increased strength and ductility compared with grey cast iron. Ductile iron is susceptible to selective leaching, resulting in a loss of iron from the microstructure, leaving a porous matrix of graphite.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in ageing management review tables
Earthen structure materials	These materials are usually a soil and rock composition found at the construction site or a nearby location. In their natural state, they do not age significantly over the lifetime of the facility. When they are used through moving or processing quantities of soil or unformed rock, the design considers a specific slope, shape and/or form to manage age degradations. Accordingly, they might erode and deform (loss of form) with time depending on the environmental conditions.
Elastomers	Natural or synthetic polymers that have elastic properties, such as rubber, ethylene propylene terpolymer (EPT), ethylene propylene diene monomer (EPDM), viton, vitril, neoprene, polyvinyl chloride (PVC), and silicone elastomer.
Electrolyte	A substance that ionizes in solution. Electrolytes conduct electricity: in batteries, they are instrumental in producing electricity by chemical action; in capacitors, paper saturated with electrolyte is used to separate aluminium foil strips.
Electronic components	Basic electronic elements, usually packaged in a discrete form with two or more connecting leads or metallic pads. Components are connected together, usually by soldering to a printed circuit board, to create an electronic circuit with a particular function.
Engineered backfill	A soil layer, which is engineered with compacted soil and binder mix, or which is a mechanically compacted soil layer without any binder mix, to achieve its designed mechanical and chemical properties in order to fulfil its intended function.
Fibre reinforced polymer	A composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, aramid or basalt. The fibres give mechanical capacity (mainly for tensile strength), while the polymer is the material matrix which gives the shape and the link to component and/or structure.
Galvanized steel	Steel coated with zinc, usually by immersion or electrodeposition. The zinc coating protects the underlying steel because the corrosion rate of the zinc coating in dry, clean air is very low and the zinc acts as a sacrificial anode to the steel. In the presence of moisture, galvanized steel is classified under the category ‘steel’.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in ageing management review tables
Glass	A hard, amorphous, brittle, super cooled liquid made by fusing together one or more of the oxides of silicon, boron or phosphorous with certain basic oxides (e.g. calcium, magnesium, potassium, sodium) and cooling the product rapidly to prevent crystallization or devitrification.
Graphitic tool steel	Steels (such as AISI O6, which is oil hardened, and AISI A10, which is air hardened) with excellent non-seizing properties. The graphite particles provide self-lubricity and hold applied lubricants.
Grease	A semisolid lubricant of a soap emulsified with mineral or vegetable oil. The characteristic feature of grease is that it possesses a high initial viscosity, which upon the application of shear, drops to give the effect of an oil lubricated bearing of approximately the same viscosity as the base oil used in the grease. Grease hardening due to, for example, elevated temperature may lead to loss of function.
Grey cast iron	An iron alloy used in nuclear plants. Cast iron is made by adding larger amounts of carbon to molten iron than would be used to make steel. Most steels have less than 1.2 % carbon, while cast irons typically have 2.5–4%. Grey cast iron has flat graphite flakes, which reduce its strength and act as crack formers, potentially initiating mechanical failures. They also cause the metal to behave in a nearly brittle fashion, rather than experiencing the elastic, ductile behaviour of steel. Fractures in this type of metal tend to take place along the flakes, which give the fracture surface a grey colour, hence the name of the metal. Grey cast iron is susceptible to selective leaching, resulting in a significant reduction of the material’s strength due to the loss of iron from the microstructure, leaving a porous matrix of graphite.
High density polyethylene	High density polyethylene (HDPE) or polyethylene high density is a polyethylene thermoplastic made from petroleum. It is sometimes called ‘alkathene’ or ‘polythene’ when used for pipes. It has been used in service water piping at some plants, as it has been found to have high corrosion and chemical resistance.
Insulation materials (various)	Materials with very low electrical conductivity. Materials used depend on environmental conditions and voltage (e.g. polymers, ceramics). Cables with mineral insulation (aluminium oxide, magnesium oxide) could exhibit reduced insulation resistance due to moisture intrusion or elevated temperature.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in ageing management review tables
Low alloy steel, actual measured yield strength ≥1034 MPa (150 ksi)	High strength Fe–Cr–Ni–Mo low alloy steel bolting materials with maximum tensile strength <1172 MPa (<170 kilopounds per square inch (ksi)) may be subject to SCC if the actual measured yield strength Sy ≥ 1034 MPa (150 ksi). Examples of high strength alloy steel designations that comprise this category include but are not limited to: SA540-Gr. B23/24, SA193-Gr. B8, and Grade L43 (AISI4340). Low-alloy steel SA193-Gr. B7 is a ferritic low-alloy steel bolting material for high temperature service. Low-alloy steel includes AISI steels 4140, 4142, 4145, 4140H, 4142H and 4145H (UNS#: G41400, G41420, G41450, H41400, H41420, H41450). Bolting fabricated from high strength (actual measured yield strength Sy ≥ 1034 MPa (150 ksi)) low-alloy steel SA193-Gr. B7 is susceptible to SCC.
Lubrite®	A patented, self-lubricating bearing technology in which the bearing substrate (bronze is commonly used, but in unusual environments other materials ranging from stainless steel and nodular iron to tool steel are used) is fastened to lubricant. Lubrite® is often defined as bronze attached to American Society for Testing and Materials (ASTM) B22, alloy 905, with G10 lubricant. Even though Lubrite® bearings are characterized as maintenance free, because of the differences in installation, fineness of the surfaces and lubricant characteristics, they can be subjected to mechanical wear and fretting. Though experience has not shown adverse conditions relating to the use of Lubrite®, the unique environment and tight installation tolerances required for installing the bearings would require bearing specific examinations. Literature from the general vendor (Lubrite Technologies) shows ten lubricant types used in the bearings, ranging from G1 (general duty) to AE7 (temperature and radiation tested) lubricants. Depending on the plant specific specification, lubricants of various requirements may be used. Any deviation from the specified tight tolerances for installation of the bearings could give rise to functional problems during challenging loading conditions (design basis accident, safe shutdown earthquake). Thus, ensuring the general installation conditions and clearing out any obstruction to their functioning will ensure the proper functioning of these bearings under challenging loading conditions. The associated ageing effects could be malfunction, distortion, dirt accumulation and fatigue effects under vibratory and cyclic thermal loads. The potential ageing effects could be managed by incorporating periodic examination in an appropriate AMP.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in ageing management review tables
Metal	An element, compound or alloy with good mechanical strength and a good conductor of electricity and heat. For electrical and I&C components, the main focus is oxidation of the metal, which leads to an increase of ohmic resistance in metal used as a conductor. For metal connections, loosening of the connection due to various ageing effects also leads to an increase in ohmic resistance.
Nickel alloys	Nickel–chromium–iron (molybdenum) alloys such as alloys 600/690. Examples of nickel alloy designations that comprise this category include alloys 82, 182, 600, 690, 800, Gr. 688 (X-750), SB-166, SB-167, SB-168 and X-750.
Non-metallic liner	An organic coating to enhance leaktightness for containment.
Oil (pressure transmitter)	Pressure transmitter oil is of a special quality and has good properties, such as thermal stability, radiation damage resistance and a low coefficient of expansion.
Paper	Used as electrical insulation in many applications because pure cellulose has outstanding electrical properties. Cellulose is a good insulator, having a dielectric constant significantly greater than one. It is used for many functions, including the insulation of wiring in transformers.
Polymer	This category generally includes flexible polymeric materials (such as rubber) and rigid polymers (like HDPE). These materials are used in mechanical components such as gaskets, seals and service water pipes. Polymers used in electrical insulation applications include PVC (polyvinyl chloride), EPR (ethylene propylene rubber), SR (silicone rubber), EPDM (ethylene propylene diene monomer), PE (polyethylene), PEEK (polyether ether ketone) and XLPE (cross-linked polyethylene). XLPE is a cross-linked polyethylene thermoplastic resin, such as polyethylene and polyethylene copolymers. EPR and EPDM are ethylene propylene rubbers in the category of thermosetting elastomers. Polymers used for cable jacketing include those containing halogens such as CSPE (chloro-sulfonated polyethylene), CPE (chlorinated polyethylene), PVC, polychloroprene (e.g. neoprene) and XLPE (cross-linked polyethylene). Non-halogen jackets are also used and go under the general term of low smoke zero halogen (LSZH).

TABLE 6. MATERIALS (cont.)

Term	Definition as used in ageing management review tables
Polyvinyl chloride	Used in the piping of some plants, PVC pipe has been found to have high corrosion and chemical resistance.
Porcelain	Hard quality porcelain is used as an insulator to support high voltage electrical insulators. Porcelain is a hard, fine grained ceramic that essentially consists of kaolin, quartz and feldspar fired at high temperatures.
Silicate	Passive fire protection features installed on structures and components may vary and are selected based on their performance in the event of a fire. One such group of materials involves the use of silicates in engineered fibres, which are used to produce insulation and fire barriers that are lightweight, resistant to thermal shock, and provide a low thermal conductivity. Commercially available and widely used materials in this group include but are not limited to Marinite®, Kaowool™, Cerafiber® and Cera® blanket.
Stainless steel	Wrought or forged austenitic, ferritic, martensitic, precipitation hardened (PH) martensitic, or duplex stainless steel (chromium content >11 %) are grouped for AMRs under the term 'stainless steel.' These materials are susceptible to a variety of ageing effects and mechanisms, including loss of material due to pitting and crevice corrosion, and cracking due to SCC. In the context of LTO, in some cases, when the recommended AMP is the same for precipitation hardened stainless steel or CASS as for stainless steel, precipitation hardened stainless steel or CASS are included as a part of the stainless steel classification. However, CASS is quite susceptible to loss of fracture toughness due to thermal and neutron irradiation embrittlement. Therefore, when this ageing effect is being considered, CASS is specifically designated in the AMR line item. Steel with stainless steel cladding may also be considered stainless steel when the ageing effect is associated with the stainless steel surface of the material, rather than the composite volume of the material. Examples of stainless steel designations that comprise this category include A-286, Gr. 660, SA193-6, SA193-Gr, B8 or B-8M, SA453, Type 304, Type 304NG, Type 308, Type 308L, Type 309, Type 309L, Type 316, Type 347, Type 403, Type 416 and Alloy 800. Examples of CASS designations include CF-3, CF-8, CF-3M, and CF-8M.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in ageing management review tables
Steel	For a given environment, carbon steel; alloy steel; cast iron; grey cast iron; malleable iron; and high strength, low alloy steel are vulnerable to general, pitting and crevice corrosion, even though the rates of ageing may vary. Consequently, these metal types are generally grouped for AMRs under the broad term ‘steel’. Note that this does not include stainless steel. However, grey cast iron is also susceptible to selective leaching, and high strength, low alloy steel is susceptible to SCC. Therefore, when these ageing effects are being considered, these materials are specifically called out. Galvanized steel (zinc coated carbon steel) is also included in this category of ‘steel’ when exposed to moisture. Examples of steel designations in this category include ASTM A36, ASTM A285, ASTM A759, SA36, SA106-Gr. B, SA155-Gr. KCF70, SA193-Gr. B7, SA194-Gr. 7, SA302-Gr. B, SA320-Gr. L43 (AISI 4340), SA333-Gr. 6, SA336, SA508-64, Class 2, SA508-Cl 2 or Cl 3, SA516-Gr. 70, SA533-Gr. B, SA540-Gr. B23/24 and SA582.
Subliming compound	Passive fire protection features installed on structures and components may vary and are selected based on their performance in the event of a fire. One such material is subliming compound, which absorbs heat as it changes directly from a solid to a gas phase (i.e. sublimation). Commercially available and widely used subliming compounds include but are not limited to Thermo-lag®, Darmatt™, and 3M™ Interam™.
Superaustenitic stainless steel	Has the same structure as the common austenitic alloys but with enhanced levels of elements such as chromium, nickel, molybdenum, copper and nitrogen, which give the alloys superior strength and corrosion resistance. Compared to conventional austenitic stainless steels, superaustenitic materials have superior resistance to pitting and crevice corrosion in environments containing halides. For example, several nuclear power plants have installed superaustenitic stainless steel (AL-6XN) buried piping.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in ageing management review tables
Titanium	Unalloyed titanium (e.g. ASTM grades 1–4) and various related alloys (e.g. ASTM grades 5, 7, 9 and 12). The corrosion resistance of titanium is a result of the formation of a continuous, stable, highly adherent protective oxide layer on the metal surface. Titanium and titanium alloys may be susceptible to crevice corrosion in saltwater environments at elevated temperatures (>70°C). Titanium grades 5 and 12 are resistant to crevice corrosion in sea water at temperatures as high as 260°C. SCC of titanium and its alloys is considered applicable in sea water or brackish raw water systems if the titanium alloy contains more than 5% aluminium, more than 0.20% oxygen or any amount of tin. For example, ASTM grades 1, 2, 7, 11 and 12 are not susceptible to SCC in sea water or brackish raw water.
Various materials used for electronic components	Electronic components can contain a wide range of electronic construction elements. These construction elements are connected, usually by soldering to a printed circuit board, to create an electronic circuit with a particular function. For example, these elements include wiring, resistors, capacitors, switches and semiconductor-based devices such as diodes, transistors and integrated circuits. The materials used depend on the specific construction element and may include, for example, various alloys (e.g. copper-based alloys in wiring), polymers (e.g. in insulation material), ceramics (e.g. in resistors) and semiconductor materials (e.g. doped silicon-based materials in transistors).
Water proofing membrane materials	Material to prevent the ingress of water.
Wood	Wooden piles or sheet piles exposed to flowing or standing water are subject to loss of material or changes in material properties due to weathering, chemical degradation, insect infestation, repeated wetting and drying or fungal decay.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in ageing management review tables
Zirconium alloy (zircaloy-4, zircaloy-2, Zr-2.5Nb)	A group of high zirconium alloys, which are often used in the high flux region of the nuclear reactor core, as zirconium has a very low absorption cross-section for thermal neutrons. Zircaloy-2 and zircaloy-4 are the most common zirconium alloys and contain about 98% zirconium. In PWRs, for example, in-core instrumentation thimble tubes are made of zircaloy-4. In CANDU reactors, the calandria tube is made of zircaloy-2. Another zirconium alloy that has significant importance is Zr-2.5Nb, which comprises 97.5wt% zirconium with 2.5wt% niobium. Zr-2.5Nb is used to make pressure tubes in CANDU/PHWRs. E125 (Zr-2.5Nb) and E110 (99wt% zirconium with 1wt% niobium) are used for in-core components in WWERs.

TABLE 7. ENVIRONMENTS

Term	Definition as used in ageing management review tables
Adverse localized environment	An environment limited to the immediate vicinity of an electrical component that is hostile to the component material, thereby leading to potential ageing effects. This can be due to significant moisture, radiation, voltage, oxygen or heat, particularly >60 year service limiting temperature (temperatures exceeding the temperature below which the material has a ≥60 year service lifetime).
Aggressive environment	This environment affects steel embedded in concrete with a water pH <5.5 or a chloride concentration >500 ppm or sulphate concentration >1500 ppm (limit values in the USA) or as specified in other Member States.
Air	Any indoor or outdoor air environment where the cited ageing effects could occur regardless of the particular air environment (e.g. 'air, indoor uncontrolled', 'air outdoor'). For example: (a) hardening or loss of strength of elastomeric components occurs in many different air environments depending on environmental parameters such as temperature, ozone, ultraviolet light and radiation; and (b) loss of preload for closure bolting can occur in a variety of air environments. The term 'air' was incorporated to allow the AMR line items to be more succinct with regard to citing environments. This term does not encompass the air environment downstream of instrument air dryers, air-dry or the underground environment. The potential for leakage from bolted connections (e.g. flanges, packing) impacting in-scope components exists when citing the air environment.
Air with borated water leakage	Air and untreated borated water leakage in indoor or outdoor systems with temperatures above or below the dew point. The water from leakage is considered to be untreated, due to the potential for water contamination at the surface.
Air with leaking secondary-side water and/or steam	Steel components within the pressure boundary and structural parts of a once-through steam generator may be exposed to an environment consisting of air with leaking secondary-side water or steam.
Air with metal temperature up to 288°C	Synonymous with the more commonly used phrase 'system temperature up to 288°C'.
Air with reactor coolant leakage	Air and reactor coolant or steam leakage in high temperature systems.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in ageing management review tables
Air with steam or water leakage	Air and untreated steam or water leakage in indoor or outdoor systems with temperatures above or below the dew point.
Air — indoor controlled	The environment to which the specified internal or external surface of the component or structure is exposed: indoor air in a humidity controlled (e.g. air-conditioned) environment. For electrical purposes, control needs to be sufficient to eliminate the cited ageing effects of contamination and oxidation without affecting the resistance. The potential for leakage from bolted connections (e.g. flanges, packing) impacting in-scope components exists.
Air — indoor uncontrolled	Indoor air on systems with temperatures higher than the dew point (i.e. condensation can occur but only rarely; equipment surfaces are normally dry).
Air — indoor uncontrolled and air outdoor >35°C	The environment to which the internal or external surface of the component or structure is exposed: indoor air above the thermal stress threshold for elastomers. If the ambient temperature is <35°C, then any resultant thermal ageing of organic materials can be considered insignificant over the operating period of interest. However, elastomers are subject to ageing effects from other factors, such as exposure to ozone, oxidation and radiation. The potential for leakage from bolted connections (e.g. flanges, packing) impacting in-scope components exists.
Air — outdoor	The outdoor environment consists of moist, possibly salt laden, atmospheric air, ambient temperatures and humidity, and exposure to weather, including precipitation and wind. The component is exposed to air and local weather conditions, including saltwater spray, where applicable. A component is considered susceptible to a wetted environment when it is submerged, has the potential to pool water, or is subject to external condensation. Also includes components exposed to air which has recently been introduced into buildings (i.e. components near intake vents). The outdoor air environment also potentially includes component contamination due to animal infestation, including by-products or excrement containing uric acid, ammonia, phosphates or other compounds.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in ageing management review tables
Air — dry	Air that has been treated to reduce the dew point well below the system operating temperature. For piping, this covers either external or internal surfaces treated to control lubricant content, particulate matter and other corrosive contaminants. Use of this term is only associated with internal air environments located downstream of the compressed air system air dryers.
Air — moist	Air with enough moisture to facilitate loss of material in steel caused by general pitting and crevice corrosion. Moist air in the absence of condensation is also potentially aggressive (e.g. under conditions where hygroscopic surface contaminants are present).
Any	Any environment — indoor or outdoor — where the ageing effects are not dependent on the environment.
Buried/ underground	Buried piping and tanks are those in direct contact with soil or concrete (e.g. a wall penetration). Underground piping and tanks are below grade but are contained within a tunnel or vault such that they are in contact with air and are located where access for inspection is restricted. When the soil environment is cited, the term includes exposure to 'groundwater/soil', and when the underground environment is cited, the term includes exposure to 'air, outdoor', 'air, indoor uncontrolled', 'air', 'raw water', 'groundwater' and 'condensation (internal/external)'.
Closed cycle cooling water	Treated water subject to the closed cycle cooling water chemistry programme. Closed cycle cooling water >60°C allows the possibility of stainless steel SCC. Examples of environment descriptors that fall in this category can include the following: Chemically treated borated water and treated component cooling water; Demineralized water on one side, closed cycle cooling water (treated water) on the other side; Chemically treated borated water on the tube side and closed cycle cooling water on the shell side.
Concrete	Steel and stainless steel components embedded in concrete.
Condensation	The environment to which the internal or external surface of the component or structure is exposed. Condensation on the surfaces of systems with temperatures below the dew point is considered raw water, due to the potential for surface contamination. The terms moist air or warm moist air are included in condensation and describe an environment where there is enough moisture for corrosion to occur.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in ageing management review tables
Diesel exhaust	Gases, fluids and particulates present in diesel engine exhaust.
Fuel oil	Diesel oil or other liquid hydrocarbons used to fuel diesel engines. Fuel oil used for combustion engines might be contaminated with water, which might promote additional ageing effects.
Gas	Internal gas environments include dry air or inert, non-reactive gases. This generic term is used only in common miscellaneous material–environment combinations where ageing effects are not expected to degrade the ability of the structure or component to perform its intended function for the period of extended operation. Does not include steam (see 'steam').
Groundwater/ expansive soil	It is a groundwater/soil environment (see definition of groundwater/ soil) composed by expansive soil, which is a clayey and unsaturated soil whose physicochemical properties lead it to a volumetric expansion (swelling) in the presence of water (groundwater).
Groundwater/ soil	Groundwater is subsurface water that percolates into the soil mass and can be detected in wells, tunnels or drainage galleries, or that flows naturally to the earth's surface via seeps or springs. Soil is a particulate medium composed of a mixture of organic and inorganic materials produced by the weathering of rock and clay minerals or the decomposition of vegetation. Voids containing air and moisture can occupy some percentage of the soil volume. Concrete subjected to a groundwater or soil environment can be vulnerable to an increase in porosity and permeability, cracking, loss of material (spalling, scaling) or aggressive chemical attack, such as from chlorides and sulphates. Other materials with prolonged exposure to groundwater or moist soils are subject to the same ageing effects as those systems and components exposed to raw water.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in ageing management review tables
Lubricating oil	Low to medium viscosity hydrocarbons that can contain contaminants or moisture. This definition also functionally encompasses hydraulic oil (non-water based). These oils are used for bearing, gear and engine lubrication. Piping, piping components and piping elements, whether copper, stainless steel or steel, when exposed to lubricating oil with some water will have limited susceptibility to ageing degradation due to general or localized corrosion. Lubricating oil (waste oil) and lubricating oil are different environments. Lubricating oil (waste oil) is oil that has been collected as it leaks from a component (e.g. reactor coolant pumps) and, as such, contains potential contaminants such as water and dirt. Lubricating oil is unlikely to contain contaminants due to the testing of the oil and corrective actions taken when contaminants are detected. As a result, one-time inspections for components exposed to these environments are treated as two separate populations.
Moderator (D_2O)	The CANDU/PHWR design uses heavy water (D_2O) as the moderator. It is kept at relatively low pressure and temperature (about 70°C) to take advantage of the neutron economy provided by deuterium. While many of the physical properties of heavy water are somewhat different than those of light water, they are similar in terms of environmental effects relating to ageing. The most important difference is that heavy water does not readily absorb neutrons. This makes heavy water one of the most effective neutron moderators available.
Neutron flux/ fluence	The neutron flux corresponds to the total length travelled by all neutrons per unit of time and volume. This is approximately equivalent to the number of neutrons travelling through unit area in unit time. The neutron fluence is defined as the neutron flux integrated over a certain period.
Primary coolant (D_2O)	The CANDU/PHWR design uses heavy water (D_2O) as the primary heat transport coolant to transfer heat generated from the reactor fuel to the steam generators. Primary heat transport coolant heavy water is at or near full operating pressure (8–10 MPa) and temperature (249–310°C). While many of the physical properties of heavy water are somewhat different than those of light water, they are similar in terms of environmental effects related to ageing.
Raw water	Comprises untreated surface or groundwater, whether fresh, brackish or saline in nature. This includes water for use in open cycle cooling water systems and may include potable water (see also ‘condensation’).

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in ageing management review tables
Reactor coolant	Treated water in the reactor coolant system and connected systems at or near full operating temperature, including steam associated with BWRs.
Reactor coolant >250°C	Treated water above the thermal embrittlement threshold temperature for CASS.
Reactor coolant >250°C, neutron flux/fluence	Treated water above the thermal embrittlement threshold temperature for CASS and neutron fluence exceeding a certain limit, for example 10^{17} n/cm^2 ($E > 1$ MeV) or another limit.
Reactor coolant and secondary feedwater/steam	Water in the reactor coolant system and connected systems at or near full operating temperature and the PWR feedwater or steam at or near full operating temperature, subject to the secondary water chemistry programme.
Secondary feedwater	Within the context of the recirculating steam generator, components such as the steam generator feedwater impingement plate and supports might be subjected to loss of material due to erosion in a secondary feedwater environment. More generally, the environment of concern is a secondary feedwater/steam combination.
Secondary feedwater/steam	PWR/CANDU/PHWR feedwater or steam at or near full operating temperature, subject to the secondary water chemistry programme.
Sodium pentaborate solution	Treated water that contains a mixture of borax and boric acid.
Soil	A mixture of inorganic materials produced by the weathering of rock and clay minerals and organic material produced by the decomposition of vegetation. Voids containing air and moisture occupy some amount of the soil volume. Properties of soil that can affect degradation kinetics include moisture content, pH, ion exchange capacity, density and hydraulic conductivity. The soil category includes components at the air–soil interface, buried in the soil or exposed to groundwater in the soil (see also ‘groundwater/soil’).
Steam	The steam environment is managed by the BWR water chemistry programme or PWR/CANDU/PHWR secondary water chemistry programme. Defining the temperature of the steam is not considered necessary for analysis.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in ageing management review tables
System temperature <288°C	Consists of a metal temperature of BWR components <288°C.
System temperature <340°C	Consists of a maximum metal temperature <340°C.
Treated borated water	Borated (PWR) water is a controlled water system. The chemical and volume control system maintains the proper water chemistry in the reactor coolant system while adjusting the boron concentration during operation to match long term reactivity changes in the core.
Treated borated water >60°C	Treated water above the 60°C SCC threshold temperature for stainless steel.
Treated borated water >250°C	Treated water with boric acid above the 250°C thermal embrittlement threshold temperature for CASS.
Treated water	Water whose chemistry has been altered and is maintained (as evidenced by testing) in a state which differs from that of water from naturally occurring sources so as to meet a desired set of chemical specifications. Treated water generally falls into one of two following categories: — The first category is demineralized water which, with the possible exception of boric acid (for PWRs only), generally contains minimal amounts of any additions. This water is generally characterized by high purity, low conductivity and very low oxygen content. This category of treated water is generally used as BWR coolant and PWR primary and secondary water. — The second category may, but need not necessarily, be based on demineralized water. It contains corrosion inhibitors and also may contain biocides or other additives. This water will generally be comparatively higher in conductivity and oxygen content than the first category of treated water. This category of treated water is generally used in HVAC systems, auxiliary boilers and diesel engine cooling systems. Closed cycle cooling water is a subset of this category of treated water.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in ageing management review tables
Wastewater	Radioactive, potentially radioactive or non-radioactive waters that are collected from equipment and floor drains. Wastewater might contain contaminants, including oil and boric acid, depending on the location, as well as originally treated water that is not monitored by a chemistry programme.
Wastewater >60ºC	Wastewater above 60°C, which is the SCC threshold temperature for stainless steel.
Water, flowing	Water that is refreshed and thus has a greater impact on leaching. This can include rainwater, raw water, groundwater or water flowing under a foundation.
Water, standing	Water that is stagnant and unrefreshed, thus possibly containing increased ionic strength up to saturation.

TABLE 8. AGEING EFFECTS

Term	Definition as used in ageing management review tables
Attenuation, increased	A general term used to denote a decrease in signal magnitude in transmission from one point to another. For fiber optics, this is a decrease of average optical power. Attenuation is generally expressed in decibels (dB).
Bearing degradation	Bearings might degrade due to excessive heat, loss of lubrication, improper sealing and clearance, improper loading and loss of cooling. Bearings might also degrade due to increased vibration caused by the rolling element issue, contamination or loosening of bearing in housing. Undue loading, surface irregularities and improper fittings might also cause bearing degradation.
Blistering or cracking of polymers	Cracking or localized loss of adhesion and lifting of the coating, lining or surfaces of polymers due to exposure to chemical attack, moisture, ozone, radiation, temperature or ultraviolet light.
Building deformation	Building deformation comprises geometrical changes of a structure due to ageing effects or external forces, which can occur as structural distortion or tilt. Symptoms of building deformations might include bulging, distortion of pipes, equipment misalignment, cracking or differential relative movement between structures.
Calibration drift and deviation offset point	Periodic deterioration in the calibration (input to output relation) of a sensor or instrument.
Carbonatation	Reaction between carbon dioxide and a hydroxide or oxide to form a carbonate, especially in cement paste, mortar or concrete; the reaction with calcium compounds to produce calcium carbonate (i.e. in the case of concrete carbonation it is the result of the dissolution of CO_2 in the concrete pore fluid and this reacts with calcium from calcium hydroxide and calcium silicate hydrate). Carbonation facilitates rebar corrosion.
Changes in chemical properties of soil foundation materials	Changes in any or all of the chemical properties (such as chemical composition, reactivity, bonding, porosity, cohesion) relied upon to perform an intended function due to chemical degradation or other phenomena.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Changes in colour	In a polymeric material, a change in colour is indicative of either water absorption (see 'water absorption') or degradation by thermal or photo-oxidation. The chemical reactions involved in oxidation degradation lead to physical and optical property changes relative to the initially specified properties. If an elevated temperature is applied to a polymer in the presence of an aggressive chemical agent (often oxygen), this may increase the rate of chemical reactions. During both thermal oxidation and photo-oxidation, chain scission occurs with the releasing of molecular chain segments from entanglements, facilitating conformational rearrangements. The material is changed irreversibly by the scission events. In addition to colour changes, other typical property changes due to oxidation degradation include reduced ductility and embrittlement, chalking, cracking or general reduction in most other desirable physical properties.
Changes in dimensions	Irreversible changes in dimension can result from various phenomena, such as void swelling, creep and, on a macroscopic level, denting.
Changes in material properties	Reduction of strength and modulus of elasticity can occur in concrete and cementitious piping, piping components and elements, joint components, exposed surfaces of cast-in-place or grouted steel and the entire length of concrete expansion anchors, above and below the concrete line, and elastomers due to exposure to aggressive environments such as raw water, air — indoor, and air — outdoor.
Changes in mechanical properties of soil foundation materials	Changes in any or all of the mechanical properties (such as density, strength, consistency, compacity, or grading of soil grains) relied upon to perform an intended function due to chemical degradation, dynamic loads and other phenomena.
Characteristic change	The input to output relationship of sensors is predictable under specified environmental conditions called characteristics. These characteristics include stability, sensitivity, linearity, precision and repeatability, accuracy, threshold, drift, zero drift, resolution, hysteresis, range and span, input impedance and loading effect. These characteristics might undergo change due to various degradation mechanisms.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Checking (splitting) due to ultraviolet radiation and ozone exposure	Elastomers exposed to ultraviolet radiation and ozone and air may undergo checking (splitting)
Concrete cracking and spalling	Cracking and exfoliation of concrete as the result of freeze–thaw cycles, aggressive chemical attack and/or reaction with aggregates.
Concrete expansion	The internal expansion of concrete caused by alkali–aggregate reaction and/or internal sulphate reaction.
Contact sticking	Contact sticking due to electrical causes occurs when excessive current flows through contacts, the heat generated causes the contacts to melt and then stick together inseparably.
Corrosion of steel plates of aseismic bearings	Aseismic bearings can be made of different layers of polymer (or rubber) and steel plates. These steel plates can become corroded with time.
Crack growth	Increase in crack size attributable to cyclic loading and other ageing phenomena such as SCC.
Cracking	Synonymous with the crack initiation and growth in metallic substrates. Cracking in concrete can be caused by restraint shrinkage, creep, settlement and aggressive environment.
Cracking due to expansion from reaction with aggregate	Cracking that appears on a concrete surface forming patterns of fine, distributed cracks and that occurs due to the expansion caused by alkali–aggregate reaction.
Cracking due to restraint shrinkage, creep and aggressive environment	Concrete shrinkage can lead to cracking if the element deformed is restrained by adjacent structures. In the same way, delayed deformation due to concrete creep can cause cracks. Aggressive environments, such as in the case of sulphate attack, can produce cracking.
Cracking due to ultraviolet radiation, ozone and temperature	Elastomers exposed to ultraviolet radiation, ozone and temperature (>35°C) might undergo cracking.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Cracking, loss of bond and loss of material (spalling, scaling)	Cracking, loss of bond, local flaking, peeling away of the near surface and loss of material (peeling, spalling, scaling) in concrete caused by reaction with aggregate or corrosion of embedded steel in concrete.
Cracking, loss of material properties	Cracking and loss of strength and modulus of elasticity can occur in concrete due to an adverse localized environment with high radiation or exposure to elevated temperature.
Cumulative fatigue damage	Damage due to fatigue, as defined by country specific national codes.
Damage to sealing components	Damage sustained by organic seal components during assembly or installation of components or during maintenance. This damage might have immediate or long term effects when combined with other stressors.
Decreased battery capacity	Decrease of the current supplying capacity of a battery, measured in units such as ampere–hour (A·h).
Defects of coatings, corrosion of reinforcement and liner, concrete degradation, increased porosity and permeability of reinforced concrete	For reinforced concrete structures, the presence of chemicals such as acids and hydroxides can lead to defects in coatings, corrosion of reinforcement steel, liners and concrete, as well as increased porosity and permeability of the reinforced concrete structures.
Degradation of electronic components	Due to continuous operation and depending on the operating and environmental conditions in their service life, electronic components such as transistors, resistors, capacitors or integrated circuits undergo progressive deterioration in their performance, resulting in characteristic changes, such as loss of sensitivity, shift in characteristic curve, reduction in insulation resistance and reduction in dielectric strength properties.
Delamination	A separation along a plane nearly parallel to a surface of a structural member.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Denting	Can result in steam generators from corrosion of carbon steel tube support plates.
Embrittlement	Embrittlement is a significant decrease of ductility of a material, which makes the material brittle. It can be an effect of exposure of the material to temperature, radiation, stresses, or diffusion of hydrogen in the material or other mechanisms changing the grain boundaries or material composition.
Excessive horizontal displacement	Excessive horizontal displacement of underground and buried structure walls resulting from excess of earth pressure compared to regular soil condition due to swelling of expansive soil.
Expansion and cracking	Can result within concrete structures, expansion and cracking from reaction with aggregates.
Flow blockage	Flow blockage is the reduction of flow and/or pressure in a component due to fouling, which can occur from accumulations of particulate fouling, biofouling, or macro fouling. In addition to affecting the 'pressure boundary' intended function (as it relates to sufficient flow at adequate pressure), flow blockage can also affect the 'heat transfer,' 'spray' and 'throttle' intended functions.
Fretting or lockup	Fretting wear due to accelerated deterioration at the interface between tight fitting surfaces as a result of extremely small amplitude relative motion of the two surfaces and, possibly, contributions of corrosion. In essence, both fretting and lock-up are due to mechanical wear.
Hardening or loss of strength	Hardening (loss of flexibility) or loss of strength (loss of ability to withstand tensile or compressive stress) that can be evaluated as an increment of compression set, can result from elastomer degradation in seals and other elastomeric components. Weathered elastomers can also experience shrinkage.
Increase in flow resistance	Reduction of flow can result from fouling or buildup of corrosion products and other deposits on the flow surfaces of piping and tubing, and other components such as valves, orifices, nozzles and sprinkler heads.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Increase in friction	Increase of the force that resists relative motion between two bodies in contact and that can lead to thermal effects and mechanical deformation.
Increase in porosity and permeability, cracking, loss of material (spalling, scaling), loss of strength	Porosity and permeability, cracking, and loss of material (spalling, scaling) in concrete can increase due to aggressive chemical attack. In concrete, the loss of material (spalling, scaling) and cracking can result from the freeze–thaw processes. Loss of strength can result from leaching of calcium hydroxide in the concrete.
Increase in resistance of connection	Ageing effect that can be caused by the loosening of bolts resulting from thermal cycling and ohmic heating. Increased resistance of connection is also caused by the following degradation mechanisms: — Chemical contamination, corrosion and oxidation (in an air, indoor controlled environment, increased resistance of connection due to chemical contamination, corrosion and oxidation does not apply); — Thermal cycling, ohmic heating, electrical transients, vibration, chemical contamination, corrosion and oxidation; — Fatigue caused by frequent manipulation or vibration; — Corrosion of connector contact surfaces caused by intrusion of borated water; — Oxidation or loss of preload.
Increase in rigidity of aseismic bearing supports	Aseismic bearings can be made of different layers of polymer (or rubber) and steel plates. The chemical composition of polymer might evolve with time, and hardening can be a consequence of this evolution.
Ingress of deleterious substances	Penetration of substances that can cause degradation of material properties.
Ligament cracking	Steel tube support plates can experience ligament cracking due to corrosion. Tube support plate signal anomalies found during eddy current testing of steam generator tubes might be indicative of support plate damage or ligament cracking.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Loss of coating integrity	The disbondment of a coating from its substrate can be due to a variety of degradation mechanisms, such as blistering, flaking, peeling or physical damage. Where the degradation mechanism results in exposure of the base material, unanticipated or accelerated corrosion of the base material can occur. Where the degradation mechanism results in the coating not remaining adhered to the substrate, the coating can become debris that could prevent an in-scope component from satisfactorily accomplishing any of its functions (e.g. reduction in flow, drop in pressure, reduction in heat transfer).
Loss of conductor strength	Transmission conductors can experience loss of conductor strength due to corrosion.
Loss of dielectric strength	Reduction in electrical potential gradient voltage (breakdown voltage) that can be applied to the insulating material without causing the breakdown of the material (e.g. and an associated decrease in the effectiveness of the electrical insulation). Loss of dielectric strength is an ageing effect associated with the following degradation mechanisms: — Thermal/thermo-oxidative degradation of organics and thermoplastics; — Radiation induced oxidation; — Moisture and debris intrusion; — Ohmic heating; — Presence of salt deposits or surface contamination (e.g. dust, oil mist); — Radiolysis and photolysis (ultraviolet sensitive materials only) of organics; — Mechanical loading and electrical stress (partial discharge).
Loss of electrical function	Can occur through the combined influence of a number of degradation mechanisms, such as ohmic heating, emergence of whiskers, abrasion of conductors or contacts, and characteristic change.
Loss of form	Geometric changes in earthen water-control structures resulting from structural distortion or tilt mechanism due to differential settlement.
Loss of fracture toughness	Can result from various degradation mechanisms, including thermal ageing embrittlement and neutron irradiation embrittlement.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Loss of leaktightness	Steel airlocks can experience loss of leaktightness in the closed position, resulting from mechanical wear of locks, hinges and closure mechanisms, or hardening of the gasket or seal material.
Loss of material	Might be due to general corrosion, boric acid corrosion, pitting corrosion, galvanic corrosion, crevice corrosion, erosion, erosion corrosion, fretting, flow accelerated corrosion, microbiologically influenced corrosion, fouling, selective leaching, wastage, wear or aggressive chemical attack. In concrete structures, loss of material can also be caused by abrasion or cavitation or corrosion of embedded steel. For high voltage insulators, loss of material can be attributed to mechanical wear or wind induced abrasion. In earthen water-control structures it can result from erosion, sedimentation, frost action, waves, currents, surface runoff or seepage. In polymer components, loss of material can also be caused by peeling and exposure to moisture, ozone, radiation, temperature, ultraviolet light or wear (e.g. rubbing on piping against the backfill when it is being placed in or during seasonal changes when the pipe might rub against the backfill).
Loss of mechanical function	In Class 1 piping and components (e.g. constant and variable load spring hangers, guides, stops, sliding surfaces, vibration isolators) fabricated from steel or other materials can occur through the combined influence of a number of degradation mechanisms. Such degradation mechanisms can include corrosion, distortion, dirt, overload, fatigue due to vibratory and cyclic thermal loads, or elastomer hardening. Clearances being lower than the design requirements can also contribute to a loss of mechanical function.
Loss of mechanical function (electrical components)	In electrical components fabricated from steel or other materials loss can occur through the combined influence of a number of degradation mechanisms. Such degradation mechanisms can include corrosion, distortion, dirt, overload, fatigue due to vibratory and cyclic thermal loads, or elastomer or lubricant hardening.
Loss of mechanical properties	Loss of strength or change of stiffness due to thermal ageing elevated temperature, exposure to ozone, oxidation, photolysis (due to ultraviolet light) and radiation. Degradation might include ageing effects such as cracking, crazing and fatigue breakdown.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Loss of preload	Can be due to gasket creep, thermal effects (including differential expansion and creep or stress relaxation) and self-loosening (includes vibration, joint flexing, cyclic shear loads, thermal cycles).
Loss of prestress	In structural steel anchorage components, loss of prestress can result from relaxation, shrinkage or elevated temperatures.
Loss of sealing function	Loss of sealing and leakage in such materials as seals, elastomers, rubber and other similar materials can result from deterioration of seals, gaskets and moisture barriers (e.g. caulking, flashing, other sealants). Loss of sealing in elastomeric phase bus enclosure assemblies can result from moisture intrusion.
Loss of strength due to irradiation	In concrete, reduction of strength can be attributed to concrete degradation due to neutron and X ray irradiation.
Loss of vibration alarm	If vibration detectors in a motor or its instrument/control cable from the motor to the display panel fail, the motor vibration data alarm will become unavailable.
Loss of winding temperature alarm/ indication	If the temperature detector in winding, thermostat or its cable from the motor to the display panel fails, the motor temperature data/alarm will become unavailable.
Melting	A change in physical state of a material (e.g. reduced viscosity) usually the result of exposure to high temperatures or radiation.
Motor failure	When a motor is unable to perform its rotating function, it is called motor failure, which might be mainly due to winding failure or mechanical failure like jamming or bearing issues.
Movement or shifting	In CANDU/PHWRs, the annulus spacers (garter springs), which are positioned along the length of the pressure tube to prevent it from making contact with the calandria tube, can potentially shift from their initial design position during operation due to fuel channel vibrations. This is of most concern for loose fitting or detensioned spacers.
No ageing effect identified	Certain material–environment combinations might not be subject to significant degradation mechanisms; thus, there are no relevant ageing effects that require management.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Plate bulging	Evolution in the shape of the containment liner due to temperature change and concrete creep.
Premature local failure	An ageing effect that occurs earlier than expected.
Reduced insulation resistance	An ageing effect used exclusively for electrical components resulting from the following degradation mechanisms: — Thermal and thermo-oxidative degradation of organics and thermoplastics (which can be accelerated by the presence of salt deposits or surface contamination); — Radiation induced oxidation; — Moisture and debris intrusion; — Ohmic heating; — Radiolysis and photolysis (ultraviolet sensitive materials only) of organics.
Reduction in concrete anchor capacity due to local concrete degradation	Can result from service induced cracking or other concrete degradation mechanisms.
Reduction in foundation strength	Can result from upheave (settlement upwards) owing to swelling of expansive soil, upheave due to increase of groundwater level and/or structure unloading, although negligible when compared to that from expansive soil, soil unconfinement due to, for instance, an excavation close to foundation, reduction in concrete strength due to delayed ettringite formation (DEF) and erosion of porous concrete, and soil liquefaction.
Reduction in heat transfer	Can result from fouling on the heat transfer surface. Although in heat exchangers the tubes are the primary heat transfer component, heat exchanger internals, including tube sheets and fins, contribute to heat transfer and might be affected by the reduction of heat transfer due to fouling. Reduction in heat transfer is also of concern for heat exchanger surfaces.
Reduction in neutron absorbing capacity	Can result from degradation of neutron absorbing materials.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Reduction in strength and modulus	Can be attributed in concrete to elevated temperatures (>65°C general, >90°C local).
Reduction or loss of isolation function	Reduction or loss of isolation function in polymeric vibration isolation elements can result from elastomers being exposed to radiation hardening, high temperature, humidity or sustained vibratory loading.
Rotor heating	A rotor is the rotating part of induction motors (squirrel cage type), which is made of metallic insulated lamination plates. Loss of insulation of these plates due to high ambient temperature or loosening due to vibration may cause increased eddy current losses in form of heat.
Signal distortion	The alteration of a transmitted signal caused by irregularities in the transmission medium.
Silting up of intake canal	Deposit of sediment near the intake canal might prevent the pumping system from collecting enough cooling water.
Spalling	A fragment usually in the shape of a flake, detached from a larger mass, which can be produced by a mechanical blow, weathering, pressure or expansion within the large mass.
Stator heating (rotating electrical machines)	A stator is a static part of rotating electrical machines (i.e. motor and generator) and consists of metallic insulated lamination plates that contain windings. Loosening of these plates might cause the failure of insulation, which increases the eddy current losses in the form of heat.
Structural distortion	Structural distortion comprises geometrical changes of structures characterized by angular variation among their elements due to differential settlement.
Tilt mechanism	A tilt mechanism is a rigid body rotation of structures (i.e. without angular variation among their elements, due to foundation settlement (downwards or upheave) that might take place if the foundation stiffness is much greater than that of the superstructure). The tilt mechanism does not generate significant variation in the stress state of the superstructure and therefore, practically does not cause cracking of concrete.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in ageing management review tables
Time dispersion	Dispersion is a phenomenon related to the variation in velocity of different frequencies (wavelengths) or different modes. The velocity of different frequencies can be different due to intrinsic properties of the medium or due to the dispersive nature of the bound structure such as the optical fibre.
Vibrating wire or pressure or temperature sensor failure or recorder obsolescence in devices installed in concrete structures	Can occur due to lack of electrical continuity, mechanical dislocation, corrosion, component rupture or excess concrete strain.
Wall thinning	A specific type of loss of material due to general corrosion, flow accelerated corrosion and erosion mechanisms, including cavitation, flashing, droplet impingement or solid particle impingement.
Welding defect propagation in stainless steel	Can occur when subjected to an environment with treated water or treated borated water.
Winding/coil failure	Breaking of winding or coil results in loss of function of the associated instrument or equipment. Associated degradation mechanisms include sustained vibratory loading, mechanical loading and ohmic heating. Winding in a motor consists of insulated copper (or aluminium) conductors. Minor failure of insulation and contact of copper conductors with other coil conductors, rotor or stator core or motor body may cause high current flow, which ends with increased heating till complete insulation failures, burning or melting of copper conductors occur.

TABLE 9. DEGRADATION MECHANISMS

Term	Definition as used in ageing management review tables
Abrasion	As water migrates over a concrete surface, it might transport material that can abrade the concrete. The passage of water may also create negative pressure at the water/air-to-concrete interface that can result in abrasion and cavitation degradation of the concrete. This might result in pitting or aggregate exposure due to loss of cement paste.
Abrasion, cutting or nicking	Damage sustained by cable or organic seal component during the initial installation, or during maintenance when working on or in the vicinity of cables or seal components where impacts or sharp edges have impacted the cable jacket and possibly the insulation (in more severe cases) or seal components that might have immediate or long term effects when combined with adverse environments.
Aggressive chemical attack	Concrete, being highly alkaline ($pH > 12.5$), is degraded by strong acids. Chlorides and sulphates of potassium, sodium and magnesium might attack concrete, depending on their concentrations in groundwater or soil that come into contact with the concrete. Exposed surfaces of Class 1 structures might be subject to sulphur based acid rain degradation (e.g. minimum thresholds causing concrete degradation in the USA are 500 ppm chlorides and 1500 ppm sulphates).
Alkali-aggregate reaction	Alkali-aggregate reaction (AAR) is an irreversible chemical reaction that covers two different types of degradation: alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). The more common is the alkali-silica reaction. ASR involves the formation of an alkali-silica gel which expands when exposed to water. The gel often causes a dark discolouration of the cement paste surrounding the crack at the concrete surface. Micro cracking is generated through forces applied by the expanding aggregate particles and/or swelling of the alkali-silica gel within and around the boundaries of the reacting aggregate particles. AAR does not necessarily result in expansion: expansion needs water to occur. High temperature will accelerate the reaction. Since the reaction depends on chemical components, the risk can be evaluated on the basis of concrete constituents (cement and aggregates) and an environmental analysis.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Biological attack	Concrete structures can undergo biodeterioration when exposed to lichens, mosses, algae, roots of plants and trees, marine molluscs, sponges, soil, water, sewage, food, agricultural products or waste materials. Biodeterioration can occur in foundations, walls, dams, harbour and maritime structures, bridges, tanks, pipelines, cooling towers or silos. Organisms colonize material surfaces and their pores, capillaries and microcracks, causing concrete damage resulting in aesthetic, functional or structural problems. Increased roughness as surfaces age facilitates the colonization of microbes. Microorganisms mainly affect the concrete by contributing to erosion of the exposed concrete surface, reducing protective cover depth, increasing concrete porosity and increasing transference into the concrete of degrading materials that can accelerate cracking, spalling and other damage and reduce the service life of the structure.
Blistering	Localized loss of adhesion and lifting of the coating, lining or surfaces of polymer piping.
Boraflex degradation	Might involve gamma radiation induced shrinkage of Boraflex and the potential to develop tears or gaps in the material. A more significant potential degradation is the gradual release of silica and the depletion of boron carbide from Boraflex, following gamma irradiation and long term exposure to the wet pool environment. The loss of boron carbide from Boraflex is characterized by slow dissolution of the Boraflex matrix from the surface of the Boraflex and a gradual thinning of the material. The boron carbide loss can result in a significant increase in the reactivity within the storage racks. An additional consideration is the potential for silica transfer through the fuel transfer canal into the reactor core during refuelling operations and its effect on the fuel clad heat transfer capability.
Boric acid corrosion	Can occur where there is borated water leakage in an environment described as air with borated water leakage.
Cavitation	Formation and instantaneous collapse of tiny voids or cavities within a liquid subjected to rapid and intense pressure changes resulting in pitting. Cavitation caused by severe turbulent flow can lead to cavitation damage.
Chemical contamination	Presence of chemicals that do not occur under normal conditions at concentrations that could result in the degradation of the component.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Chemical degradation	Alteration or deterioration of the material through chemical reaction.
Chemical reaction; corrosion of reinforcement, settlement or weathering; cavitation, delamination, exfoliation, popout, scaling or spalling	This term applies to concrete, concrete cylinder pipe, reinforced concrete, asbestos cement and cementitious components. Degradation mechanisms associated with cracking (chemical reaction, corrosion of reinforcement, settlement or weathering) are described in ACI 224.1R-07, Causes, Evaluation, and Repair of Cracks in Concrete Structures. For example, chemical reaction includes: (a) reaction with aggregates, (b) effects of sulphates in the soil, and (c) effects of de-icing salts. Increased porosity and permeability of cementitious materials can result in cracking. Degradation mechanisms associated with loss of material (cavitation, delamination, exfoliation, popout, scaling or spalling) are described in ACI 201.1R-08, Guide for Conducting a Visual Inspection of Concrete in Service.
Cladding/lining degradation	Degradation of the cladding or lining can lead to the loss of material due to pitting and crevice corrosion of piping, piping components and piping elements fabricated from steel.
Component rupture or excess concrete strain	Sensor stops measuring or is damaged by the strain of concrete exceeding the sensor’s measuring range.
Compression set	Organic materials placed in compression for extended periods might exhibit an effect known as compression set; this is defined as the amount that a material fails to return to its original dimension or shape after a compressive load is removed.
Corrosion	Chemical or electrochemical reaction between a metallic material and the environment, or between two dissimilar metallic materials, which produces a deterioration of the materials and their properties.
Corrosion of embedded steel	If the pH of concrete in which steel is embedded is reduced below 11.5 by the intrusion of aggressive ions (e.g. chlorides in concentrations >500 ppm) in the presence of oxygen, embedded steel might corrode. A reduction in pH may be caused by the leaching of alkaline products through cracks, entry of acidic materials or carbonation. Chlorides might be present in the constituents of the original concrete mix. The severity of the corrosion is affected by the properties and types of cement and aggregate, and the moisture content.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Corrosion of embedded steel (without spalling, scaling and loss of concrete material)	This type of corrosion (also known as black or green rust due to the colour) can be found in submerged concrete structures with a lack of oxygen. Typical for this kind of corrosion is no indication of cracking, spalling or scaling of concrete. This is because of the small expansion of the oxide Fe_3O_4, which means that the volume of the black rust is only slightly larger than the original steel (in contrast to corrosion in an oxygen rich environment, where the volume of the products from rust is two to five times greater than the original steel). The reinforcement might therefore be severely affected before corrosion is detected. In any case, visual signs of rust deposits on concrete surfaces are common signs of degradation (see also 'corrosion of embedded steel').
Creep	For a metallic material, a time dependent continuous deformation process under constant stress. It is an elevated temperature process and is not a concern for low alloy steel below 370°C, for austenitic alloys below 540°C, or for nickel based alloys below 982°C. Creep, in concrete, is related to the loss of absorbed water from the hydrated cement paste. It is a function of the modulus of elasticity of the aggregate. It might result in loss of prestress in the tendons used in prestressed concrete containment.
Crevice corrosion	Localized corrosion of a metal surface at, or immediately adjacent to, an area that is shielded from full exposure to the environment because of the close proximity of the metal to the surface of another dissimilar material. Crevice corrosion occurs in a wetted or buried environment when a crevice or area of stagnant or low flow exists that allows a corrosive environment to develop in a component. It occurs most frequently in joints and connections, or points of contact between metallic materials and non-metallic materials, such as on gasket surfaces, in lap joints and under bolt heads. Carbon steel, cast iron, low alloy steels, stainless steel, copper, aluminium and nickel base alloys are all susceptible to crevice corrosion. Steel can be subject to crevice corrosion in some cases after cladding and lining degradation.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Cyclic loading	One source of cyclic loading is the periodic application of pressure loads and forces due to thermal movement of piping transmitted through penetrations and structures to which penetrations are connected. The typical result of cyclic loads on metal components is fatigue cracking and failure; however, cyclic loads also might cause changes in dimensions that result in functional failure. Another source of cyclic loading is earthquakes. Nuclear power plants are designed for earthquakes with magnitude equal to seismic level 1. Cyclic loading is used to describe cracking that occurs due to fatigue when there are no calculations of a cumulative usage factor or similar parameter to evaluate the condition.
Delayed ettringite formation (DEF)	Delayed ettringite formation (DEF) is a case of chemical sulphate reaction where the source of sulphate ions happens to be internal. Cases of DEF are likely to happen when the concrete temperature during setting is higher than 65°C. This can occur in thick elements due to the exothermic nature of the reaction cement undergoes during the curing process. In fact, ettringite is not stable above 65–70°C, and the released ions during its decomposition are absorbed by calcium-silicate hydrate. Later, during service when sulphate ions are desorbed, the re-formation of ettringite causes expansion with possible cracking. Again, water is necessary for expansion to occur.
Delayed hydride cracking (DHC)	Loss of structural integrity due to the formation of brittle hydrides in zirconium alloy pressure tubes (or fuel cladding).
Deposit of sediment material	Suspended particles through water settling on the bottom of channels causing greater flow resistance.
Deterioration of gaskets, moisture barriers and seals (caulking, flashing and other sealants)	Subject to loss of sealing and leakage due to containment caused by ageing degradation of these components.
Distortion	The degradation mechanism of distortion associated with component supports can be caused by time dependent strain or by gradual elastic and plastic deformation of metal that is under constant stress at a value lower than its normal yield strength.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Dynamic strain ageing	A phenomenon associated with post-yielding plastic deformation in metals as a result of interactions between mobile dislocations and the dissolved interstitial solute atoms (e.g. carbon, nitrogen) which leads to unsteady flow phenomena at the macroscopic scale, appearing as a serrated stress–strain response and deformation banding and reduced ductility. There are five major factors that affect the extent of dynamic strain ageing: (i) the amount of interstitial nitrogen and carbon atoms, (ii) temperature, (iii) strain rate, (iv) extent of prestrain (i.e. initial dislocation density), and (v) stress state.
Elastomer degradation	Degradation mechanisms for elastomers include abrasion, chemical attacks, exposure to ultraviolet, ozone, oxygen, light and heat.
Electrical surface tracking	The combination of voltage and moisture can affect insulation that is dirty or deteriorated, resulting in surface tracking paths between conductor and ground, or conductor to conductor. Moisture allows leakage currents to flow across the insulation surface when a potential gradient exists. The leakage current flow will cause the moisture in the tracking path to evaporate; the leakage current will tend to remain constant such that the current density in the tracking path increases as moisture evaporates. This can result in localized burning of the insulation and carbonization at the ends of the tracking paths and ultimately in insulation failure.
Electrical transients	Stressors caused by a voltage spike that can contribute to ageing degradation. Certain types of high energy electrical transient can contribute to electromechanical forces, ultimately resulting in fatigue or loosening of bolted connections. Transient voltage surges are a major contributor to the early failure of sensitive electrical components.
Electrical treeing	In medium voltage applications, partial discharge can occur between conducting components internal to the penetration structure or between insulators separated by a gaseous medium (including air or inert gas) due to the presence of a high voltage gradient and might result in insulation degradation. The damage patterns in the insulation look like trees, thus the term ‘electrical treeing.’
Electrolyte dry out	Over time, electrolytes start to dry out and their capacitance value changes.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Electrostatic discharge	A sudden flow of electricity between two objects caused by contact, an electrical short or dielectric breakdown, which can be caused by a buildup of static electricity because of tribocharging or by electrostatic induction, and can result in a range of harmful effects, including the failure of solid state electronic components such as integrated circuits, which can suffer permanent damage.
Elevated temperature	Temperature rise above a given threshold defined by manufacturer or by analysis.
Emergence of whiskers	Metal whiskering is a crystalline metallurgical phenomenon involving the spontaneous growth of tiny filiform hairs from a metallic surface. The effect is primarily seen on elemental metals but also occurs with alloys. The mechanism behind metal whisker growth is not well understood but seems to be encouraged by compressive mechanical stresses including the following: — Residual stresses caused by electroplating; — Mechanically induced stresses; — Stresses induced by diffusion of different metals; — Thermally induced stresses.
Environmentally assisted fatigue	Also called corrosion fatigue, a reduction in fatigue life in the reactor water environment compared to the fatigue life in ambient air.
Erosion	The progressive loss of material from a solid surface due to mechanical interaction between the surface and a moving fluid, a multicomponent fluid or solid particles carried by the fluid, attributed to cavitation, flashing, droplet impingement or solid particle impingement.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Fatigue	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 or 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, microstructural damage might accumulate, leading to macroscopic crack initiation at the most vulnerable regions. Subsequent mechanical or thermal cyclic loading might lead to growth of the initiated crack. Vibration might result in high cyclic fatigue for components, as well as in cutting, wear and abrasion if left unabated. Vibration is generally induced by external equipment operation. It might 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 and the presence of deleterious chemical species.
Fatigue in fuse holder clamps	Fatigue in metallic fuse holder clamps can result from ohmic heating, thermal cycling, electrical transients, frequent manipulation and vibration.
Flaking	Lifting of the coating from the underlying surface in the form of flakes or scales.
Flow accelerated corrosion	A corrosion mechanism which results in wall thinning in susceptible materials. An example is carbon steel piping exposed to moving, high temperature, low oxygen water, such as PWR/CANDU/PHWR primary and secondary water, and BWR reactor coolant. Flow accelerated corrosion is the result of dissolution of the surface film of the steel, which is transported away from the site of dissolution by the movement of water.
Flow induced vibration	The dynamic response of structures immersed in or conveying fluid flow. Fluid flow is a source of energy that can induce structural and mechanical oscillations. Flow induced vibrations best describe the interaction that occurs between the fluid’s dynamic forces and a structure’s inertial, damping and elastic forces.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Fouling	An accumulation of deposits on the surface of a component or structure. This term includes accumulation and growth of aquatic organisms on a submerged metal surface or the accumulation of deposits (usually inorganic) on heat exchanger tubing and surfaces. Biofouling, a subset of fouling, can be caused by either macroorganisms (e.g. barnacles, various types of clams and mussels, and others found in fresh and salt water) or microorganisms (e.g. algae). Fouling can also be categorized as particulate fouling from sediment, silt, dust and corrosion products, marine biofouling or macrofouling (e.g. peeled coatings, debris). Fouling in a raw water system can occur on the surfaces of piping, valves and heat exchangers. Fouling can result in a reduction of heat transfer or loss of material.
Freeze–thaw, frost action	Repeated freezing and thawing can cause severe degradation of concrete, characterized by scaling, cracking and spalling, caused by water freezing within the pores of the concrete, creating hydraulic pressure. If unrelieved, this pressure will lead to freeze–thaw degradation. If the temperature cannot be controlled, other factors that enhance the resistance of concrete to freeze–thaw degradation include the following: — Adequate air content (i.e. within ranges specified in American Concrete Institute specification 301-84); — Low permeability; — Protection until adequate strength has developed; — Surface coating applied to frequently wet–dry surfaces.
Fretting	Wear due to accelerated deterioration at the interface between tight fitting surfaces as the result of extremely small amplitude relative motion of the two surfaces and, possibly, contributions of corrosion.
Fungal decay	Species of fungus that digests moist wood, causing it to rot and degrade. High moisture content is a prerequisite for the wood to be attacked by various fungi.
Galvanic corrosion	Accelerated corrosion of a metal because of an electrical contact with a more noble metal or non-metallic conductor in a corrosive electrolyte. It is also called bimetallic corrosion, contact corrosion, dissimilar metal corrosion or two-metal corrosion. Galvanic corrosion is an applicable degradation mechanism for steel materials coupled to more noble metals in heat exchangers; galvanic corrosion of copper is of concern when coupled with the nobler stainless steel.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
General corrosion	General corrosion, also known as uniform corrosion, proceeds at approximately the same rate over a metal surface. Loss of material due to general corrosion is an ageing effect requiring management for low alloy steel, carbon steel and cast iron in virtually any wetted environment, including outdoor environments. Some potential for pitting and crevice corrosion might exist even when pitting and crevice corrosion is not explicitly listed in the ageing effect and degradation mechanism column in the IGALL spreadsheets and when the descriptor might only be loss of material due to general corrosion.
Grease dry-out	Hardening of grease as oil separates from thickener over time, causing it to lose its ability to lubricate. Stressors that might accelerate this process are, for example, elevated temperature and contamination.
Gumming of lubricant	Transformation of a lubricant over time, resulting in increase in viscosity.
Hydraulic pressure fluctuation	Induced by liquid flow irregularity, the fluctuations are usually permanent and, depending on their intensity, create specific pressure differences. The fluctuations can be caused by temperature distribution irregularity in pipelines, unequal density of liquid or mechanical eccentricity of pumps. Significant hydraulic fluctuations could be generated when more than one pump is operated on a common collector with amplitude addition of the pressure fluctuations at or behind the output of the pumps.
Hydrogen assisted stress cracking	Occurs when hydrogen generated during corrosion is absorbed and diffused into metals. The hydrogen gets trapped at the sites of dislocations, grain boundaries and inclusions, which leads to the brittle behaviour of metals that are normally ductile.
Hydrogen/ deuterium uptake	Refers to hydrogen (or its isotope deuterium) ingress in zirconium alloy pressure tubes during CANDU/PHWR operation. The sources of hydrogen/deuterium are corrosion (the reaction of heavy water (D_2O) and zirconium), the dissociation of heavy water on the oxidized surface of the pressure tube, and the radiolytic decomposition of water. High hydrogen concentration (the sum of the initial hydrogen content before operation and the deuterium uptake during operation) in the pressure tube material can make them susceptible to delayed hydride cracking.
Insect infestation	Pervasive influx and development of insects or parasites, affecting materials.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Intergranular attack	In austenitic stainless steels and nickel alloys, the precipitation of chromium carbides, usually at grain boundaries, on exposure to temperatures of about 450–850°C (during manufacture and repair), leaves the grain boundaries depleted of chromium and therefore susceptible to preferential attack (intergranular attack) by a corroding (oxidizing) medium.
Intergranular stress corrosion cracking	Cracking occurs along the grain boundaries and is the most common in austenitic stainless steel and nickel based alloys which have undergone sensitization (formation of chromium carbide precipitate at grain boundaries) or cold working (when it might initiate as transgranular SCC).
Irradiation assisted deformation	In zirconium alloy material, irradiation assisted deformation includes irradiation creep and irradiation growth. Irradiation creep refers to a time dependent change in dimension of a reactor component under a stress, even if that stress is below the yield stress. The two most prominent mechanisms of irradiation creep are stress induced preferential absorption of point defects at dislocations and climb followed by glide of the dislocations. Irradiation growth strain occurs when a point defect is absorbed by a lattice defect (sink), such as a dislocation, dislocation loop, grain boundary or phase boundary, and when the distribution of sinks receiving a net flux of vacancies is different from the distribution of sinks receiving a net flux of interstitials.
Irradiation assisted stress corrosion cracking (IASCC)	Intergranular cracking in aqueous environments of stressed materials exposed to ionizing radiation. Irradiation by high energy neutrons can promote SCC by affecting material microchemistry (e.g. radiation induced segregation of elements such as phosphorus, sulphur, silicon and nickel to the grain boundaries), material composition and microstructure (e.g. radiation hardening), as well as water chemistry (e.g. radiolysis of the reactor water, making it more aggressive).
Irradiation induced creep	For components made of zirconium alloys, changes in volume and dimension occur due to the increase in concentration and migration of crystalline defects, induced by neutron irradiation. In the presence of applied stresses far below the yield stress, material can be strained in the applied direction due to preferential movement of vacancies and interstitials. In CANDU reactors, creep can result in elongation, sag, diametrical expansion and wall thinning of the pressure tube.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Lack of electrical continuity	Discontinuity of relevant electrical signal from sensor to evaluation unit.
Leaching of calcium hydroxide	Water passing through cracks, inadequately prepared construction joints or areas that are not sufficiently consolidated during placing might dissolve some calcium containing products (of which calcium hydroxide is the most readily soluble, depending on the solution pH) in concrete. Once the calcium hydroxide has been leached away, other cementitious constituents become vulnerable to chemical decomposition, finally leaving only the silica and alumina gels behind, with little strength. The water's aggressiveness in the leaching of calcium hydroxide depends on its salt content, pH and temperature. This leaching action is effective only if the water passes through the concrete.
Material depletion/ changing material properties	Depletion in material mass and natural changes in material properties over time. Over long periods of time, changes in material properties might result in degraded performance. For example, in radiation detectors this degradation mechanism generally leads to changes in detector characteristics and consequently sensitivity. Ageing degradation will normally be manifested as calibration drift (high or low output), reduced sensitivity or reduced response time. In ion chambers, degradation is often related to degradation of the sensitive lining (i.e. neutron burnup of the boron).
Mechanical dislocation	A loss of bond between sensor and concrete causing inadequate transfer of strain from concrete to the sensor.
Mechanical loading	Applied loads of mechanical origins rather than from other sources (e.g. thermal).
Mechanical vibration	Repetitive and periodic oscillations of parts of components and structures.
Microbiologically influenced corrosion	Any of the various forms of corrosion influenced by the presence and activities of such microorganisms as bacteria, fungi and algae and the products produced in their metabolism. Degradation of material that is accelerated due to conditions under a biofilm or microfouling tubercle (e.g. anaerobic bacteria that can set up an electrochemical galvanic reaction or inactivate a passive protective film), or acid producing bacteria that might in turn produce corrosive metabolites.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Moisture intrusion	Influx of moisture through any viable process.
Neutron irradiation embrittlement	Embrittlement of carbon and low alloy steels, austenitic stainless steel, nickel alloys and zirconium alloys. It might produce changes in mechanical properties by increasing tensile and yield strengths, with a corresponding decrease in fracture toughness and ductility. The extent of embrittlement depends on neutron flux, neutron fluence, temperature and trace material chemistry.
Ohmic heating	Induced by current flow through a conductor, it can be calculated using first principles of electricity and heat transfer. Ohmic heating is a thermal stressor and can be induced by conductors passing through electrical penetrations. It is especially significant for power circuit penetrations.
Oil mist	Micro sized oil droplets suspended or distributed in the air, which can form with the evaporation of fuel oil, grease, synthetic lubricants or hydraulic oil. When mixed with dust in the air and resting on a part, equipment or component, it might have a negative impact on operation or cause material degradation.
Outer diameter stress corrosion cracking	Intergranular SCC which occurs on the outer diameter (secondary side) of steam generator tubes.
Overload	One of the degradation mechanisms that can cause loss of mechanical function in Class 1 piping and components, such as constant and variable load spring hangers, guides, stops, sliding surfaces, design clearances and vibration isolators, fabricated from steel or other materials, such as Lubrite.
Oxidation	Involves one of two types of reaction: (i) an increase in valence resulting from a loss of electrons or (ii) a corrosion reaction in which the corroded metal forms an oxide.
Partial discharge	A very weak partial breakdown in one part of the winding insulation. Over time, it leads to ever-increasing insulation damage, which in the worst case could extend to a total loss of dielectric strength.
Peeling	Disbonding of particles of a coating from substrate in the form of strips, due to loss of adhesion.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Pitting corrosion	Localized corrosion of a metal surface, confined to a point or small area, which takes the form of cavities called pits.
Plastic deformation	Time dependent strain, or gradual elastic and plastic deformation, of metal that is under constant stress at a value lower than its normal yield strength.
Polymer creep of elastomers	For elastomer materials used in antiseismic devices, polymer creep refers to a time dependent continuous deformation process under constant stress from the structures for which the antiseismic devices are provided.
Preferential weld attack	Arises because weld metal compositions tend to be slightly anodic to the parent metal, and therefore the weld metal corrodes at a higher rate than the parent material. It can occur for a number of reasons (e.g. differences in chemical composition and microstructure, and work hardening between the weld metal and the parent metal).
Primary water stress corrosion cracking	An intergranular cracking mechanism that necessitates the presence of high applied or residual stress, susceptible microstructures (few intergranular carbides), a primary water environment and high temperatures. This degradation mechanism is most likely a factor for nickel alloys and welds in the PWR environment.
Radiation damage	A general term used to describe various mechanisms by which ionizing radiation might affect materials and devices in deleterious ways, including the following: — Nuclear transmutation of the elements within the material, which can in turn alter the mechanical properties of the materials and cause swelling and embrittlement; — Radiolysis (breaking chemical bonds) within the material, which can weaken it, cause it to swell, polymerize, promote corrosion, promote cracking or otherwise change its desirable mechanical or electronic properties; — Formation of reactive compounds, affecting other materials; — Ionization, causing electrical breakdown, particularly in semiconductors employed in electronic equipment, with subsequent currents introducing operation errors or even permanently damaging the devices.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Radiation hardening, humidity, temperature, sustained vibratory loading	Reduction or loss of isolation function in polymeric vibration isolation elements can result from a combination of radiation hardening, humidity temperature loading and sustained vibratory loading.
Radiation induced oxidation	Two types of reaction caused by radiation are an increase in valence resulting from a loss of electrons and a corrosion reaction in which the corroded metal forms an oxide (this is a very limited form of oxidation and applies to metal enclosed bus insulation).
Radiolysis	A chemical reaction induced or assisted by radiation. Radiolysis and photolysis degradation mechanisms can occur in ultraviolet sensitive organic materials.
Reaction with aggregates	Chemical reactions between aggregates in concrete and the cement paste. These reactions might lead to expansion and cracking.
Relaxation	Loss of force in time at constant deformation.
Restraint shrinkage	Can cause cracking in concrete transverse to the longitudinal construction joint.
Selective leaching	Also known as de-alloying (e.g. dezincification, graphitic corrosion), it involves selective corrosion of one or more components of an alloy.
Service induced cracking or other concrete degradation mechanisms	Cracking of concrete under load over time of service (e.g. from shrinkage or creep) or other concrete degradation mechanisms that may include freeze–thaw cycles, leaching, aggressive chemicals, reaction with aggregates, corrosion of embedded steels, elevated temperatures, irradiation, abrasion and cavitation.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Settlement	Settlement (or upheave when upwards) is displacement of the foundation owing to variations of the soil stress state that, in addition to the application of the structure permanent and accidental loadings, might result from variation of groundwater level, structure unloading or reloading, undesired displacement of soil particles (soil erosion) due to poorly performed dewatering, excavations close to the foundation, and expansive and collapsible soils. Differential settlement is the most usual condition in which the foundation displacement values are different, leading to structural distortion that might cause concrete cracking due to an increase in the stress levels of the structure.
Shrinkage	Decrease in either length or volume of a material resulting from changes in moisture content or chemical changes.
Significant moisture	Long term wetting or submergence over a continuous period that if left unmanaged could have an adverse effect on operability or lead to failure of the cable insulation system.
Soil erosion	The displacement of soil particles due to the action of water that might result from poorly performed dewatering.
Stress corrosion cracking	Cracking that necessitates the presence of a susceptible metal, a corrosive environment and a sufficiently high tensile stress (applied and residual). SCC is highly chemically specific, in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments under certain temperature ranges. SCC includes intergranular SCC, transgranular SCC, primary water SCC and low temperature crack propagation as degradation mechanisms. High strength bolting materials with yield strength in excess of 1034 MPa exposed to corrosive lubricant such as molybdenum and humidity or water are also susceptible to SCC.
Stress relaxation	Many of the bolts and other fastener components (e.g. keys, springs) in reactor internals are stressed to a cold initial preload. When subject to high operating temperatures, over time these fasteners might loosen, and the preload might be lost. Radiation can also cause stress relaxation in highly stressed members.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Sulphate attack	Sulphates can damage concrete by causing excessive expansion, delamination, cracking and loss of strength. Attacks come from exposure to excessive amounts of sulphate from internal sources (soluble sulphate sources incorporated into concrete at the time of mixing, or gypsum or pyrite being naturally present in the aggregate or admixtures) or from external sources. External attack sources include magnesium, sodium, calcium and potassium sulphates present in soils, groundwater and sea water. Delayed ettringite formation is a special case of internal sulphate attack.
Surface contamination	Contamination of the surfaces by corrosive constituents or fouling.
Surge or voltage spike	A voltage surge is a sudden rise in voltage lasting one and a half cycles or more that damages the electrical equipment of an installation. A voltage spike is a voltage pulse of extremely short duration, with damaging effect less than that of a voltage surge.
Sustained vibratory loading	Vibratory loading over time.
Swelling of expansive soil	Consists of volumetric expansion of a soil mass due to expansive soil that causes foundation upheave (settlement upwards).
Thermal ageing embrittlement	A time and temperature dependent degradation mechanism that decreases material toughness, also termed thermal ageing or thermal embrittlement. At operating temperatures of 260–343°C, CASS exhibits a spinodal decomposition of the ferrite phase into ferrite rich and chromium rich phases. This might give rise to significant embrittlement (reduction in fracture toughness), depending on the amount, morphology and distribution of the ferrite phase and the composition of the steel. Thermal ageing of materials other than CASS includes temper embrittlement and strain ageing embrittlement. Ferritic and low alloy steels are subject to both of these types of embrittlement, but wrought stainless steel is not affected by either of these processes.
Thermal and irradiation enhanced stress relaxation	Observed decrease in preload in response to the same amount of strain generated in the structure, dependent on temperature, which can be enhanced by high irradiation.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Thermal and mechanical loading	Loads (stress) due to mechanical or thermal (temperature) sources.
Thermal cycling	The process of exposing a material repeatedly to higher and lower temperatures. If two materials with different thermal expansion coefficients form a connection, thermal cycling might cause a loosening of the connection or might induce mechanical stresses due to the different absolute dimensional changes.
Thermal degradation of organic materials	Includes both short and long term thermal degradation. Organic materials in this category are polymers, including elastomers. Thermal energy absorbed by polymers can result in cracking, cross-linking and chain scission. Cross-linking generally results in ageing effects such as increased tensile strength and hardening of material, with some loss of flexibility and eventual decrease in elongation-at-break and increase in compression set. Scission generally reduces tensile strength. Other reactions that might occur include crystallization and chain depolymerization.
Thermal effects, gasket creep, self-loosening	Loss of preload due to gasket creep, thermal effects (including differential expansion and creep or stress relaxation) and self-loosening (which includes vibration, joint flexing, cyclic shear loads and thermal cycles).
Thermal exposure	Exposure of material to elevated temperature causing deterioration of its mechanical properties.
Thermal fatigue	Can result from phenomena such as thermal loading, thermal cycling (where there is cycling of the thermal loads), thermal stratification and turbulent penetration. Thermal stratification is a thermohydraulic condition with a definitive hot and cold water boundary, inducing thermal fatigue of the piping. Turbulent penetration is a thermohydraulic condition where hot and cold water mix as a result of turbulent flow conditions, leading to thermal fatigue of the piping. Higher temperatures generally decrease fatigue strength. I&C thermal fatigue is the progressive failure of the instrumentation material when it is repeatedly strained (thermal cycling) below its maximum stress value but at a level sufficient to result in damage to the instrumentation components (e.g. transmitter or sensor installed on process piping). Loss of instrumentation function results from cyclic stresses due to temperature changes.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Thermo-oxidative degradation	In the presence of oxygen and stimulated by heat the ageing rate of (organic) material increases. Higher concentrations of oxygen often result in a greater oxidation reaction rate and, hence, more rapid degradation of the physical properties of the material. The ageing rate caused by thermo-oxidative degradation can accelerate and become more prominent in a radiation environment.
Transgranular stress corrosion cracking	Most often occurs in components made of stainless steel as a result of chloride contamination (e.g. from insulation, ocean aerosols, tapes) if the surfaces are wetted. It initiates on the outside surfaces of components mainly due to lack of attention to adequate cleanliness (also known as external chloride SCC). It can also initiate on the inner surfaces, mainly in pipe sections containing stagnant two phase coolant, where evaporation and concentration of chlorides can occur.
Ultraviolet (UV) radiation and ozone exposure	The exposure to ultraviolet radiation and ozone causes a change in material properties and cracking of elastomers. The deterioration could be accelerated in the presence of oxygen.
Underclad cracking	Cracking that occurs in base metal resulting from fabrication (pressure vessel and piping of low alloy steel and carbon steel) that is cladded with stainless steel with high heat input.
Upheave	It is settlement upwards (see definition of settlement).
Vibrational fatigue	Fatigue in which the loading cycles are caused by flow induced vibrations or high cycle mechanical loading.
Void swelling	Vacancies created in the materials making up reactor internals (metallic) as a result of irradiation might accumulate into voids that might in turn lead to changes in dimensions (swelling) of the material.
Volatilization of plasticizers	Evaporation of plasticizers (materials that make insulation elastic) under conditions of high and low temperature, which leads subsequently to loss of elasticity of the insulation. Due to the volatilization of the plasticizer and the decay products, the weight of plastic (insulation) declines and its volume might decrease. Thermal ageing of plastic, such as PVC, is mainly caused by the volatilization of the plasticizer, resulting in a loss of elasticity of the plastic.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in ageing management review tables
Volumetric changes	Volumetric changes in organic materials might occur when exposed to chemicals or solvents. Swelling tends to aid sealing through volumetric expansion yet might affect other properties such as tear and abrasion resistance and extrusion potential. Shrinkage, on the other hand, might reduce the sealing force, and make leakage more likely (all else remaining constant). Shrinkage might occur as a result of exposure to chemicals or solvents, as well as thermal and radiation exposure.
Water absorption	Can decrease the yield strength of the polymer materials and cause significant reductions in the strengths of glass fibre composites. In the presence of environmental moisture, most polymers absorb some moisture through diffusion in high humidity environments. The extent of moisture absorption in each polymer will be a function of its hydrophilicity or chemical compatibility with water. Water absorption is of special concern in the case of glass fibre reinforced polymer matrix composites, since glass is known to be subject to permanent hydrolytic damage, especially when simultaneously exposed to stress. The nature of the water induced damage is not well understood since its effect is often, but not always, reversible on drying.
Water trees	Occur when the insulating materials are exposed to long term electrical stress and moisture. These trees eventually result in breakdown of the dielectric and ultimate failure. The growth and propagation of water trees is somewhat unpredictable. Water treeing is a degradation and long term failure phenomenon.
Wear	The removal of surface layers due to relative motion between two surfaces or under the influence of hard, abrasive particles. Wear occurs in parts that experience intermittent relative motion or frequent manipulation, or in clamped joints where relative motion is not intended but may occur due to a loss of the clamping force.
Weathering	The mechanical or chemical degradation of external surfaces of materials when exposed to an outside environment.

Appendix VI

GROUPING OF CIVIL STRUCTURES EXCEPT FOR CONTAINMENT

The civil structures in AMR tables 302 and 303 are grouped as follows:

- Group 1: BWR reactor building, PWR shield building, and control room and building;
- Group 2: BWR reactor building with steel superstructure;
- Group 3: Auxiliary building, diesel generator building, radwaste building, turbine building, switchgear room, yard structures (e.g. auxiliary feedwater water pumphouse, utility and piping tunnels, security and lighting poles, maintenance holes, duct banks) and station black out structures (e.g. transmission towers, startup towers circuit breaker foundation, electrical enclosure);
- Group 4: Containment internal structures, excluding refuelling canal;
- Group 5: Fuel storage facility and refuelling canal;
- Group 6: Water control structures;
- Group 7: Concrete tanks and missile barriers;
- Group 8: Steel tanks and missile barriers;
- Group 9: BWR unit vent stack.
- Group 10: Spent fuel dry storage concrete structures.

Appendix VII

EXAMPLES OF PERFORMANCE INDICATORS FOR PLANT LEVEL AGEING MANAGEMENT PROGRAMMES

Performance indicators for a plant level AMP that could support evaluation of the effectiveness of a plant's entire ageing management activity are used to measure the performance of the activities meant to maintain the conditions of the SSCs.

Potential performance indicators as proposed below are ratios or absolute numbers. Absolute numbers can be compared to target numbers or, for example, to the average of the preceding years. In the latter case, if the average number is already sufficiently low, stagnating state can also be acceptable, and the acceptance is a matter of engineering judgement. In case of a ratio, proposed target ranges for some indicators can be as presented in Table 10.

Indicators might be calculated using the following formula:

$$\text{Indicator}_{\text{AMP}} \equiv \left(1 - \frac{n_{\text{counted parameter}}}{N}\right) \times 100 \tag{1}$$

where $n_{\text{counted parameter}}$ is the number of an ageing related parameter counted to determine the indicator;

and N is the total number of a quantity to which the given counted number $n_{\text{counted parameter}}$ is compared.

For other indicators, the target is to be in the low range (0–10%); in this case, the table and the formula need to be adjusted. Also, the limit values

TABLE 10. PROPOSED TARGET RANGES FOR INDICATORS

Level of performance of the indicator	Judgement ranges of the indicator [%]
Excellent	90–100
Good	80–89
Satisfactory	70–79
Unacceptable	<70

of the ranges can be adjusted applying flexibility to the plant needs and to the given indicator.

This calculation is performed separately for each indicator using specific information that is descriptive of the indicator, as identified in the examples below. The results of these indicator calculations could be used to develop an assessment of overall effectiveness for the plant level AMP, but that is beyond the scope of this publication.

Use of all indicators proposed below might not be appropriate for a plant and some of the indicators might not be efficient to be used together. The plant therefore needs to assess and decide which of the indicators are appropriate and which are not useful. Also, the indicators might be modified and combined with each other according to the plant needs. Plant specific definition of indicators of safety significance (e.g. safety classification of SSCs) can also be considered by weighting. Also, some indicators may be evaluated by types of activities (e.g. maintenance, engineering, in-service inspection), by plant organizational units responsible for the actions (for walkdowns performed by operation, chemistry or maintenance) or by technical areas (mechanical, electrical and I&C, civil).

VII.1. PLANT LEVEL INDICATORS FOR AGEING MANAGEMENT PROGRAMMES

The proposed plant level AMP indicators can be summarized as follows:

(1) Completion of ageing management actions. This is the ratio of the number of completed recommendations or actions from all AMPs (e.g. requirement on new inspection, test, calculation, replacement). This is a general number that characterizes the completion of ageing management activities. Usually, it is the task of the ageing management coordinators or of the ageing management unit of the plant to specify and check if all ageing related actions are planned for the given year and, at the end of the year, to check that all have been fully and adequately implemented. Implementation of the particular actions (i.e. in-service inspection, maintenance) is the responsibility of the technical units. In this sense the number could also indicate the cooperation and coordination of ageing management within the plant.

(2) Ageing related events. This is defined as the proportion of events (including low level events) initiated by or contributed to by an ageing issue of in-scope SSCs to the total number of events reported in the plant (not only events reported to the regulator). If an event happens in a plant, it is expected

that the causes (direct, contributing or root causes) will be determined irrespective of the significance of the event. For safety related events, this is usually more formalized (for example, in the form of an investigation or a root cause analysis), while for less significant, or low level events this can be based on simple engineering judgement. If an in-scope SSC is concerned in the event and if an ageing related cause is determined, the event is taken into account for the evaluation of this indicator. In order to achieve a good (representative) indicator, the plant needs to evaluate as many events as possible. This means that low level occurrences (e.g. early replacements during maintenance, smaller degradations revealed during walkdowns) may need to be counted, not just events by definition. The target is to have only a small portion of the events as ageing related.

(3) Unplanned ageing management. This is defined as the ratio of unplanned ageing management actions to planned ageing management actions. The type, number and schedule of ageing management actions (e.g. in-service inspection, walkdowns, maintenance, trend analysis) are planned according to the AMPs. If additional actions are necessary because of an event, other internal (e.g. detection of ageing effects) or external operating experience, the number of these additional actions are counted. Also, if an action was not appropriately implemented and needs to be repeated (e.g. unsuccessful pressure test, mistake during recording or documentation, error of measuring device), this needs to be counted as an unplanned action. The number of repetitions can indicate an unexpected ageing effect or that the action was inadequately prepared for. Both cases are important to consider when assessing the effectiveness of ageing related activities. Such an indicator can be the number of corrective maintenance orders issued.

(4) Planned frequency of replacements and maintenance. This is defined as the ratio of frequency of replacements and maintenance performed based on ageing management considerations to the frequency established in plant documentation (i.e. SAR and its supporting documents). This is the number of cases when it is necessary to change (increase) the frequency of repairs, replacements and maintenance due to ageing effects. This indicator shows a persisting situation that needs to be followed by more planned ageing related actions: for example, when a new or unexpected ageing effect is detected and during the following year the number of actions needs to be increased to reveal the situation at all similar locations or components or it becomes necessary to inspect a whole area or repeat an action of the previous year that was not planned for the coming year.

(5) Unplanned maintenance costs. This is defined as the ratio of additional costs incurred by increased ageing related actions to the planned ageing management costs. Unplanned costs of additional actions are usually

characterized by the number or extent of additional actions and the loss of time attributable to unexpected occurrences and inappropriate planning or preparation of actions. If a plant can evaluate the additional costs of ageing related activities this can be a good indicator to characterize the effectiveness of planning, preparing and implementing the activities.

(6) Number of ageing management related findings. This is defined as the number of regulatory, peer review or self-assessment findings that necessitate action from the plant to modify the ageing management scope, actions, procedures or documentation. There are many review activities (e.g. self-assessment; reviews by WANO, the regulatory body, SALTO, PSR, insurance company) in the plants that address ageing management as a whole or some components of it. The plant may define targets for the number of findings under which it considers its activities appropriate. There are years when there are more review activities and years when there are fewer. As a result, specific targets can be defined (e.g. target number of findings per one review activity). Also, it is possible to give more weight to more important findings than to less important ones to provide a more accurate picture of effectiveness.

(7) Modifications. This is defined as the number of cases when AMPs or related procedures were changed due to a plant modification, but based on further changes of operating experience, re-assessment had to be performed. If a modification necessitates changes in the technical or administrative procedure of a plant related to ageing management activities, it is usually captured in the modification process of the plant. If this fails and (a) AMPs and related activities have to be adjusted later (e.g. a new in-service inspection technique is needed but it was not identified before the modification), (b) if the ageing effect is more serious than expected (e.g. a flow rate change causes more significant erosion–corrosion), or (c) if a new, unexpected ageing effect occurs (e.g. if water chemistry changes cause unexpected deposition and corrosion, or a new pump type causes vibrations), this is an indication of issues with the effectiveness of the plant level AMP. The plant may define a target number (in this case practically zero is the expected target) to measure such problems.

(8) Component unavailability, loss of production. This is defined as the weighted summary of ratios of component and/or system unavailability times caused by ageing or time ratio during which a unit is unable to adequately operate because of a component failure. A number can be generated by adding up the ratio of the time during which the component (system) was unavailable to the time it is required to be available for all components. In this case a suitable appropriate target value needs to be selected. Another possibility is to count the loss of production time due to ageing related failures. This

might be a high level (but important) indicator, since most ageing related component failures do not necessitate a full or partial shutdown of the unit.

(9) Availability of ageing related knowledge. This is defined as the number of cases when ageing related information or knowledge was unavailable at the plant. Any new or unexpected behaviour of an identified ageing effect or degradation mechanism or identification of such cases from external operating experience will require specific consideration, studying or research and development results. If such results or the knowledge to find or generate the needed results is not readily available at the plant, it is an indication that the plant level AMP is deficient.

(10) Qualitative and quantitative measurement of AMP effectiveness. The effectiveness of the AMPs is measured by applying one of the following two approaches:
- — Qualitative effectiveness method;
- — Quantitative effectiveness method.

The following subsection provides information and examples on the application of each of these methods.

VII.2. EXAMPLES OF QUALITATIVE AND QUANTITATIVE MEASUREMENT OF EFFECTIVENESS OF THE AGEING MANAGEMENT PROGRAMME

A. Qualitative measurement approach for AMP effectiveness

This section describes the process followed during implementation of an AMP to determine its qualitative effectiveness. Plants applying this method measure the effectiveness of the AMP with an initial frequency of 3 years, which could vary depending on the frequency of the inspections or activities performed as part of the AMP. As a result of this process, an AMP implementation report is developed which includes the effectiveness evaluation of the AMP. The aim of an AMP implementation report is to improve the AMP by using the feedback obtained from the implementation process, and to measure the effectiveness of the AMP in detecting ageing effects before components lose their intended function.

The following input data are needed for measuring the qualitative effectiveness of an AMP:

- — Approved AMP reference document;
- — Results of inspection activities;

— Annual AMP monitoring reports (e.g. brief summary, elaborated yearly, with the main results of the existing activities in the plant included as part of the AMP);
— Analysis reports of operating experience;
— Previous AMP implementation reports.

The process followed to develop an AMP implementation report includes the following steps:

(1) Analysis of AMP modifications: Components included in the scope of the AMP are reviewed in order to verify whether new components have been included or eliminated due to plant design modifications.

Activities modification analysis consists of verifying whether the activities needed to comply with the AMP model requirements have been modified or eliminated. The evaluation includes the revision of new activities that could improve the AMP. If a modification, which affects AMP compliance, is detected an AMP re-evaluation is proposed.

Standards, guides and regulations related to the AMP are analysed to evaluate the AMP references with the aim of identifying any potentially necessary modifications.

(2) Compilation of results (e.g. in-service inspection reports, work orders, maintenance, chemistry monitoring reports) of activities performed during the proposed evaluation period (it can be 3 years initially and then modified based on experience). Once the results of activities have been collected, the following analyses are carried out:
   (i) Analysis of activities execution:
      — Verifying that the activities have been executed according to the frequency established in the AMP;
      — Verifying that all the components included in the scope of the activities have been inspected according to the AMP;
      — Confirming the inspector's qualification.

At the conclusion of this analysis, all deviations associated with the activities schedule will be identified.

   (ii) Analysis of activities results: Identifying whether the inspections results have been acceptable, acceptable after evaluation or unacceptable.
   (iii) Analysis of detected degradation: All the activities results classified as 'acceptable after evaluation' or 'unacceptable' need to be further

evaluated in order to determine the ageing effect and the associated mechanism. First it will be determined if the ageing effect was identified in the AMP. If not, a review of the AMR process will be proposed.

(iv) Analysis of corrective actions: Verifying that the corrective actions carried out (to correct the measures to manage the ageing effects detected) comply with the requirements described in the AMP. Any deviation will be identified.

(v) Analysis of the evolution of the detected degradations: If the evaluated AMP has previous AMP implementation reports, the evolution of the detected degradations will be evaluated to identify trends.

(3) Analysis of operating experience related to the AMP: The internal and external operating experience associated with the AMP under evaluation will be collected and analysed. At the conclusion it will be determined if the ageing effects, identified in the analysis of operating experience, are already managed by the AMP. If the ageing effects are not managed by the AMP, an enhancement is proposed in order to include the management of the new ageing effect in the AMP.

(4) Status of the AMP´s previously identified enhancements: Verifying if the enhancements identified during the preceding AMP development and the implementation process have been resolved correctly.

(5) Enhancements for the AMP implementation process: If during the abovementioned points, deviations are identified, an AMP enhancement will be proposed and included in the management system in order to resolve and implement the identified deficiencies and possible improvements.

(6) Evaluation of effectiveness of the AMP: By taking into consideration the results of the previous analyses (1–5), the effectiveness of the AMP will be determined in a qualitative manner.

The AMP will be considered effective if the following apply:

— No deviations are identified;
— Deviations were identified and resolved according to the processes described in the AMP, before the component would have lost its intended function.

The AMP is considered not effective or partially effective in the following cases:

— Components lose their intended functions before the activities can detect the ageing effects;

- The structure or component shows degradation mechanisms or ageing effects that have not previously been identified by any AMP;
- Analysis revealed that the parameters monitored and analysed for trends do not or only partially contributed to an effective ageing management of the SCCs in scope.
- Deviations or degradations are not identified or resolved according to the processes described in the AMP.

B. Quantitative approach for measuring the effectiveness of the AMP — Measuring Method 1

In the case of a quantitative method for measuring effectiveness, the effectiveness of the AMP is determined during a fixed period, for example every 3 years.

In this example, the indicator is obtained by considering four variables: activities, evaluation, resolution of AMP commitments and operating experience. The following are evaluated through the four variables:

(a) Activities (IACT): Indicate the degree of compliance with the plant activity requirements included in the AMP;
(b) Evaluation (IEVAL): Evaluates the ageing effects and degradation mechanisms identified with the AMP activities;
(c) Resolution of AMP commitments (ICOM): Indicates the degree of compliance with the identified AMP enhancements or new activities as a result of the implementation of the AMP;
(d) Operating Experience (IOE): Indicates the impact of degradation mechanisms identified in the operation of the nuclear power plant or in another nuclear power plant in the case of external operating experiences.

To determine the contribution of each of the previously mentioned variables, points are first assigned to each variable. The following criteria are used to determine the points associated with each variable:

IACT:

(0–100 points)

- 100 points If the AMP activity has been executed according to the schedule;
- 50 points: If the activity was executed partially;
- 0 points: If the activity was not performed.

IEVAL:

(0–100 points)

- 100 points: If the AMP activity does not identify degradation that exceeds expectations (extent of degradation and no new or different ageing effects/degradation mechanisms).
- If the activity detects degradation that exceeds the expected levels (either extent of degradation or different ageing effects or degradation mechanisms), the number of points assigned depends on the following:
  - (i) The kind of ageing effects/degradation mechanisms detected, expected or unexpected;
  - (ii) Whether the ageing effect detected exceeded the acceptance criteria and required a corrective action.
- 0 points: If the activity identifies degradation that results in a loss of intended function.

ICOM:

(0–100 points)

The first step is to identify all AMP enhancements scheduled to be performed within the period of the evaluation of the AMP. If the activity is included in the management system for the facility and activities, then the foreseen closure date will be considered. Once identified, the following criteria are applied:

- 100 points: All identified AMP enhancements have been executed, including the associated final documental closure;
- 76–99 points: Amount of AMP enhancements performed within the period of the evaluation of the AMP;
- 51–75 points: If the enhancement has been executed but the associated final documental closure is still pending;
- 0–50 points: Enhancements have not been executed or only partially.

If the AMP enhancement has been rescheduled to be performed during the next year the evaluation will be between 50 and 75 points and if reprogrammed the points to be assigned will be half of the points appointed during the previous year.

IOE:

(0–100 points)

As previously mentioned this variable determines if any internal or external operational incidents, associated with the degradation mechanisms managed by the AMP, have occurred.

The detection of an ageing effect during the execution of an AMP activity is not considered an operational incident. An operational incident is considered if the ageing effect was not detected and requires a change in the operating mode of the system. The following evaluation criteria are applied:

- 100 points: No operational incidents have been identified.
- If an operational incident is identified it will be evaluated as follows:
  - (i) 0 points: Operational incident causes plant shutdown or requires safety system actuation.
  - (ii) 0–25 points: Operational incidents not considered in the previous condition but causing operating limitations.
  - (iii) 26–50 points: Operational incidents that do not meet the above conditions and cause a change in the operating mode of the system or components.
  - (iv) 51–99 points: Operational incidents that do not comply with the above conditions and that require additional or different actions to those included in the AMP.

Once all variables have been evaluated the final AMP indicator is determined using the following formula:

$$\text{IAMP} = (0.2 \times \text{IACT}) + (0.4 \times \text{IEVAL}) + (0.2 \times \text{ICOM}) + (0.2 \times \text{IOE}) \qquad (2)$$

As indicated in the formula the activity variable (IACT) and the evaluation variable (IEVAL) combined are considered the most important variables and contribute 60% to the AMP indicator. The variables, resolution of AMP commitments (ICOM) and operating experience (IOE) equally contribute the remaining 40% to the indicator.

Finally, AMP effectiveness is measured against a scale of 0–100. This can be linked to qualitative indicators such as the following:

- $90 \leq \text{IAMP} \leq 100$ — ‘Excellent’: The AMP has been effective during the evaluation period considered. The activities of the AMP have been carried out successfully and the SSCs included in the AMP scope maintain their intended function.

— 75 ≤ IAMP ≤ 90 — 'Satisfactory': The AMP is still effective during the evaluation period considered. Although some of the planned activities of the AMP have not been executed or some events of degradation have been identified, the intended functions of the SSCs have not been jeopardized.
— 60 ≤ IAMP ≤ 75 — 'Need for improvement': The AMP has been less effective in the evaluation period considered, and the deficiencies identified need to be analysed to define possible corrective actions. The deficiency can be that a significant portion of the planned activities of the AMP have not been executed, or that the result of these identified some events of degradation that affect the intended function of SSCs.
— 0 ≤ IAMP ≤ 60 — 'Not satisfactory': The AMP has not been effective during the evaluation period considered and it is necessary to re-valuate the AMP.

C. Quantitative approach for measuring the effectiveness of the AMP — Measuring Method 2

Table 11 shows proposed indicators for evaluating the effectiveness of the plant level AMP; these are divided into three categories.

TABLE 11. PROPOSED INDICATORS FOR A PLANT LEVEL AMP

Indicator	Parameter
Cost (C)	To measure the financial performance
CRE	Cost of repair
CRL	Cost of replacement
Quality (Q)	To measure the quality performance
QAQC	Number of findings per inspection
QMS	Number of findings per audit
Deviation	Number of deviations from plan
Rework	Number of reworks per inspection
Safety (S)	To measure the safety performance
SC	Number of findings per safety inspection
AC	Number of reportable accidents

The financial cost, including the cost of repair (CRE) and the cost of replacement (CRL) of components can be calculated as follows:

$$\mathrm{C} = \alpha 1 \times \mathrm{CRE} + \alpha 2 \times \mathrm{CRL} \tag{3}$$

The quality indicator can be calculated using the total number of findings per inspection (QAQC), the total number of findings per audit (QMS), the total number of deviations from the plan (Dev) per all plan items, and the number of reworks per inspection (Rew). So, the final score can be calculated as follows:

$$\mathrm{Q} = \lambda 1 \times \mathrm{QAQC} + \lambda 2 \times \mathrm{QMS} + \lambda 3 \times \mathrm{Dev} + \lambda 4 \times \mathrm{Rew} \tag{4}$$

The safety indicator can be introduced as the combination of the number of findings per safety inspection and number of reportable accidents. The final factor of safety indicator can be obtained as follows:

$$\mathrm{S} = \beta 1 \times \mathrm{SC} + \beta 2 \times \mathrm{AC} \tag{5}$$

The parameters *α, λ* and *β* are weighting factors and can empirically be obtained based on an optimization approach. Finally, the following formula can be used to calculate the effectiveness of the plant level AMP using the indicators calculated using Eqs (3–6):

$$f = w^1 \times C + w^2 \times Q + w^3 \times S \tag{6}$$

where, the *w* parameters are importance factors. For example, $w^1 = 10^{-5}$, $w^2 = 10^{-3}$, $w^3 = 10^{-2}$, meaning that the safety factors are more important than the quality factors and both are more important than the financial costs.

The overall effectiveness number can be obtained as follows:

$$\mathrm{Eff} = 1/f \tag{7}$$

Table 12 provides an example of data obtained during the implementation of a plant level AMP in a typical plant. Using Eqs (3–7), the related data are obtained and presented in Table 13.

Figure 3 shows an example of the trend observed in the effectiveness of a plant level AMP.

TABLE 12. EXAMPLE DATA FOR CALCULATING THE EFFECTIVENESS OF A PLANT LEVEL AMP

Cost of repair = \$2500
Cost of replacement = \$5000
Number of findings per inspection = 8
Number of findings per audit = 2
Number of deviations from plan = 3
Number of reworks per inspection = 4
Number of findings per safety inspection = 12
Number of reportable accidents = 16

TABLE 13. WEIGHTING AND IMPORTANCE FACTORS

Indicators	Weighting factors	Interim calculation	Importance factor	Effectiveness = 1/0.74 = 1.35
		C = 22 500	$w_1 = 10^{-5}$	
CRE = \$7500	α1 = 1	C = 2500 +		
CRL = \$5000	α2 = 3	5*5000		
			$w1 = 10^{-3}$	
QAQC = 8	λ1 = 5			$F = 10^{-5}*22\,500 + 10^{-3}*79 + 10^{-2}*44 \cong 0.74$
QMS = 2	λ 2 = 5	5*8 + 5*2 +		
Dev = 3	λ 3 = 7	7*3 + 2*4		
Rew = 4	λ 4 = 2			
		S = 44	$w1 = 10^{-2}$	
SC = 12	β1 = 1			
AC = 16	β2 = 2			

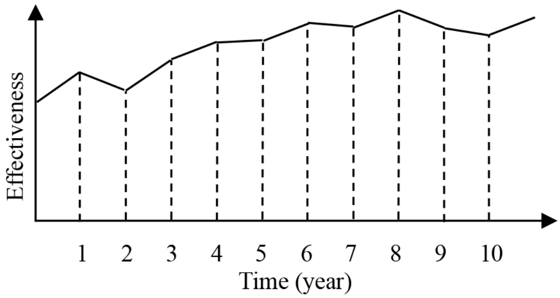

FIG. 3. Example of a trend analysis of the effectiveness of a plant level AMP.

Appendix VIII

EXAMPLES OF PERFORMANCE INDICATORS FOR INDIVIDUAL AGEING MANAGEMENT PROGRAMMES

VIII.1. GENERAL INDICATORS FOR STRUCTURE OR COMPONENT SPECIFIC AMPs

Adequacy of the AMP

The indicator on the adequacy of the AMP receives a value of ‘1’ if it was necessary to modify the AMP because of a plant’s operating experience (i.e. the AMP appeared to properly meet its objectives), otherwise the value is ‘0’.

If the AMP had to be modified and/or revised because of the occurrence or progress of degradation or because the AMP has become unacceptable or for any other technical reason (e.g. inappropriate in-service inspection, change of maintenance strategy or tools, change of monitoring device or frequency), the indicator is ‘1’. If the reason for the modification of the AMP is only formal or regular review or to reflect an administrative change, the indicator remains ‘0’.

Performance of AMP activities

The indicator on the performance of AMP activities receives a value of ‘1’ if several actions scheduled in the AMP were not completed; otherwise the value is ‘0’.

This indicator detects if any preventive, mitigative, in-service inspection, maintenance, monitoring or corrective action did not take place as scheduled.

Data management

The indicator on data management receives a value of ‘1’ if the data (or group of data) generated during the implementation of the AMP were not entered into the appropriate database and/or were inadequately managed or used. If the data were entered, the indicator receives a value of ‘0’.

Operational data (e.g. transient cycle numbers) and in-service inspection, maintenance, monitoring, surveillance, chemistry results and all other related lifetime data are to be entered in the appropriate ageing management database of the plant. Moreover, if the data were used, but expected trend analysis did not take place the indicator may also detect this.

Data analysis

The indicator on data analysis receives a value of ‘1’ if the parameters measured or monitored, as indicated by the AMPs, are analysed and the analysis does not give useful or convincing information (probably compared with non-conformity reports), and the AMP or the AMR needs to be analysed. Otherwise, the indicator receives a value of ‘0’.

One of the objectives of monitoring and trend analysis is to find out whether the AMP applied is appropriate. If the monitoring results do not provide appropriate information and further actions are to be taken in order to confirm if the AMP is appropriate, the monitoring activity may need to be modified and this could be detected by the indicator.

Use of commodity group AMP

The indicator on the use of commodity group AMP is defined as the failure rate of components managed by a commodity group AMP.

The effectiveness of commodity group AMPs, especially when large numbers of similar components are managed by them, and the failure rate of components (if the failure is related to or partially related to ageing effects) can be used as an indicator. After several years the trend of failure rates may indicate if the effectiveness of an AMP has changed (or even improved).

Correctness of ageing prediction

The indicator is defined using the absolute value of the difference of predicted and detected value characterizing the aged condition. The indicator is the ratio of this absolute value to the predicted value.

The indicator compares the predicted and measured characteristic parameter of a given degradation mechanism, such as wall thickness, number (or density) of flaws, growth of flaws, embrittlement, hardness, conductivity, settlement or tendon strength. The frequency of evaluation of this indicator needs to be adjusted to the measurement frequency of the parameter (e.g. during maintenance, in-service inspection).

VIII.2. SPECIFIC INDICATORS FOR INDIVIDUAL AMPs IN IGALL

Indicators for AMP101 low cycle fatigue

A possible indicator (Indicator 1) can be the ratio of the locations where the indications caused by low cycle fatigue are under the acceptance criteria to the locations that are evaluated for low cycle fatigue.

The ratio characterizes the occurrence and severity of problems caused by fatigue. If any location is not compliant with the acceptance criteria it will decrease the ratio and the indicator may change colour.

Another possible indicator (Indicator 2) can be the ratio of real lifetime usage to planned usage of a component.

The use of cycle numbers can be calculated after every completed campaign and compared with planned usage. If a limit value is defined the indicator may initiate an investigation into the causes of the increase. This indicator can be defined for any other components of the primary circuit that is affected by low cycle fatigue and so can be used for all low cycle fatigue AMPs.

Indicator for AMP114 flow accelerated corrosion and erosion

A possible indicator is the comparison of real wall thickness to the wall thickness as anticipated by analyses.

This indicator can detect if the difference between the real usage and the anticipated usage grows (trend analysis for more years) or if the growth accelerates or reaches an unacceptable level (e.g. wall thickness will reach the minimum before the planned usage time).

Indicator for AMP116 steam generator

The ratio of plugged heat exchanger tubes to the allowed number of plugged tubes can be an indicator that can show how far the plant is from the acceptance criteria and from the trend of several years if the corrosion process accelerates, steadily progresses or improves.

Indicator for AMP118 and AMP152 reactor vessel surveillance

A possible indicator is the ratio of the actual to planned lifetime, which can show how the planned lifetime of the reactor vessel is used and, from the trend of several years, if the planned lifetime is feasible or if intervention is needed to achieve it.

Indicator for AMP201–203 electrical insulation for electrical cables

A possible indicator is the ratio of unplanned cable replacements (costs) to all cable replacements (costs).

The indicator can show the accuracy of the information the plant has about the condition of the insulation of electrical cables and how well the replacements are planned based on knowledge of their condition.

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ABBREVIATIONS

AISI	American Iron and Steel Institute
AMP	ageing management programme
AMR	ageing management review
ASR	alkali-silica reaction
ASTM	American Society for Testing and Materials
BWR	boiling water reactor
CANDU	Canada deuterium–uranium reactor
CASS	cast austenitic stainless steel
CLB	current licensing basis
HVAC	heating, ventilation and air-conditioning
I&C	instrumentation and control
IGALL	International Generic Ageing Lessons Learned
LTO	long term operation
PHWR	pressurized heavy water reactor
PSR	periodic safety review
PVC	polyvinyl chloride
PWR	pressurized water reactor
SAR	safety analysis report
SCC	stress corrosion cracking
SSC	structure, system and component
TLAA	time limited ageing analysis
WWER	water cooled water moderated power reactor

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Vienna, Austria: 6–9 October 2020, 1–4 June 2021,
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Prague, Czech Republic, 15–18 November 2022

‘Working Group on WWER Ageing Management and LTO Experience Exchange’ Meetings

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This publication provides a technical basis and practical guidance based on proven practices on managing ageing of mechanical, electrical and instrumentation and control components and civil structures of nuclear power plants to support the application of the IAEA safety standards on design, commissioning and operation with respect to ageing management and long term operation and periodic safety reviews. It presents a common, internationally recognized basis for effective ageing management programmes and time limited ageing analyses, as well as a knowledge base on ageing management for design of new plants, design reviews and safety reviews.

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