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No. 82

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

Most IAEA Member States that operate nuclear power plants have regulations that limit commercial power reactor operation over a specified time period or that require comprehensive operational safety reviews at certain intervals. The original period of licensed operation for reactors is based mainly on economic considerations rather than the limitations of nuclear technology or the actual materials of construction.

As of June 2007, out of the total number of nuclear power plants operating in the world, approximately 25% had been in operation for more than 30 years, and about 70% for more than 20 years. A number of IAEA Member States are considering extended operation of nuclear power plants beyond the time frame originally anticipated, in other words long term operation.

This Safety Report provides detailed information on specific programmes to manage existing and potential ageing and degradation of systems, structures and components (SSCs) that will assist operating organizations and regulatory bodies by specifying a technical basis and practical guidance on managing ageing of mechanical, electric and instrumentation and control components, and civil structures of nuclear power plants important to safety. It also provides a common, internationally recognized basis on what constitutes an effective ageing management programme; a knowledge base on ageing management for design of new plants, design reviews, evaluations of safety analyses and time limits assumed; and a roadmap to available information on ageing management. It contains a collection of proven ageing management programmes for SSCs important to safety developed and implemented in various types of water moderated reactors, which will be periodically updated.

This Safety Report complements the IAEA Safety Standards Series No. SSR-2/2, Safety of Nuclear Power Plants: Commissioning and Operation, its implementing Safety Guides, and other related IAEA guidance, such as IAEA Safety Standards Series No. NS-G-2.12, Ageing Management for Nuclear Power Plants, and IAEA Safety Reports Series No. 57, Safe Long Term Operation of Nuclear Power Plants.

The contributions of all those who were involved in the drafting and review of this Safety Report are greatly appreciated. Particular acknowledgement goes to those provided by J. Mok (Canada), R. Havel (Czech Republic), M. Calatayud (Spain), and A. Hiser and E. Patel (United States of America). The IAEA officers responsible for this publication were R. Krivanek, E. Liszka and O. Polyakov of the Division of Nuclear Installation Safety.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

According to IAEA Safety Standards Series No. SSR-2/1, "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" [1]. In addition, according to IAEA Safety Standards Series No. SSR-2/2, "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" [2]. Data on operating experience can be collected and retained for use as input for the management of plant ageing.

Systematic ageing management provides for the availability of safety functions throughout the service life of the plant and decommissioning, taking into account changes that occur with time and use. This requires addressing both physical ageing of systems, structures and components (SSCs), which results in degradation of their performance characteristics, and obsolescence of SSCs, i.e. their becoming out of date in comparison with current knowledge, standards and regulations, and technology [3]. Effective ageing management throughout the service life of SSCs requires the use of a systematic approach that provides a framework for coordinating all programmes and activities relating to the understanding, prevention, detection, monitoring and mitigation of ageing effects on the plant components or structures, and 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 [3–5].

The IAEA started to develop guidance on the safety aspects of ageing management in the 1990s [6]. Subsequently, a number of reports on the subject were published, providing general methodological guidance [7–9], as well as specific guidance for selected major nuclear power plant structures and components, such as reactor vessels, reactor internals, piping, steam generators, containment, etc. [10–20].

In recent decades, the number of IAEA Member States giving high priority to continuing the operation of nuclear power plants beyond the time frame originally anticipated (typically 30–40 years) has steadily increased. Recognizing the need to assist its 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 in 2003–2006 [21]. The outcome of the programme was consolidated in a Safety Report on Safe Long Term Operation of Nuclear Power Plants [22]. Ageing management is one of the focal points of Refs [21, 22].

General recommendations on methodology, key elements and implementation of the effective ageing management programmes (AMPs) for SSCs important to the safety of nuclear power plants are provided in Ageing Management for Nuclear Power Plants (IAEA Safety Standards Series No. NS-G-2.12) [3]. Reference [3] however does not provide comprehensive information on specific degradation mechanisms of SSCs or related mitigation specific AMPs.

In parallel with the development of the safety related publications described above, the IAEA also developed and published information focused on engineering, technological and scientific aspects of ageing management [23–25].

To complement the existing guidance and technical information described above, 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 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 [26–29], and, at the request of the IAEA, agreed to provide the current revision of the Generic Aging Lessons Learned Report [29], as a basis to be used in developing this Safety Report.

The development of this publication was initiated in May 2009 during a Technical Meeting at the IAEA and conducted through the IAEA Extrabudgetary Programme on International Generic Ageing Lessons Learned (IGALL) in 2010–2013 [30].

1.2. OBJECTIVE

The objective of this publication is to provide a technical basis and practical guidance on managing ageing of mechanical, electrical and instrumentation and control (I&C) components and civil structures of nuclear power plants important to safety to support the application of the Specific Safety Requirements on design [1], commissioning and operation [2]; the Safety Guides on ageing management [3] and periodic safety review [5]; and the Safety Report on safe LTO [22].

This publication contains for SSCs important to safety:

— A generic sample of ageing management review (AMR) tables;
— A collection of proven AMPs;
— A collection of typical time limited ageing analyses (TLAAs).

This information is based on approaches developed and implemented in various types of water moderated reactors in participating Member States, and will be periodically updated.

This Safety Report provides a common, internationally agreed basis on what constitutes an acceptable AMP, as well as a knowledge base on ageing management for design of new plants, design reviews, safety reviews (such as periodic safety review), etc., and serves as a roadmap to available information on ageing management.

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

1.3. SCOPE

This Safety Report addresses ageing management of passive and active structures and components for water moderated reactors that can have an impact, directly or indirectly, on the safe operation of the plant and that are susceptible to ageing degradation. The information provided in this publication is relevant for plants in operation, for plants considering LTO, as well as for new plants including new designs. It is important to implement ageing management from the start of operation of nuclear power plants and to make adequate provisions to facilitate effective ageing management during plant design, construction, commissioning, operation and decommissioning.

In this publication, passive structures and components are defined as those 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.

As stated in Ref. [3], managing ageing for nuclear power plants implies ensuring the availability of required safety functions throughout the service life of the plant, taking into account the changes that occur over time and with use. This requires addressing both physical ageing of SSCs, which results in degradation of their performance characteristics, and obsolescence of SSCs, i.e. their becoming out of date with respect to current knowledge, standards and technology.

Although this publication is focused on management of physical ageing, obsolescence of SSCs important to safety has to be managed proactively throughout their service life. Aspects of technological obsolescence, such as insights into individual degradation mechanisms, 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. However, new insights have to be addressed in future updates of the AMPs.

More general aspects of technological obsolescence have to be addressed within a programme for the management of obsolescence, which is to be established by the operating organization according to Ref. [3] (a description of a generic technological obsolescence programme is provided in the TOP401 Technological Obsolescence Programme, which is documented on the IGALL pages of the IAEA web site). Within this framework, procedures can be put in place to provide for the availability of:

— Documentation to support SSC maintenance and replacement;
— Required technical support;
— Sufficient spare parts.

Conceptual aspects of obsolescence (such as consistency with current knowledge and standards) can be evaluated in the framework of a periodic safety review (Safety Factors 1–4 of Ref. [5]) or as a part of ongoing regulatory processes.

Consequently, these aspects of obsolescence are not further discussed in this publication.

This publication is not intended to facilitate comprehensive identification of structures and components for ageing management. In particular, this publication does not address identification of structures and components (scope setting) for LTO and should not be used as a checklist or as a scope setting document. Scope setting is described in Ref. [22].

The inclusion of a certain AMP, TLAA or SSCs in this publication does not mean that this particular example is within the scope of LTO for all plants. Conversely, the absence of a certain AMP, TLAA or SSCs in this publication does not mean that this particular example is not included in the scope of LTO for any plant.

The information provided in the AMR tables is not applicable to each plant type, and even for a specific reactor type the information may not be applicable due to design, construction and operational measures.

The information provided in this publication represents proven practices of participating Member States. These proven practices may not be applicable to every nuclear power plant or Member State.

The definitions of the terms used, provided in Section 5 and Appendix III, are selected definitions and may not include all SSCs and other items as applicable to a given nuclear power plant.

1.4. STRUCTURE

The main body of this Safety Report is divided into five sections. Section 1 contains the background, objective and scope of the publication. Section 2 summarizes information on AMR and provides a roadmap to the AMR tables. Section 3 presents basic concepts of AMPs, describes the nine generic attributes of an effective AMP and provides details on contents for each of the attributes. Section 4 provides general information on TLAAs and Section 5 provides definitions of specific terms used in the publication.

The publication includes three appendices. Appendix I provides a list of proven AMPs based on input from participating Member States. Appendix II provides a list of TLAAs based on input from participating Member States. Appendix III provides definitions of terms for structures and components, materials, environments, ageing effects and degradation mechanisms to facilitate consistent use of terms.

The information referred to in Appendices I and II, and the AMR tables are provided in the IGALL database on the IAEA web site. The information provided in the appendices reflects the status at the date of publication of this Safety Report. The current IGALL database consists of 2351 line items in the AMR tables, 76 AMPs and 27 TLAAs.

The most up to date information is available in the IGALL database.

2. AGEING MANAGEMENT REVIEW

Scope setting is an essential prerequisite for AMR. The SSCs that are subject to AMR are identified through a scope setting process as described in Refs [2, 22]. Each plant may use an individual approach based on its current licensing basis (CLB) and national regulatory requirements.

The AMR process involves, but is not limited to, the identification of the following elements:

— System;
— Structure/component;
— Ageing effect/degradation mechanism;
— Critical location/part;
— Material;
— Environment;
— AMP;
— TLAA(s).

For structures and components that are identified as being subject to an AMR in general, or in the scope of LTO, IAEA safety standards require the operating organization to "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" [2] (see Requirements 14 and 16 of Ref. [2]; for an example from a Member State see item 54.21(a) (3) of Ref. [26]).

Taking as a basis the AMR tables of Ref. [29], participating Member States have provided their own AMR results by comparing their structure/component information and data towards the relevant lines in the tables in Ref. [29]. In cases when the line items of Ref. [29] were not fully or partly applicable, a new line item has been added with the complete information of the participating Member State in each column.

After compilation of the information provided by each Member State, clarification, and discussion, the information was consolidated/reconciled into an IGALL AMR line item (i.e. only one line for each combination of system, structure/component, ageing effect/degradation mechanism, material, environment, AMP, etc., is provided in the IGALL AMR tables).

The IGALL AMR tables could be used as an internationally agreed basis on what constitutes an acceptable AMP and/or TLAA for each critical location/part of SSCs, ageing effect/degradation mechanism, material and environment. For applicability refer to Section 1.3.

The AMR approach described in this publication uses numerous terms to identify structures/components, construction 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 in Appendix III.

The AMPs used to address the ageing effects requiring management are identified in the AMP column of the AMR tables. The IGALL AMPs are structured according to the nine generic attributes of an effective AMP defined in Ref. [3]. A general description of AMPs, including the nine generic attributes, is provided in Section 3. The list of IGALL AMPs for mechanical components, electrical and I&C components, and civil structures is provided in Appendix I. The most up to date versions of IGALL AMPs, which are based on consolidated input from participating Member States, are provided in the IGALL database.

The use of TLAA(s) in the 'further action' 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. For a TLAA, the qualified life of equipment can be reassessed during its lifetime, taking into account the progress in knowledge of degradation mechanisms. It should be stressed that identification of TLAAs depends on national regulatory requirements and may not apply to all plants. A general description of TLAAs is given in Section 4. The list of IGALL TLAAs for mechanical components, electrical and I&C components, and civil structures is provided in Appendix II. The most up to date versions of IGALL TLAAs, which are based on individual input from participating Member States, are provided in the IGALL database.

AMR is implemented on a plant specific basis using established procedures and methods in line with the national regulatory requirements [30]. The IGALL AMR tables may be used as an additional basis to supplement plant specific AMRs (for development or review).

The AMR tables in the IGALL database provide a knowledge base on ageing management for design of new plants, design reviews, safety reviews (such as periodic safety review), etc., and could serve as a roadmap to information on ageing management.

The elements identified during the plant specific AMR process (see first two paragraphs of this section) can be compared to the applicable line items in the IGALL tables to determine whether the ageing management approach is consistent with IGALL or differences are justified properly.

AMR tables (see Table 3) in the IGALL database contain the following information (column headings):

— Table number: AMR tables in the IGALL database are numbered as described in Table 1.
— IGALL number: The sequential number of the line item (or row) in the AMR table assigned in each area separately and numbered as described in Table 1. A combination of table number and IGALL number creates a unique ID number for each line item.

— Systems: Indicates the systems to which the structure/component subject to AMR belongs. For electrical and I&C plant equipment, this column indicates only if the equipment concerned is environmentally qualified or not.
— Structure/component: Identifies the structure or component subject to AMR. These are listed in alphabetical order in Table 5. (Note that Tables 5–9 can be found in Appendix III.)
— Ageing effect/degradation mechanism: Identifies the applicable ageing effect and degradation mechanism(s). Ageing effects and degradation mechanisms are listed in alphabetical order in Table 8 and Table 9, respectively.
— Critical location/part: Identifies the location or part within a given structure/component susceptible to the ageing effect/degradation mechanism.
— Material: Identifies the material of construction. These are listed in alphabetical order in Table 6.
— Environment: Identifies the environment to which the structure/component is exposed. Internal or external service environments are indicated as applicable. They are listed in alphabetical order in Table 7.
— AMP: Identifies the AMP used to manage the ageing effect. AMPs are addressed in Section 3 and are listed in Appendix I.
— Further action: Indicates whether additional evaluation or activities are necessary (e.g. TLAAs or plant specific AMPs).
— Remarks: Provides additional information as needed.
— Design: Indicates pressurized water reactor (PWR) (including water cooled water moderated power reactor (WWER)), boiling water reactor (BWR) or Canada deuterium–uranium (CANDU) reactor/pressurized heavy water reactor (PHWR) as applicable.

TABLE 1. 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
Electrical and I&C	Electrical components environmentally qualified	201
	Electrical components not environmentally qualified	202
	I&C components environmentally qualified	203
	I&C components not environmentally qualified	204
Civil structures and components	Containment structures	301
	Civil structures except of containment[c]	302, 303
	Anchors and supports for equipment, piping and components	304

[a] May relate to mechanical, electrical and I&C, or civil structures and components for all classes applicable to all designs.
[b] Mechanical non-class 1 applicable to all designs.
[c] Grouping of these structures is described in Appendix IV.

For purposes of self-assessment or demonstration of compliance with this Safety Report, the results of the evaluation of plant specific AMP consistency with proven IGALL AMPs can be summarized by using the IGALL AMR table format with two additional columns. The first additional column can be a note column that provides space for a notation to indicate the results of the review. A designation as described in Table 2 can be added to the note column.

TABLE 2. NOTE COLUMN DESIGNATION

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

For line items with Notes B to E, additional discussion can be provided for each line item by adding the rationale in the second additional column.

The review for consistency with IGALL spreadsheets may also identify some line items that require further action. These may include any inconsistency between plant specific and IGALL TLAAs. For these line items, it will be helpful to include specific discussion in the text of the review report.

Table 3 contains an example of an AMR table.

TABLE 3. EXAMPLE OF AGEING MANAGEMENT REVIEW TABLE FOR PWR MECHANICAL COMPONENTS

Table No.	IGALL No.	Systems	Structure/ component	Ageing effect/ degradation mechanism	Critical location/part	Material	Environ-ment	Ageing management programme	Further action	Refer-ences	Remarks	Design
104	577	Auxiliary systems	Spent fuel pool cooling and cleanup (PWR)	Loss of material due to general, pitting, crevice, galvanic corrosion	Piping, piping component, piping element	Copper alloy	Closed cycle cooling water	AMP117 Closed Treated Water Systems	No			PWR
104	578	Auxiliary systems	Chemical and volume control system (PWR)	Cracking due to stress corrosion cracking, cyclic loading	High pressure pump, closure bolting	Steel, high strength	Air with steam or water leakage	AMP115 Bolting Integrity	No			PWR
104	583	Auxiliary systems	Chemical and volume control system (PWR)	Loss of material due to pitting, crevice corrosion	Piping, piping component, piping element, tank	Stainless steel	Air, outdoor	AMP134 External Surfaces Monitoring of Mechanical Components	Yes, envi-ronmental condi-tions need to be evaluated			PWR
104	581	Auxiliary systems	Chemical and volume control system (PWR)	Loss of material due to general, pitting, crevice, galvanic corrosion	Heat exchanger components	Copper alloy	Closed cycle cooling water	AMP117 Closed Treated Water Systems	No			PWR
104	582	Auxiliary systems	Chemical and volume control system (PWR)	Cracking due to stress corrosion cracking	Piping, piping component, piping element, tank	Stainless steel	Air, outdoor	AMP134 External Surfaces Monitoring of Mechanical Components	Yes, envi-ronmental condi-tions need to be evaluated			PWR

3. AGEING MANAGEMENT PROGRAMMES

An AMP is a set of plant activities relating to understanding, prevention, detection, monitoring and mitigation of a specific ageing effect on a structure, component or group of components. Plant activities include maintenance, in-service inspection, testing and surveillance, as well as operational conditions and technical support programmes.

According to Ref. [3]:

> "The ageing management programme should identify: (a) effective and appropriate actions and practices for managing ageing that provide for timely detection and mitigation of ageing effects in the structure or component; and (b) indicators of the effectiveness of the programme. Thus the effectiveness of current practices should be confirmed in light of applicable ageing evaluations and condition assessments, and/or improvements to current practices should be recommended, as appropriate."

Ageing management of SSCs should be implemented proactively (with foresight and anticipation) throughout the plant's lifetime, i.e. in design, fabrication and construction, commissioning, operation (including LTO and extended shutdown) and decommissioning. Many decisions related to ageing management are made early in the process, during the phases of design, construction and commissioning.

Current nuclear power plants have been designed for 30 to 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 has also been recognized that the ageing of plants needs to be assessed, and an effective management strategy developed in a timely manner, to ensure the necessary technical basis for maintaining safety margins throughout the plant's operation.

There are several ways to accomplish ageing management. This publication deals with the following AMP types:

— A degradation mechanism specific AMP (e.g. flow accelerated corrosion, stress corrosion cracking, thermal ageing);
— A structure or component specific AMP (e.g. reactor coolant pumps, control rod drive housing).

As described in Section 1, effective ageing management for SSCs includes maintenance, in-service inspection, testing, and surveillance activities, with a goal of improving the reliability of SSCs.

Maintenance of components [4] typically involves implementation of recommended maintenance schedules from the vendor of each component. 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 are identified. In addition, various test and surveillance procedures that are regularly performed due to existing requirements can provide benefits for AMPs to ensure 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 activities, depends on the regulatory requirements in each Member State. In some Member States, such as the United States of America, 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 [31], which provide a performance based approach to ensure component reliability and include maintenance, testing and surveillance activities. In other Member States, ageing management deals with both active and passive structures and components.

Although this publication is concerned with development and implementation of AMPs and does not provide specific guidance for maintenance, in-service inspection, testing and surveillance activities, the latter 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 the AMPs, like all other plant programmes and processes, are documented in the quality management system, and that they are included in the final safety analysis report (FSAR) of the plant [32].

The list of IGALL AMPs for mechanical components, electrical and I&C components, and civil structures is provided in Appendix I.

The collection of full IGALL AMPs, which are based on input from participating Member States, is provided in the IGALL database. The IGALL AMPs are structured according to the nine generic attributes of an effective AMP. These attributes, against which each AMP is evaluated, are described as follows [3, 22]:

1. Scope of the AMP based on understanding ageing

The scope of an effective programme includes structures (including structural elements) and components subject to ageing management.

Understanding of ageing phenomena is based on (significant degradation mechanisms and susceptible sites):

— Structure/component materials, service conditions, stressors, degradation sites, degradation mechanisms and effects;
— Structure/component condition indicators and acceptance criteria;
— Quantitative or qualitative predictive models of relevant ageing phenomena.

2. Preventive actions to minimize and control ageing degradation

— Identification of preventive actions. These activities are defined as those that are necessary to prevent or minimize initiation of degradation:
  • The activities for prevention programmes are described as they contribute to preventing ageing degradation.
  • Condition or performance monitoring programmes that do not rely on preventive actions need not be provided.
  • Condition or performance monitoring programmes that rely on preventive actions, such as maintenance of water chemistry, or the use of appropriate lubrication, are specified.
— Determination of service conditions (i.e. environmental conditions and operating conditions) to be maintained and operating practices aimed at slowing down potential degradation of the structure or component. For prevention programmes, the parameters monitored will be the specific parameters being controlled to achieve prevention of ageing effects. An example is the coolant oxygen level that is being controlled in a water chemistry programme to prevent pipe cracking.

3. Detection of ageing effects

— Identification of parameters to be monitored or inspected:
  • This programme element will identify the ageing effects that the programme manages, and provide a link between the parameter or parameters that will be monitored and how the monitoring of these parameters will ensure adequate ageing management.
  • In an effective condition monitoring programme, the parameter monitored or inspected will be capable of detecting the presence and

extent of ageing effects. Some examples are measurements of wall thickness and detection and sizing of cracks.

- In an effective performance monitoring programme, a link will be established between the degradation of the particular structure or component intended function(s) and the parameter(s) 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 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, such as pressure boundary. Thus, an effective performance monitoring programme ensures that the structures and components are capable of performing their intended functions by using a combination of performance monitoring and evaluation (if outside acceptable limits specified in acceptance criteria) that demonstrate that a change in performance characteristics is a result of an age related degradation mechanism.
- In effective prevention or mitigation programmes, 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.

— Effective technology (inspection, testing and monitoring methods) for detecting ageing effects before failure of the structure or component:

- Detection of ageing effects should occur before there is a loss of the structure/component intended function(s). In an effective programme, the parameters to be monitored or inspected are appropriate to ensure that the structure/component intended function(s) will be adequately maintained under all CLB design conditions. Thus, the discussion for an effective detection of ageing effects programme element addresses (a) how the programme element would be capable of detecting or identifying the occurrence of age related degradation or an ageing effect prior to a loss of structure/component intended function or (b) for prevention/mitigation programmes, how the programme would be capable of preventing or mitigating their occurrence prior to a loss of structure/component intended function. The discussion provides information that links the parameters to be monitored or inspected to the ageing effects being managed.
- Nuclear power plant safety is based on redundancy, diversity and defense-in-depth principles. A degraded or failed component reduces

the reliability of the system, challenges safety systems, and contributes to 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 function(s) as designed when called upon. In this way, all system level intended functions consistent with the plant's CLB, including redundancy, diversity and defense-in-depth, are maintained.

- This programme element describes when, where, and how programme data are collected (i.e. all aspects of activities to collect data as part of the programme).
- For condition monitoring programmes, the method or technique (such as visual, volumetric or 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 structure/component intended function. 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 toward 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.
- In an effective performance monitoring programme, the detection of ageing effects programme element discusses and establishes the monitoring methods that will be used for performance monitoring. In addition, the detection of ageing effects programme element also establishes and justifies the frequency that will be used to implement these performance monitoring activities.
- In an effective prevention or mitigation programme, the detection of ageing effects programme element discusses and establishes the monitoring 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. *Monitoring and trending of ageing effects*

— Condition indicators and parameters monitored. Monitoring and trending activities are described, and they provide a prediction of the extent of degradation and thus enable timely corrective or mitigative actions. Plant specific and/or industry wide operating experience may be considered in evaluating the appropriateness of the technique and frequency.
— Data to be collected to facilitate assessment of structure or component ageing.
— Assessment methods (including data analysis and trending). Description of how the data collected are evaluated is provided and may also include trending for a forward look. Trending is a comparison of the current monitoring results with previous monitoring results in order to make predictions for the future. The description includes an evaluation of the results against the acceptance criteria, and a prediction regarding the rate of degradation, in order to confirm that the next scheduled inspection will occur before a loss of structure/component intended function. Although ageing indicators may be quantitative or qualitative, ageing indicators are quantified, to the extent possible, to allow trending. The parameter or indicator trended is described. The methodology for analysing the inspection or test results against the acceptance criteria is described.

5. *Mitigating ageing effects*

— Activities that mitigate further degradation when degradation has been observed, but the condition of the structure/component is still within the bounds of the acceptance criteria.
— Operations, maintenance, repair and replacement actions to mitigate detected ageing effects and/or degradation of the structure or component:
  • The activities for mitigation programmes are described. These activities mitigate ageing degradation.
  • An example is the coolant oxygen level that is being controlled in a water chemistry programme to mitigate pipe cracking.

6. *Acceptance criteria*

— Acceptance criteria against which the need for corrective action is evaluated:
  • The quantitative or qualitative acceptance criteria of the programme, and their basis, are described. The acceptance criteria, against which the need for corrective actions is evaluated, ensure that the structure/component intended function(s) is consistently maintained under all CLB design conditions. The programme includes a methodology for

analysing the results against applicable acceptance criteria. For example, carbon steel pipe wall thinning may occur under certain conditions due to flow accelerated corrosion. An effective AMP for flow accelerated corrosion may consist of periodically measuring the pipe wall thickness and comparing that to 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 (such as deadweight, seismic, and other loads). This acceptance criterion provides for timely corrective action before loss of intended function under these CLB design loads.

- The acceptance criteria for an effective AMP could be specific numerical values, or could consist of a discussion of the process for calculating specific numerical values to define conditional acceptance criteria to ensure that the structure/component intended function(s) will be maintained under all CLB design conditions. Information from available references may be cited.
- It is not necessary to justify any acceptance criteria taken directly from the design basis information included in the FSAR, 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 respective regulatory body, such as those that may be given in regulatory body approved or endorsed topical reports or endorsed codes and standards. Also, it is not necessary to discuss CLB design loads if the acceptance criteria do not permit degradation because a structure and component without degradation should continue to function as originally designed. Acceptance criteria that do permit degradation are based on maintaining the intended function under all CLB design loads.

7. Corrective actions

— Corrective actions if a structure or component fails to meet the acceptance criteria:
  - 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 determination and prevention of recurrence, are timely.

- If corrective actions permit analysis without repair or replacement, the analysis ensures that the structure/component intended function(s) is maintained consistent with the CLB.
- 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. For example, in the United States of America for a plant specific condition monitoring programme that is based on American Society of Mechanical Engineers (ASME) Section XI requirements, the implementation of 10 CFR Part 50, Appendix B (Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants) ensures that any corrective actions are performed in accordance with applicable code requirements or regulatory body approved code cases.

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

— A mechanism that ensures timely feedback of operating experience as well as research and development results (if applicable), and provides objective evidence that they are taken into account in the AMP.
  - Consideration is given to plant specific and industry operating experience from all Member States and international organizations relating to AMPs. Reviews of operating experience by the applicant in the future can identify areas where AMPs should 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 AMPs. This information should provide objective evidence to support the conclusion that the effects of ageing will be managed adequately so that the structure and component intended function(s) will be maintained.
  - Operating experience with existing programmes is discussed. The operating experience of existing AMPs, including past corrective actions resulting in programme enhancements or additional programmes, is considered. A past failure would not necessarily invalidate an AMP because the feedback from operating experience should have resulted in appropriate programme enhancements or new programmes. 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. This information should provide objective evidence to support the conclusion that the effects of ageing will be managed adequately

so that the structure/component intended function(s) will be maintained during the period of extended operation.

- For new AMPs that have yet to be implemented, the programmes have not yet generated any operating experience. However, there may be other relevant plant specific operating experience at the plant, or generic operating experience in the industry that is relevant to the AMP's elements even though the operating experience was not identified as a result of the implementation of the new programme. Thus, to ensure a new programme is effective, the plant operator may need to consider the impact of relevant operating experience that results from the past implementation of its existing AMPs, and the impact of relevant generic operating experience when developing the programme elements. Therefore, operating experience applicable to new programmes will be discussed. Additionally, the plant operator will perform a review of future plant specific and industry operating experience, and research and development results for new programmes, to confirm their effectiveness.

9. Quality management

— Administrative controls that document the implementation of the AMP and actions taken.
  - The administrative controls of the programme are described. Administrative controls provide a formal review and approval process.
  - For example, in the United States of America any AMPs to be relied on for licence renewal should have regulatory and administrative controls. That is the basis for 10 CFR 54.21(d) [26] to require that the FSAR supplements include a summary description of the programmes and activities for managing the effects of ageing for licence renewal. Thus, any informal programmes relied on to manage ageing for licence renewal will be administratively controlled and included in the FSAR supplement.

— Indicators to facilitate evaluation and improvement of the AMP. The effectiveness of prevention and mitigation programmes is verified periodically. For example, in managing internal corrosion of piping, a mitigation programme (water chemistry) may be used to minimize susceptibility to corrosion. However, it may also be necessary to have a condition monitoring programme (ultrasonic inspection) to verify that corrosion is indeed insignificant.

— Confirmation (verification) process for ensuring that preventive actions are adequate and appropriate, and that all corrective actions have been completed and are effective:
  - The confirmation process is described. The process ensures that preventative actions are adequate, and that appropriate corrective actions have been completed and are effective.
  - When corrective actions are necessary, there are follow-up activities to confirm that the corrective actions have been completed, a root cause determination was performed and recurrence will be prevented.

— Record keeping practices to be followed.

4. TIME LIMITED AGEING ANALYSES

The time limited ageing analyses (TLAAs) (also termed safety analyses that use time limited assumptions) are plant specific safety analyses that consider time and ageing and involve SSCs within the scope of ageing management. TLAAs are analyses that meet all six of the following criteria [22]:

(1) *Involve SSCs within the scope of LTO*. Scope setting is plant specific based on the CLB and national regulatory requirements.

(2) *Consider the effects of ageing degradation*. The effects of ageing include, but are not limited to: loss of material, change in dimension, change in material properties, loss of toughness, loss of prestress, settlement, cracking and loss of dielectric properties.

(3) *Involve time limited assumptions defined by the current operating term.* The defined operating term is explicit in the analysis. Simply asserting that a component is designed for a service life or plant life is not sufficient. The assertion is supported by calculations or other analyses that explicitly include a time limit.

(4) *Were determined to be relevant by the plant in making a safety determination as required by national regulations*. Relevancy is a determination that the plant makes based on a review of the information available. A calculation or analysis is relevant if it can be shown to have a direct bearing on the action subsequently taken as a result of the analysis performed. Analyses are also relevant if they provide the basis for a plant's safety determination and, in the absence of the analyses, the plant might have reached a different safety conclusion.

(5) *Involve conclusions or provide the basis for conclusions related to the capability of the system, structure, or component to perform its intended function(s).*
(6) *Are contained or incorporated by reference in the CLB*. The CLB includes the technical specifications as well as design basis information, or plant commitments documented in the plant specific documents contained or incorporated by reference in the CLB, including, but not limited to: the safety analysis report, regulatory safety evaluation reports, the fire protection plan/hazards analyses, correspondence to and from the regulator, the quality assurance plan, and topical reports included as references to the safety analysis report. If a code of record is in the FSAR for particular groups of structures or components, reference material includes all calculations called for by that code of record for those structures and components.

This publication also includes, among the list of TLAAs, other safety analyses that do not meet criterion 6 (above) because these analyses have been newly developed in Member States to demonstrate preparedness for LTO. The list of TLAAs in this publication may not address all plant specific analyses that should be considered to demonstrate readiness for LTO, and each listed TLAA may not apply to all plants.

As outlined in IAEA Safety Standards Series No. NS-G-2.12 [3], para. 6.3, the review process for ageing management of nuclear power plants involves revalidation of safety analyses that were developed using time limited assumptions, to demonstrate their continuing validity or that the ageing effects will be effectively managed, that is, to demonstrate that the intended function of a structure or component will remain within the design safety margins throughout the planned LTO period.

Revalidating TLAAs means assessing an identified ageing effect (time dependent degradation due to normal service conditions) and certain plant specific safety analyses that were developed on the basis of an explicitly specified length of component life. TLAAs include, for example, fatigue calculations, pressurized thermal shock analysis, equipment qualification of electrical and I&C cables, and concrete containment tendon prestress analysis.

TLAAs involve two types of parameters. The first parameter, a time dependent parameter, is used to evaluate an analysis parameter, which is then compared to a regulatory limit or criterion to determine acceptability of the component for service. Examples of time dependent parameters include component operating time, neutron fluence or number of thermal cycles on a component. The analysis parameters associated with these time dependent parameters could include fracture toughness of thermally aged cast austenitic stainless steel, neutron embrittlement of reactor pressure vessel materials and fatigue cumulative usage factors, respectively.

Evaluation of 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_{k0}, 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, such that acceptability of the component for continued service can be determined.

For LTO, TLAAs are reviewed to determine 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. A TLAA is acceptable if it meets one of the following cases [22]:

(1) *The analysis remains valid for the intended period of operation.* The time dependent parameter value for the intended period of operation does not exceed the time dependent parameter value used in the existing analysis.
(2) *The analysis has been projected to the end of the intended period of operation.* The analysis parameter value is changed based on the time dependent parameter projected for the LTO period and the value of the analysis parameter continues to meet the regulatory limit or criterion.
(3) *The effects of ageing on the intended function(s) of the structure or component will be adequately managed for the intended period of operation.* The value of the analysis parameter will be managed (using an AMP) to ensure that the effects of ageing are adequately managed and that the value of the analysis parameter will continue to meet the regulatory limit or criterion during the operation period.

If the TLAA cannot be found acceptable under one of these three cases, then corrective actions are necessary. Corrective actions could include refinement of the analysis to remove excess conservatism, and repair or replacement of the component, depending on the specific analysis.

The plant's FSAR can be supplemented to include a summary description of the analyses concerned and their evaluation for the LTO period [22].

Generic TLAAs typically include [28]:

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

Examples of potential plant specific TLAAs may include [28]:

— 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.

The following examples illustrate analyses that are not TLAAs:

— Population projections;
— Cost–benefit analyses for plant modifications.

A sample process for identifying potential TLAAs and a basis for disposition is provided in Table 4 [27].

TABLE 4. EXAMPLES OF DISPOSITION OF POTENTIAL TLAAs

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 plant operating life. Therefore, does not meet criterion 3 of the TLAA definition.
Maximum wind speed of 161 km/h (100 mph) 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 regulator states that the membrane on the containment base mat 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.
Fatigue usage factor for the pressurizer surge line was 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. 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 for comparing measured to predicted lift-off forces.	This example is a TLAA because it meets all six criteria. 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 required technical specification surveillance.

In the AMR tables, some line items identify related TLAAs, but only as examples. Some TLAAs provided in the IGALL database are not linked to a line item in the AMR tables. Some TLAAs represent an approach specific to one or a few Member States.

Lists of IGALL TLAAs for mechanical components, electrical and I&C components, and civil structures are provided in Appendix II. The most up to date collection of the IGALL TLAAs, based on input from participating Member States, is provided in the IGALL database.

5. DEFINITIONS

For consistent use, the definitions of the most commonly used terms are provided in this section and in Tables 5–9 in Appendix III. It is important to ensure that a structure or a component under question has similar characteristics (i.e. material, environment, ageing effect and degradation mechanism) as the items described in this publication before adopting the recommended AMPs provided for the subject item. Should a structure or a component under question not have similar characteristics, a new AMP can be developed in accordance with the acceptable AMP criteria described in Section 3.

The format and content of the AMR tables described in Section 2 have been developed to provide generalization of terms used within this publication. The line items are made more generic and less prescriptive. As a simple example, the phrase ‘piping, piping components and piping elements’ is used to replace various combinations of the terms ‘piping’, ‘fittings’, ‘tubing’, ‘flow elements/indicators’, ‘demineralizer’, ‘nozzles’, ‘orifices’, ‘flex hoses’, ‘pump casing and bowl’, ‘safe ends’, ‘sight glasses’, spray head’, ‘strainers’, ‘thermo wells’, 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 Tables 5–9 before reaching any conclusion. Treatment of external or internal surfaces should consider the following:

— *Specification of external or internal surface:* 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 listed below such as air, indoor controlled; air, indoor uncontrolled; air, outdoor; condensation; or air, indoor uncontrolled >35°C, the component description should 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 must be internal to the barrier.

Table 6 defines many generalized materials used in the nuclear industry. Different countries may not have the same material composition. It is important to carefully compare the materials used and the materials in the following tables 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 applicability of the results.

— *Temperature threshold of 35°C for thermal stresses in elastomers:* In general, if the ambient temperature is less than about 35°C, then thermal ageing may be considered not significant for rubber, butyl rubber, neoprene, nitrile rubber, silicone elastomer, fluoroelastomer, ethylene propylene rubber (EPR) and ethylene propylene diene monomer (EPDM) [29]. Hardening and loss of strength of elastomers can be induced by thermal ageing, exposure to ozone, oxidation and radiation. With regard to the elastomers used in electrical cable insulation, it should be noted that most cable insulation is manufactured as either 75°C or 90°C rated material.
— *Temperature threshold of 60°C for stress corrosion cracking (SCC) in stainless steel:* SCC occurs very rarely in austenitic stainless steels below 60°C. Although SCC has been observed in stagnant, oxygenated borated water systems at lower temperatures than this 60°C threshold, in all of these instances a significant presence of contaminants (halogens, specifically chlorides) was identified in the failed components. With a harsh enough environment (i.e. significant contamination), SCC can occur in austenitic stainless steel at ambient temperature. However, these conditions are considered event driven, resulting from a breakdown of chemistry controls.
— *Temperature threshold of 250°C for thermal embrittlement in cast austenitic stainless steel (CASS):* Subjecting CASS to sustained temperatures below 250°C will not result in a reduction of room temperature Charpy impact energy below 68 J (50 ft-lb) for exposure times of approximately 300 000 hours (for CASS with ferrite content of 40% and approximately 2 500 000 hours for CASS with ferrite content of 14%). For a maximum exposure time of approximately 420 000 hours (48 effective full power years), a screening temperature of 250°C is conservatively chosen because (a) the majority of nuclear grade materials are expected to have a ferrite content well below 40%, and (b) the 68 J (50 ft-lb) limit is very conservative when applied to cast austenitic materials; it is typically applied to ferritic materials (e.g. US Federal Regulation 10 CFR 50 Appendix G).

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. Examples would be boric acid corrosion, ohmic heating, or settlement.

Appendix I

LIST OF IGALL AGEING MANAGEMENT PROGRAMMES

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

I.1. IGALL AMPS FOR MECHANICAL COMPONENTS

AMP101	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 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 Vessel Internals
AMP114	Flow-accelerated Corrosion
AMP115	Bolting Integrity
AMP116	Steam Generators
AMP117	Closed Treated Water Systems
AMP118	Reactor 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 Refueling) Handling Systems
AMP128	Compressed Air Monitoring
AMP129	BWR Reactor Water Cleanup System
AMP130	Fire Protection
AMP131	Fire Water System
AMP132	Aboveground 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	CANDU/PHWR Auxiliary System Valves
AMP144	CANDU/PHWR Auxiliary System Pumps
AMP145	CANDU/PHWR Moderator and Moderator Purification Heat Exchangers
AMP146	CANDU/PHWR In-service Inspection/Periodic Inspection
AMP147	Containment Bellows

I.2. IGALL AMPS FOR ELECTRICAL AND I&C COMPONENTS

AMP201	Insulation Materials for Electrical Cables and Connections Not Subject to Environmental Qualification Requirements
AMP202	Insulation Materials for Electrical Cables and Connections Not Subject to Environmental Qualification Requirements Used in Instrumentation Circuits
AMP203	Inaccessible Power Cables Not Subject to Environmental Qualification Requirements
AMP204	Metal Enclosed Bus
AMP205	Fuse Holders
AMP206	Electrical Cable Connections Not Subject to Environmental Qualification Requirements
AMP207	Environmental Qualification of Electrical and I&C Components
AMP208	High Voltage Insulators and Transmission Conductors

AMP209 Ongoing Qualification of Electrical and I&C Components Relevant to an Environmental Qualification

AMP210 Condition Monitoring of Electrical and I&C Cables Subject to Environmental Qualification Requirements

AMP211 Power Transformers

AMP212 Panels, Distribution Cabinets and Local Control Boxes

AMP213 Whiskers and Capacitors with Liquid Electrolyte

AMP214 Motors/Motor Operated Valve Actuators/Generators

AMP215 Switchgears/Breakers/Distribution Panels/Contactors/Protection Relays/Relays

AMP216 Batteries

I.3. IGALL AMPS FOR CIVIL STRUCTURES

AMP 301 In-service Inspection for Containment Steel Elements

AMP 302 In-service Inspection for Concrete Containment

AMP 303 Safety Class 1, 2 and 3 Piping and Metal Containment Components Supports

AMP 304 Containment Leak Rate Test

AMP 305 Masonry Walls

AMP 306 Structures Monitoring

AMP 307 Water-control Structures

AMP 308 Protective Coating Monitoring and Maintenance Programme

AMP 309 Non-metallic Liner

AMP 310 Ground Movement Surveillance

AMP 311 Containment Monitoring System

AMP 312 Concrete Expansion Detection and Monitoring System

AMP 313 Containment Prestressing System

Appendix II

LIST OF IGALL TIME LIMITED AGEING ANALYSES

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

II.1. TLAAs FOR MECHANICAL COMPONENTS

TLAA101	Low-cycle Fatigue Usage
TLAA102	RPV Neutron Embrittlement
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TLAA104	Corrosion Allowances
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TLAA106	Environmentally Assisted Fatigue
TLAA107	High-cycle Fatigue for Steam Generator Tubes
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II.2. TLAAs FOR ELECTRICAL AND I&C COMPONENTS

TLAA201	Environmental Qualification of Electrical and I&C Components

II.3. TLAAs FOR CIVIL STRUCTURES

TLAA301	Concrete Containment Tendon Prestress
TLAA302	CANDU/PHWR Concrete Strength Reduction Due to Creep and Shrinkage
TLAA303	Cumulative Fatigue Damage of Containment Liners and Penetrations
TLAA304	Foundation Settlement Due to Soil Movement

Appendix III

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

Note: Many of these definitions are from Ref. [29].

TABLE 5. STRUCTURES AND COMPONENTS

Term	Definition as used in this publication
Anchorages	Anchorages are used to join components to the structure.
Antiseismic devices	Antiseismic devices are bearings that are able to isolate a component or a building from vibration due to earthquake movement.
Bolting	Bolting can refer to either structural bolting or closure bolting, which can contain bolted closures that are necessary for the pressure boundary of the components being joined/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 the USA), or the temperature exceeds a certain level, for example 100°C (93°C in the USA). Closure bolting is used to join pressure boundaries or where a mechanical seal is required.
Chimney made of fibre reinforced polymer	Such chimney is made of composite material where both polymer and fibres are included.
Concrete submitted to high temperature during setting	These concrete elements are elements where high temperature can occur during setting: the temperature limit is usually 65°C.
Containment	Containment refers to 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 concrete and/or metallic parts such as liners and penetrations, which separate the reactor coolant pressure boundary components from the environment.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in this publication
Encapsulation components/ valve chambers	These are 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 end fittings are 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.
External surfaces	In the context of structures and components, the term external surfaces is used to represent the external surfaces of structures and components such as tanks that are not specifically listed elsewhere.
Feeders	The feeders of the CANDU/PHWR consist of small diameter piping, configured with a combination of bends and straight pipe runs that carry reactor coolant to/from the end fittings of each fuel channel to inlet/outlet headers of the primary heat transport system.
Fuel coolant channels	The fuel coolant channels of the CANDU/PHWR are 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 discharging new fuel and the other accepting used fuel.
Heat exchanger components	A heat exchanger is a device that transfers heat from one fluid to another without the fluids coming in contact with each other. This includes air handling units and other devices that cool or heat fluids. Heat exchanger components may include, but are not limited to, 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 reduction of heat transfer due to fouling.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in this publication
Heating, ventilation and air-conditioning (HVAC) duct	HVAC duct and its components include heating, ventilation and air-conditioning components. Examples include ductwork, ductwork fittings, access doors, closure bolts, equipment frames and housing, housing supports, including housings for valves, dampers (including louvers and gravity dampers), mesh, filters and fire dampers, and ventilation fans (including exhaust fans, intake fans and purge fans). In some cases, this also includes HVAC closure bolts or HVAC piping.
Electrical penetration	Electrical penetration is the leaktight passage device where the cables go through the containment wall.
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. The high voltage insulators that are evaluated for licence renewal are those used to support and insulate high voltage electrical components in switchyards, switching stations and transmission lines.
Masonry walls	The masonry walls refer to construction parts made of concrete blocks or bricks. The masonry wall can be reinforced by rebars or not. Stability can be required for preventing interaction with SSCs, for fire area separation or for other safety reasons.
Metal enclosed bus	Metal enclosed bus is the term used in electrical and industry standards (Institute of Electrical and Electronics Engineers (IEEE) and American National Standards Institute (ANSI)) for electrical buses installed on electrically insulated supports constructed with all phase conductors enclosed in a metal enclosure.
Piping elements (glass)	This general category includes components made of glass, such as sight glasses and level indicators. This ‘piping elements’ designation is used in the AMR tables only when the material is defined as glass.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in this publication
Piping, piping components and piping elements	This general category includes features of the piping system within the scope of AMR; specific features included in this category may vary in different countries. Examples include piping, fittings, tubing, flow elements/indicators, demineralizers, nozzles, orifices, flex hoses, pump casings and bowls, safe ends, sight glasses, 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 is located where access for inspection is restricted.
Pressure housings	Pressure housing only refers to pressure housing for the control rod drive mechanisms (for PWR reactor vessels).
Pressure tubes and calandria tubes	The 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.
Prestressed cables and rods of retaining wall	These prestressed cables and rods are designed to support the retaining wall and to limit its deformation.
Primary heat transport system	The primary heat transport system is the reactor coolant pressure boundary of the CANDU/PHWR. Primary heat transport system boundary components include, but are not limited to: the fuel coolant channels, steam generators, primary heat transport system pumps, inlet headers, outlet headers, feeders and interconnecting piping.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in this publication
Reactor assembly (CANDU/ PHWR)	The CANDU/PHWR reactor assembly components include, but are not limited to: calandria vessel, end shield, shield tank (or water filled, steel lined calandria vault), guide tubes and fuel coolant channels. • Calandria vessel: The calandria vessel, which 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. • 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. • Shield tank/calandria vault: The shield tank is 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. The calandria vault is 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. • Guide tubes: Guide tubes for the reactivity control units penetrate the calandria vessel, passing between the calandria tubes, and screw into locators on the inside of the calandria vessel.
Reactor coolant pressure boundary components	Reactor coolant pressure boundary components include, but are not limited to: the 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 barriers (caulking, flashing and other sealants)	Elastomer components used as sealant or as gaskets including metal reinforced sealing materials.
Spillway	This structure located inside the river is dedicated to maintaining a minimum water level so that the pumping system is fed with sufficient water under all circumstances.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in this publication
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.
Switchyard bus	Switchyard bus is 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	Tanks are large reservoirs used as hold-up volumes for liquids or gases. Tanks may have an internal liquid and/or vapour space and may be partially buried or in close proximity to soils or concrete. Tanks are treated separately from piping due to their potential need for different AMPs. One example is IGALL AMP132 Aboveground Metallic Tanks for tanks partially buried or in contact with soil or concrete that experience general corrosion as the ageing effect at the soil or concrete interface. 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.
Transmission conductors	Transmission conductors are 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, and transformers and passive switchyard buses.
Vacuum building	A concrete containment structure, 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 for supporting components prone to vibration.
Water control structures	Water control structures are integral parts of the systems that provide plant cooling water and residual heat removal.

TABLE 6. MATERIALS

Term	Definition as used in this publication
Aluminium/ steel	Aluminium conductor steel reinforced (ACSR) transmission conductor.
Boraflex	Boraflex is a material that is composed of 46% silica, 4% polydimethyl siloxane polymer and 50% boron carbide, by weight. 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. For example, IGALL AMP126 is used for Boraflex monitoring.
Boral, boron steel	Boron steel is steel with boron content (^{10}B) ranging from one to several per cent. Boron steel absorbs neutrons and thus is often used to make control rods to help control the neutron flux. Boral is material consisting of aluminium and boron carbide (B_4C) sandwiched between aluminium. Boral refers to patented aluminium–boron master alloys; these alloys can contain up to 10% boron as B_4C–Al composite.
Cast austenitic stainless steel (CASS)	CASS is a family of steels, such as 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 grades Type 304L, Type 304, Type 316L and Type 316, except that CASS typically contains 5–25% ferrite. CASS is susceptible to loss of fracture toughness due to thermal and neutron irradiation embrittlement.
Coatings	Paint or other material applied to structures and components to protect the external surfaces from the environment.
Concrete and cementitious material	When used generally, this category of concrete applies to concrete in many different configurations (block, cylindrical, etc.) and 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. When mixing concrete, 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 health implications.
Contact material	A material used for electrical contacts. Contacts are usually made of materials which have good contact resistance (e.g. noble metals such as silver or gold).

TABLE 6. MATERIALS (cont.)

Term	Definition as used in this publication
Copper alloy (>15% Zn or >8% Al)	The broad purpose of this material category is to collect those copper alloys whose critical alloying elements are above certain thresholds that make the alloy susceptible to ageing effects. Copper–zinc alloys >15% zinc are susceptible to SCC, selective leaching (except for inhibited brass), and pitting and crevice corrosion. Additional copper alloys may be susceptible, such as aluminium bronze >8% aluminium. The elements that are most commonly alloyed with copper are zinc (the alloy is referred to as brass), tin (referred to as bronze), nickel, silicon, aluminium (referred to as aluminium bronze), cadmium and beryllium. Additional copper alloys may be susceptible to these ageing effects above the threshold for the critical alloying element.
Elastomers	Elastomers are flexible materials such as rubber, EPT, EPDM, viton, vitril, neoprene 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	A basic electronic element 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.
Fibre reinforced polymer	A material in which fibres give mechanical capacity (mainly for tensile stress) and polymer is the material matrix which gives the shape and the link to component and/or structure.
Galvanized steel	Galvanized steel is 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’.
Glass	This category includes any glass material. Glass is a hard, amorphous, brittle, supercooled liquid made by fusing together one or more of the oxides of silicon, boron or phosphorous with certain basic oxides (e.g. Na, Mg, Ca, K), and cooling the product rapidly to prevent crystallization or devitrification.
Graphitic tool steel	Graphitic tool steels (such as AISI O6, which is oil hardened, and AISI A10, which is air hardened), have excellent non-seizing properties. The graphite particles provide self-lubricity and hold applied lubricants.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in this publication
Grease	Grease is a semisolid lubricant. It generally consists 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 for example to elevated temperature may lead to loss of function.
Grey cast iron	This form of cast iron is 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 are less than about 1.2% carbon by weight, while cast irons are typically 2.5 to 4% carbon by weight. 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 (HDPE)	HDPE has been used in service water piping at some plants. HDPE pipe has been found to have high corrosion and chemical resistance.
Insulation materials	Materials with very low electrical conductivity. Materials used depend on environmental conditions and voltage (e.g. polymers, ceramics). Cables with mineral insulation (Mg or Al oxide) could exhibit reduced insulation resistance due to moisture intrusion or elevated temperature.
Low alloy steel, actual measured yield strength $\geqslant$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 $\geqslant$ 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 $\geqslant$ 1034 MPa (150 ksi)) low alloy steel SA193-Gr. B7 is susceptible to SCC.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in this publication
Lubrite	Lubrite (self-lubricated bearings) refers to a patented 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 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 with the use of Lubrite bearings has not shown adverse conditions related 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 required 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 malfunctioning, distortion, dirt accumulation, and fatigue effects under vibratory and cyclic thermal loads. The potential ageing effects could be managed by incorporating periodic examination in the appropriate AMP.
Metal	Metal is an element, compound or alloy that is a good conductor of electricity and of heat. For electrical and I&C components, the main focus is oxidation of metal, which leads to increase of ohmic resistance in metal used as a conductor.
Nickel alloys	Ni–Cr–Fe (Mo) alloys are those 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	Paper is 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.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in this publication
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 applications include EPR (ethylene propylene rubber), SR (silicone rubber), EPDM (ethylene propylene diene monomer) 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.
Polyvinyl chloride (PVC)	PVC has been used in 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 for supporting high voltage electrical insulators. Porcelain is a hard, fine grained ceramic that essentially consists of kaolin, quartz and feldspar that is fired at high temperatures.
Pressure vessel steels cladded with stainless steel using a high heat input welding process	Quenched and tempered vacuum treated carbon and alloy steel used for pressure vessels that may be susceptible to underclad cracking when cladded with stainless steel using high heat input welding processes.
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 PH stainless steel or CASS as for stainless steel, PH 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 and Type 416. Examples of CASS designations include CF-3, CF-8, CF-3M and CF-8M.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in this publication
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 that comprise 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.
Superaustenitic stainless steel	Superaustenitic stainless steels have the same structure as the common austenitic alloys, but they have enhanced levels of elements such as chromium, nickel, molybdenum, copper and nitrogen, which give them superior strength and corrosion resistance. Compared to conventional austenitic stainless steels, superaustenitic materials have a superior resistance to pitting and crevice corrosion in environments containing halides. As an example several nuclear power plants have installed superaustenitic stainless steel (AL-6XN) buried piping.
Titanium	The category titanium includes 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 or 12 are not susceptible to SCC in sea water or brackish raw water.
Waterproofing membranes	Material to prevent the ingress of water.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in this publication
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.
Zirconium alloy (Zircaloy-4, Zircaloy-2, Zr-2.5%Nb)	Zirconium alloys are 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. For example, in PWR reactors, 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-2.5%Nb, which consists of 97.5 wt% Zr with 2.5 wt% Nb. Zr-2.5%Nb is used to make pressure tubes in CANDU/PHWR reactors. E125 (Zr-2.5%Nb) and E110 (99 wt% Zr with 1 wt% Nb) are used for in-core components in WWERs.

TABLE 7. ENVIRONMENTS

Term	Definition as used in this publication
Adverse localized environment	An adverse localized environment is 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 moisture, radiation, voltage, the presence of oxygen, or heat, particularly >60 year service limiting temperature (temperatures exceeding the temperature below which the material has a 60 year or greater 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 in the USA or as specified in other Member States.
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. This is germane to PWRs.
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 and/or steam.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in this publication
Air with metal temperature up to 288°C	This environment is 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. This is germane to BWRs.
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.
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 >35°C (internal/ external)	The environment to which the internal or external surface of the component or structure is exposed: indoor air above thermal stress threshold for elastomers. If ambient temperature is <35°C, then any resultant thermal ageing of organic materials can be considered to be 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.
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 salt water 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).
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.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in this publication
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 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.
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 comprise this category can include, but are not limited to: • 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 tube side and closed cycle cooling water on shell side.
Concrete	Steel and stainless steel components embedded in concrete.
Condensation (internal/ external)	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 potential for surface contamination. The terms ‘moist air’ or ‘warm moist air’ are included in the ‘condensation’ category and describe an environment where there is enough moisture for corrosion to occur.
Containment environment (inert)	The drywell is made inert with nitrogen to render the primary containment atmosphere non-flammable by maintaining the oxygen content below 4% by volume during normal operation (only applicable to BWRs).
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 may be contaminated with water, which may promote additional ageing effects.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in this publication
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/ soil	Groundwater is subsurface water that 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 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/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 exposures to groundwater or moist soils are subject to the same ageing effects as those systems and components exposed to raw water.
Lubricating oil	Lubricating oils are low to medium viscosity hydrocarbons that can contain contaminants and/or moisture. This definition also functionally encompasses hydraulic oil (non-water based). These oils are used for bearing, gear and engine lubrication. IGALL AMP 136, Lubricating Oil Analysis, addresses this environment. 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.
Moderator (D_2O)	The CANDU/PHWR reactor 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 related 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 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 time period.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in this publication
Primary coolant (D_2O)	The CANDU/PHWR reactor 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 D_2O 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	Raw water consists of 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’.
Reactor coolant	Reactor coolant is 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 and neutron flux	Treated water above the thermal embrittlement threshold temperature for CASS and neutron flux exceeding a certain limit.
Reactor coolant and neutron flux	Reactor coolant and neutron flux exceeding a certain limit, for example 10^{17} n/cm^2 (E >1 MeV) or other 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 (IGALL AMP103).
Secondary feedwater	Within the context of the recirculating steam generator, components such as the steam generator feedwater impingement plate and supports may 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 (IGALL AMP103).
Sodium pentaborate solution	Treated water that contains a mixture of borax and boric acid.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in this publication
Soil	Soil is 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 (IGALL AMP103). Defining the temperature of the steam is not considered necessary for analysis.
System temperature up to 288°C	This environment consists of a metal temperature of BWR components <288°C.
System temperature up to 340°C	This environment 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 with boric acid in PWR systems 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.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in this publication
Treated water	Treated water is 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 categories. (a) 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. (b) 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
Treated water >60°C	Treated water above the 60°C SCC threshold temperature for stainless steel.
Wastewater	Radioactive, potentially radioactive or non-radioactive waters that are collected from equipment and floor drains. Wastewater may contain contaminants, including oil and boric acid, depending on location, as well as originally treated water that is not monitored by a chemistry programme.
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 this publication
Ageing of composite material (polymer degradation)	Composite material made of both fibre and polymer is subject to chemical evolution. This chemical evolution causes mechanical capacity reduction.
Calibration drift and deviation of set point	Periodic deterioration in the calibration (input to output relation) of a sensor/instrument.
Change in dimensions	Irreversible changes in dimension can result from various phenomena, such as void swelling, creep and, at a macroscopic level, denting.
Changes of material properties	Loss of strength and modulus of elasticity can occur in concrete and cementitious piping, piping components and piping elements due to exposure to aggressive environments such as raw water and external air.
Characteristic change	The input to output relationship of sensors is predictable under specified environmental conditions called characteristics. These characteristics include stability, sensitivity, linearity, precision/repeatability, accuracy, threshold, drift, zero drift, resolution, hysteresis, range/span, input impedance and loading effect. These characteristics may undergo change due to various degradation mechanisms.
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. Alkali aggregate reaction is a reaction between the alkali present in the concrete pore solution and reactive mineral content in aggregates, while internal sulphate reaction is a reaction between sulphates in the pore solution of concrete and other substances present, mainly the cement aluminates.
Corrosion of steel plates of antiseismic bearings	Antivibration seismic 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.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in this publication
Cracking	This term is synonymous with the phrase ‘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	Alkali–aggregate reaction is an irreversible chemical reaction that has two different types: alkali–silica reaction and alkali–carbonate reaction. The more common type is the alkali–silica reaction. Alkali–silicate gels of variable chemical composition are produced, and they may lead to concrete cracking.
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, 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 adverse localized environment with high radiation or exposure to elevated temperature.
Cumulative fatigue damage	Cumulative fatigue damage is due to fatigue, as defined by country specific national codes.
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/or hydroxides can lead to defects of coatings, corrosion of reinforcement steel, liners and concrete, as well as increased porosity and permeability of the reinforced concrete structures.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in this publication
Degradation of electronic components	Due to continuous operation and depending on the operating and environmental conditions in their service life, the various 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.
Denting	Denting in steam generators can result from corrosion of carbon steel tube support plates.
Elastomer degradation	Elastomer materials are substances whose elastic properties are similar to those of natural rubber. The term elastomer is sometimes used to technically distinguish synthetic rubbers and rubber like plastics from natural rubber. Degradation may include mechanisms such as cracking, crazing, fatigue breakdown, abrasion, chemical attacks, change in material properties and weathering.
Fretting or lockup	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. In essence, both fretting and lockup are due to mechanical wear.
Hardening and loss of strength (elastomers)	Hardening (loss of flexibility) and loss of strength (loss of ability to withstand tensile or compressive stress) can result from elastomer degradation in seals and other elastomeric components. Weathered elastomers can also experience shrinkage.
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 freeze–thaw processes. Loss of strength can result from leaching of calcium hydroxide in the concrete.
Increase in rigidity of antivibration seismic bearing supports	Antivibration seismic bearings can be made of different layers of polymer (or rubber) and steel plates. The chemical composition of polymer may evolve with time and hardening can be a consequence of this evolution.
Increased 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 this publication
Increased resistance of connection	Increased resistance of electrical connection is an 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 do 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.
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 may be indicative of support plate damage or ligament cracking.
Loss of coating integrity	Loss of coating integrity is the disbondment of a coating from its substrate. Loss of coating integrity can be due to a variety of ageing mechanisms such as blistering, cracking, flaking, peeling or physical damage. Where the ageing mechanism results in exposure of the base material, unanticipated or accelerated corrosion of the base material can occur. Where the ageing 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 and reduction in heat transfer).
Loss of conductor strength	Transmission conductors can experience loss of conductor strength due to corrosion.
Loss of electrical function	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 fracture toughness	Loss of fracture toughness can result from various degradation mechanisms, including thermal ageing embrittlement and neutron irradiation embrittlement.
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 gasket or seal material.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in this publication
Loss of material	Loss of material may 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 and 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.
Loss of material, loss of form	In earthen water control structures, the loss of material and loss of form can result from erosion, settlement, sedimentation, frost action, waves, currents, surface runoff and seepage.
Loss of mechanical function	Loss of mechanical function in Class 1 piping and components (such as constant and variable load spring hangers, guides, stops, sliding surfaces and 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 less than the design requirements can also contribute to loss of mechanical function.
Loss of mechanical function (electrical components)	Loss of mechanical function in electrical components 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 or lubricant hardening.
Loss of preload	Loss of preload can be 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).
Loss of prestress	Loss of prestress in structural steel anchorage components 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 (caulking, flashing and 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.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in this publication
Movement or shifting	In CANDU/PHWR reactors the annulus spacers (garter springs), which are positioned along the length of the pressure tube to prevent it from contacting 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.
None	Certain material/environment combinations may not be subject to significant degradation mechanisms; thus, there are no relevant ageing effects that require management.
Plate bulging	Plate bulging is evolution in the shape of the containment liner due to temperature change and concrete creep.
Reduced insulation resistance	Reduced insulation resistance is an ageing effect used exclusively for electrical components and results from the following degradation mechanisms: • Thermal/thermoxidative degradation of organics/thermoplastics (which can be accelerated by the presence of salt deposits or surface contamination); • Radiation induced oxidation; • Moisture/debris intrusion; • Ohmic heating; • Radiolysis and photolysis (ultraviolet sensitive materials only) of organics.
Reduction in concrete anchor capacity due to local concrete degradation	Reduction in concrete anchor capacity due to local concrete degradation can result from service induced cracking or other concrete degradation mechanisms.
Reduction in ductility and fracture toughness	Reduction in ductility and fracture toughness can occur in reactor vessel internal stainless steel and nickel alloy items due to neutron fluence.
Reduction in foundation strength, cracking, differential settlement	Reduction in foundation strength, cracking, and differential settlement can result from erosion of porous concrete subfoundation. Differential settlement or soil erosion can lead to a modification of structure load and consequently cause some disorder.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in this publication
Reduction of heat transfer	Reduction of 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 may be affected by the reduction of heat transfer due to fouling. Reduction in heat transfer is also of concern for heat exchanger surfaces.
Reduction of neutron absorbing capacity	Reduction of neutron absorbing capacity can result from degradation of neutron absorbing materials.
Reduction of strength and modulus	In concrete, reduction of strength and modulus can be attributed 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.
Silting up of intake canal	Deposit of sediment near the intake canal may prevent the pumping system from collecting enough cooling water
Tilt mechanism (differential settlement/ heave effect) of structures	The phenomenon of continued elevation or upheave of the foundation material of structures can occur due to swelling of marl (a calcium carbonate or lime rich mud or mudstone that contains 35–65% clays and silt) when in contact with water.
Vibrating wire or pressure or temperature sensor failure or recorder obsolescence in devices installed in concrete structures	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	Wall thinning is 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.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in this publication
Welding defect propagation in stainless steel	The propagation of weld defects such as cracks in stainless steel material can occur when it is subjected to an environment with treated water or treated borated water.
Winding/coil failure	Breaking of winding/coil results in loss of function of the associated instrument or equipment. The degradation mechanisms associated with this ageing effect may be sustained vibratory loading, mechanical loading, ohmic heating, etc.

TABLE 9. DEGRADATION MECHANISMS

Term	Definition as used in this publication
Abrasion	As water migrates over a concrete surface, it may 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 may result in pitting or aggregate exposure due to loss of cement paste.
Aggressive chemical attack	Concrete, being highly alkaline (pH >12.5), is degraded by strong acids. Chlorides and sulphates of potassium, sodium, and magnesium may attack concrete, depending on their concentrations in groundwater/soil that comes into contact with the concrete. Exposed surfaces of Class 1 structures may be subject to sulphur based acid rain degradation. The minimum thresholds causing concrete degradation are 500 ppm chlorides and 1500 ppm sulfphates in the USA or as specified in other Member States.
Borated water intrusion	The influx of borated water.
Boric acid corrosion	Boric acid corrosion can occur where there is borated water leakage in an environment described as air with borated water leakage.
Cavitation damage	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 potentially 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.
Cladding/lining degradation	Degradation of cladding/lining due to the loss of material because of pitting and crevice corrosion of piping, piping components and piping elements fabricated from steel, with elastomer lining or stainless steel cladding.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
Corrosion	Chemical or electrochemical reaction between a metallic material and the environment, or between two dissimilar metallic materials, that produces a deterioration of the materials and their properties.
Corrosion of connector contact surfaces	Corrosion of exposed connector contact surfaces caused by borated water intrusion.
Corrosion of embedded steel	If the pH of concrete in which steel is embedded is reduced below 11.5 by intrusion of aggressive ions (e.g. chlorides in concentrations >500 ppm) in the presence of oxygen, embedded steel may corrode. A reduction in pH may be caused by the leaching of alkaline products through cracks, entry of acidic materials, or carbonation. Chlorides may 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 aggregates, and the moisture content.
Creep	Creep, for a metallic material, refers to 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 may 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/lining degradation.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
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 may 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 (SL-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)	DEF is a chemical sulphate reaction where the source of sulphate ions happens to be internal. Cases of DEF are likely to happen when concrete temperature during setting is more than 65°C. This can occur in thick elements due to the exothermic nature of the reaction cement undergoes during the curing process.
Delayed hydride cracking	Loss of structural integrity due to the formation of brittle hydrides in zirconium alloy pressure tubes (or fuel cladding).
Deterioration of seals, gaskets and moisture barriers (caulking, flashing and other sealants)	Seals, gaskets and moisture barriers (caulking, flashing and other sealants) are 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.
Dry out	Over time electrolytes start to dry out and their capacitance value changes.
Electrical transients	An electrical transient is a stressor caused by a voltage spike that can contribute to ageing degradation. Certain types of high energy electrical transients 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

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
Electrostatic discharge (ESD)	ESD is a sudden flow of electricity between two objects caused by contact, an electrical short or dielectric breakdown. ESD can be caused by a buildup of static electricity by tribocharging, or by electrostatic induction. ESD can cause a range of harmful effects including failure of solid state electronic components such as integrated circuits. These can suffer permanent damage when subjected to ESD.
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: • 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. Reduction in fatigue life in the reactor water environment compared to the fatigue life in ambient air.
Erosion	Erosion is 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.
Erosion settlement	Erosion settlement is the subsidence of a containment structure that may occur due to changes in the site conditions (e.g. erosion or changes in the water table). The amount of settlement depends on the foundation material. A synonymous term is ‘erosion of the porous concrete subfoundation’.
Erosion, settlement, sedimentation, frost action, waves, currents, surface runoff, seepage	In earthen water control structures, the loss of material and loss of form can result from erosion, settlement, sedimentation, frost action, waves, currents, surface runoff and seepage.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
Fatigue	Fatigue is a phenomenon leading to fracture under repeated or fluctuating stresses having a maximum value less than the tensile strength of the material. Fatigue fractures are progressive, and grow under the action of the fluctuating stress. Fatigue due to vibratory and cyclic thermal loads is defined as the structural degradation that can occur from repeated stress/strain cycles caused by fluctuating loads (e.g. from vibratory loads) and temperatures, giving rise to thermal loads. After repeated cyclic loading of sufficient magnitude, microstructural damage may accumulate, leading to macroscopic crack initiation at the most vulnerable regions. Subsequent mechanical or thermal cyclic loading may lead to growth of the initiated crack. Vibration may result in 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 may also result from flow resonance or movement of pumps or valves in fluid systems. Crack initiation and growth resistance is governed by factors including stress range, mean stress, loading frequency, surface condition 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.
Flow accelerated corrosion	Flow accelerated corrosion is 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.
Fouling	Fouling is 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 also can be categorized as particulate fouling from sediment, silt, dust and corrosion products, or 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.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
Freeze–thaw, frost action	Repeated freezing and thawing can cause severe degradation of concrete, characterized by scaling, cracking and spalling. The cause is 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 are (a) adequate air content (i.e. within ranges specified in American Concrete Institute specification 301-84), (b) low permeability, (c) protection until adequate strength has developed, and (d) surface coating applied to frequently wet–dry surfaces.
Fretting	Fretting is 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.
Galvanic corrosion	Galvanic corrosion is accelerated corrosion of a metal because of an electrical contact with a more noble metal or nonmetallic 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.
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 may exist even when pitting and crevice corrosion is not explicitly listed in the ageing effects/degradation mechanism column in the IGALL spreadsheets and when the descriptor may only be loss of material due to general corrosion. For example, AMP134, External Surfaces Monitoring of Mechanical Components, calls for the inspection of general corrosion of steel through visual inspection of external surfaces for evidence of material loss and leakage. This visual inspection acts as a screening for pitting and crevice corrosion, because the symptoms of general corrosion will be noticed first. Wastage is thinning of component walls due to general corrosion.
Gumming of lubricant	Transformation of a lubricant over time, resulting in increase in viscosity.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
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, repair, etc.), leaves the grain boundaries depleted of chromium and, therefore, susceptible to preferential attack (intergranular attack) by a corroding (oxidizing) medium.
Intergranular stress corrosion cracking	SCC in which the cracking occurs along the grain boundaries. It is 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 may initiate as transgranular SCC).
Irradiation assisted stress corrosion cracking (IASCC)	IASCC is 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.
Leaching of calcium hydroxide and carbonation	Water passing through cracks, inadequately prepared construction joints, or areas that are not sufficiently consolidated during placing may 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.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
Material depletion/ changing material properties	Depletion in material mass and/or natural changes in material properties over time. Over long periods of time, changes in material properties may 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 loading	Applied loads of mechanical origins rather than from other sources, such as thermal.
Micro-biologically influenced corrosion	Any of the various forms of corrosion influenced by the presence and activities of such microorganisms as bacteria, fungi and algae, and/or the products produced in their metabolism. Degradation of material that is accelerated due to conditions under a biofilm or microfouling tubercle, for example, anaerobic bacteria that can set up an electrochemical galvanic reaction or inactivate a passive protective film, or acid producing bacteria that might produce corrosive metabolites.
Moisture intrusion	Influx of moisture through any viable process.
Neutron irradiation embrittlement	Irradiation by neutrons results in embrittlement of carbon and low alloy steels, austenitic stainless steel, nickel alloys and zirconium alloys. It may 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	Ohmic heating is induced by current flow through a conductor and 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, for example. Ohmic heating is especially significant for power circuit penetrations.
Outer diameter stress corrosion cracking	Outer diameter SCC is intergranular SCC which occurs on the outer diameter (secondary side) of steam generator tubes.
Overload	Overload is 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.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
Oxidation	Oxidation involves two types of reactions: (a) an increase in valence resulting from a loss of electrons, or (b) a corrosion reaction in which the corroded metal forms an oxide.
Photolysis	Chemical reactions induced or assisted by light.
Pitting	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.
Primary water stress corrosion cracking	Primary water SCC is an intergranular cracking mechanism that requires the presence of high applied and/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	Ionizing radiation can cause temporary or permanent damage to electronics. The damage may be in the form of increase in leakage current, degradation in gain, variation in bias current, variation in offset voltage, etc.
Radiation hardening, temperature, humidity, sustained vibratory loading	Reduction or loss of isolation function in polymeric vibration isolation elements can result from a combination of radiation hardening, temperature, humidity and sustained vibratory loading.
Radiation induced oxidation	Two types of reactions caused by radiation are (a) an increase in valence resulting from a loss of electrons, and (b) 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	Radiolysis is a chemical reaction induced or assisted by radiation. Radiolysis and photolysis degradation mechanisms can occur in ultraviolet sensitive organic materials.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
Reaction with aggregate	The presence of reactive alkalis in concrete can lead to subsequent reactions with aggregates that may be present. These alkalis are introduced mainly by cement, but also may come from admixtures, salt contamination, sea water penetration or solutions of deicing salts. These reactions include alkali–silica reactions, cement–aggregate reactions and aggregate–carbonate reactions. These reactions may lead to expansion and cracking.
Restraint shrinkage	Restraint shrinkage can cause cracking in concrete transverse to the longitudinal construction joint.
Selective leaching	Selective leaching is also known as de-alloying (e.g. dezincification or graphitic corrosion) and 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.
Settlement	Settlement of structures may occur due to changes in the site conditions (e.g. water table, soil settlement and heaving). The amount of settlement depends on the foundation material.
Strain induced corrosion cracking	Corrosion in which the presence of localized dynamic straining is essential for crack formation, but in which cyclic loading is either absent or restricted to a very low number of infrequent events. Strain induced corrosion cracking has been observed in pressurized components made of high strength carbon steel and low alloy steel.
Stress corrosion cracking (SCC)	SCC is cracking that requires the presence of a susceptible metal, a corrosive environment and a sufficiently high tensile stress (applied and/or 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.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
Stress relaxation	Many of the bolts and other fastener components (e.g. keys and springs) in reactor internals are stressed to a cold initial preload. When subject to high operating temperatures, over time these fasteners may loosen and the preload may be lost. Radiation can also cause stress relaxation in highly stressed members.
Surface contamination	Contamination of the surfaces by corrosive constituents or fouling.
Sustained vibratory loading	Vibratory loading over time.
Thermal ageing embrittlement	Also termed ‘thermal ageing’ or ‘thermal embrittlement.’ Thermal ageing of materials is a time and temperature dependent degradation mechanism that decreases material toughness. At operating temperatures of 260–343°C (500–650°F), CASS exhibits a spinoidal decomposition of the ferrite phase into ferrite rich and chromium rich phases. This may 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 mechanical loading	Loads (stress) due to mechanical or thermal (temperature) sources.
Thermal degradation of organic materials	Organic materials, in this case, are polymers. This category includes both short term thermal degradation and long term thermal degradation. Thermal energy absorbed by polymers can result in cross-linking and chain scission. Cross-linking will generally result in such ageing effects 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 may occur include crystallization and chain depolymerization.
Thermal effects, gasket creep and 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).

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in this publication
Thermal fatigue	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 (e.g. transmitter/sensor installed on process piping) components. Loss of instrumentation function results from cyclic stresses due to temperature changes.
Thermoxidative degradation of organics/ thermoplastics	Degradation of organics/thermoplastics via oxidation reactions (loss of electrons by a constituent of a chemical reaction) and thermal means (see 'thermal degradation of organic materials').
Transgranular stress corrosion cracking	SCC in which the cracking is transgranular. It most often occurs in components made of stainless steel as a result of chloride contamination (for example from insulation, ocean aerosols and 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 stress corrosion cracking). 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.
Underclad cracking	Cracking that occurs in base metal (pressure vessel/piping of low alloy steel and carbon steel) that is cladded with stainless steel with high heat input.
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 may accumulate into voids that may, 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/low temperature, which leads subsequently to loss of elasticity of the insulation. Due to the volatilization of plasticizer and the decay products the weight of plastic (insulation) declines and its volume decreases. Thermal ageing of plastic 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 this publication
Water trees	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	Wear is defined as 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	Weathering is the mechanical or chemical degradation of external surfaces of materials when exposed to an outside environment.
Wind induced abrasion	See ‘abrasion’. The fluid carrier of abrading particles is wind rather than water/liquids.

Appendix IV

CIVIL STRUCTURES EXCEPT OF CONTAINMENT

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

— Group 1: BWR reactor building, PWR shield building, control room/building;
— Group 2: BWR reactor building with steel superstructure;
— Group 3: Auxiliary building, diesel generator building, radwaste building, turbine building, switchgear room, yard structures, such as auxiliary feedwater water pump house, utility/piping tunnels, security/lighting poles, manholes, duct banks; station black out structures, such as transmission towers, startup towers circuit breaker foundation, electrical enclosure;
— Group 4: Containment internal structures, excluding refuelling canal;
— Group 5: Fuel storage facility, 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.

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ABBREVIATIONS

AMP	ageing management programme
AMR	ageing management review
BWR	boiling water reactor
CANDU	Canada deuterium–uranium
CASS	cast austenitic stainless steel
CLB	current licensing basis
EPDM	ethylene propylene diene monomer
EPR	ethylene propylene rubber
FSAR	final safety analysis report
HDPE	high density polyethylene
I&C	instrumentation and control
IGALL	International Generic Ageing Lessons Learned
LTO	long term operation
PHWR	pressurized heavy water reactor
PWR	pressurized water reactor
SCC	stress corrosion cracking
SSCs	systems, structures and components
TLAA	time limited ageing analysis
WWER	water cooled, water moderated power reactor

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