Safety Reports Series
No. 82 (Rev. 1)

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

IAEA
International Atomic Energy Agency

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available on the IAEA Internet site

https://www.iaea.org/resources/safety-standards

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at: Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Emergency Preparedness and Response** publications, **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

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

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ESWATINI
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORTH MACEDONIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAINT LUCIA
SAINT VINCENT AND THE GRENADINES
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
TOGO
TRINIDAD AND TOBAGO
TUNISIA
TURKEY
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

SAFETY REPORTS SERIES No. 82 (Rev. 1)

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

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2020

Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
www.iaea.org/publications

Printed by the IAEA in Austria
August 2020
STI/PUB/1895

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Ageing management for nuclear power plants: International Generic Ageing Lessons Learned (IGALL) / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2020. | Series: IAEA safety reports series, ISSN 1020–6450 ; no. 82 (rev. 1) | Includes bibliographical references.
Identifiers: IAEAL 20-01326 | ISBN 978–92–0–107419–5 (paperback : alk. paper) | ISBN 978–92–0–105220–9 (pdf)
Subjects: LCSH: Nuclear power plants — Safety measures. | Nuclear power plants — Maintainability. | Nuclear reactors — Maintenance and repair.
Classification: UDC 621.039.58 | STI/PUB/1895

FOREWORD

As of April 2020, of the total number of nuclear power plants operating in the world, approximately 25% had been in operation for more than 40 years and about 68% for more than 30 years. As a consequence, a number of IAEA Member States are considering long term operation of nuclear power plants beyond the time frame originally anticipated.

This publication is an updated and revised version of Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL), published in 2015. It complements IAEA Safety Standards Series Nos SSR-2/2 (Rev. 1), Safety of Nuclear Power Plants: Commissioning and Operation, and SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants.

This publication provides detailed information on specific programmes to manage existing and potential ageing and degradation of structures, systems and components that will assist operating organizations and regulatory bodies by specifying a technical basis for and practical guidance on managing ageing of mechanical, electrical and instrumentation and control components, and civil structures important to safety. It also serves as a roadmap to available information on ageing management and provides a common, internationally recognized basis on what constitutes an effective ageing management programme in the design of new plants, design reviews and safety reviews. The publication contains a collection of proven ageing management programmes for structures, systems and components important to safety developed and implemented in various types of water moderated reactor, which will be periodically updated.

The IAEA is grateful to all who contributed to the drafting and review of this publication, in particular E. Gallitre (France), R.-M. Zander (Germany), M.A. Calatayud (Spain), J. Heldt (Switzerland) and A. Hiser (United States of America). The IAEA officers responsible for this publication were R. Krivanek, K. Mäkelä and O. Polyakov of the Division of Nuclear Installation Safety.

EDITORIAL NOTE

Although great care has been taken to maintain the accuracy of information contained in this publication, neither the IAEA nor its Member States assume any responsibility for consequences which may arise from its use.

This publication does not address questions of responsibility, legal or otherwise, for acts or omissions on the part of any person.

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

The use of particular designations of countries or territories does not imply any judgement by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the IAEA.

The IAEA has no responsibility for the persistence or accuracy of URLs for external or third party Internet web sites referred to in this book and does not guarantee that any content on such web sites is, or will remain, accurate or appropriate.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

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

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

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

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

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

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

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

This includes maintenance, in-service inspection, testing and surveillance, as well as operations, technical support programmes (including analysis of any ageing effects and degradation mechanisms) and external programme such as research and development (see also IAEA Safety Standards Series Nos NS-G-2.6, Maintenance, Surveillance and In-service Inspection in Nuclear Power Plants [4], and SSG-25, Periodic Safety Review for Nuclear Power Plants [5]).

The IAEA started to develop guidance on the safety aspects of ageing management in the 1990s [6]. In addition to SSG-48 [3], a number of reports have since been published that provide general methodological guidance (see Ref. [7]) and specific guidance (see Refs [8–18]) for selected major nuclear power plant structures and components, such as reactor vessels, reactor internals, piping, steam generators and containment.

More recently, the number of IAEA Member States which give 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 States in dealing with the unique challenges associated with long term operation (LTO), the IAEA conducted the Extrabudgetary Programme on Safety Aspects of Long Term Operation of Water Moderated Reactors from 2003 to 2006; the outcome of which was published in Refs [3, 19], which also focus on ageing management. Although SSG-48 [3] provides recommendations on the methodology, key elements and implementation of effective ageing management programmes (AMPs) for SSCs important to the safety of nuclear power plants, it does not provide comprehensive information on specific degradation mechanisms of SSCs or related AMPs and time limited ageing analysis (TLAA).

In addition to safety related publications, the IAEA has also issued publications on the engineering, technological and scientific aspects of ageing management (see Refs [20–22]). To complement the existing guidance and technical information, a need was identified to establish a process to collectively and systematically document and analyse research results and operating experience. The resulting effort addresses various types of water moderated reactor. The process facilitates the exchange of technical information on ageing management among participating Member States. The results provide guidance on what constitutes an acceptable AMP for specific structures and components, and on ageing effects and degradation mechanisms, as well as tools for assessing existing plant programmes.

The United States Nuclear Regulatory Commission has developed a consistent approach to ageing management in connection with licence renewal for operating plants (see Refs [23–26]). At the request of the IAEA, it provided

Ref. [26] for the 2015 version of this publication. This version of the publication was developed through the IAEA Extrabudgetary Programme on International Generic Ageing Lessons Learned in 2014–2017.

1.2. OBJECTIVE

The objective of this publication is to provide a technical basis and practical guidance based on proven practices 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 IAEA safety standards on design [1], commissioning and operation [2], ageing management and LTO [3] and periodic safety review [5]. With regard to SSCs important to safety, this publication contains:

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

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

1.3. SCOPE

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

In this publication, passive structures and components are defined as those structures and components that perform their intended functions without moving parts or a change in configuration or properties. This includes those that do not display a change in state. Although this publication focuses on the management of physical ageing, the obsolescence of 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 SSG-48 [3].[1] Within this framework, procedures can be put in place to provide for the availability of the following:

— 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 within the framework of a periodic safety review (see safety factors 1–7 of SSG-25 [5]) or as part of ongoing regulatory processes, and are not discussed in this publication. This publication is not intended to facilitate comprehensive identification of structures and components for ageing management. In particular, it does not address the identification of structures and components (scope setting) for LTO and should not be used as a checklist or as a scope setting document, which is described in SSG-48 [3]. The inclusion of a certain SSC, AMP or TLAA does not mean that this particular SSC, AMP or TLAA is within the scope of LTO for all nuclear power plants. Conversely, the absence of an SSC, AMP or TLAA in this publication does not mean that this particular SSC, AMP or TLAA is not included in the scope of LTO for any plant.

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

[1] A description of a generic technological obsolescence programme is provided in the TOP401 Technological Obsolescence Programme (see https://gnssn.iaea.org/NSNI/PoS/IGALL/SitePages/Home.aspx).

are selected definitions and might not include all SSCs and other items as applicable to a given nuclear power plant. Guidance provided here, describing good practices, represents consensus of the expert opinion of the Member States involved in IGALL.

1.4. STRUCTURE

Section 2 summarizes information on AMRs 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 for each of the attributes. Section 4 provides general information on TLAAs and Section 5 defines the terms used.

The appendices are based on input from participating Member States. Appendix I provides a list of proven AMPs, and Appendices II and III lists TLAAs and other plant programmes, respectively. Appendix IV provides definitions of terms for structures and components, materials, environments, ageing effects and degradation mechanisms to facilitate consistent use of terms, and Appendix V provides grouping of civil structures except for containment.

The AMR tables and the information referred to in Appendices I–III are provided in the IGALL database, which comprises more than 2600 line items in the AMR tables, 92 AMPs, 26 TLAAs and 1 technological obsolescence programme as of the end of IGALL Phase 3.[2]

2. AGEING MANAGEMENT REVIEW

Scope setting is an essential prerequisite for AMR. The SSCs subject to AMR are identified on a plant specific basis through a scope setting process as described in SSR-2/2 (Rev. 1) [2] and SSG-48 [3]. Each plant may use an individual approach based on its current licensing basis (CLB) and national regulatory requirements.

The AMR tables were developed on a generic basis using available operating experience and research and development results from participating Member States to identify ageing effects and degradation mechanisms that require ageing management for each combination of structure or component, critical

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

location/part, material and environment. Participating Member States provided information, which was discussed and consolidated by the IGALL programme working groups. Since the AMR tables comprise results provided by Member States, it cannot be guaranteed that each combination of structure/component, critical location/part, material, environment or ageing effect/degradation mechanism has been included for all nuclear power plant designs.

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

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

For structures and components that are identified as being subject to an AMR in general or in the scope of LTO, it is required to demonstrate that the effects of ageing will be adequately managed to ensure that intended safety functions of SSCs are fulfilled over the entire operating lifetime of the plant (see Requirements 14 and 16 of SSR-2/2 (Rev. 1) [2] and 10 CFR 54.21(a)(3) [23]).

The AMR tables identify recommended AMPs and TLAAs for each combination of structure/component, material, environment and ageing effect/degradation mechanism. In this publication, IGALL documents are identified as AMR/AMP/TLAA, and plant specific AMR/AMP/TLAA are titled “plant specific AMR”, “plant specific AMP” and “plant specific TLAA”.

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

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

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

The use of TLAAs in the 'Time limited ageing analysis (TLAA)' column of the AMR tables indicates that one or more specific TLAAs could be used to analyse the identified degradation with respect to projected operational time. It should be emphasized 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 TLAAs for mechanical components, electrical and I&C components, and civil structures is provided in Appendix II. The most up to date versions of TLAAs, which are based on individual input from participating Member States, are provided in the IGALL database.

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

An AMR is implemented on a plant specific basis using established procedures and methods in line with the national regulatory requirements [27]. The AMR tables may be used as an additional basis to supplement plant specific AMRs (for development or review). AMR tables in the IGALL database contain the following information (see Table 1):

— Table number: AMR table number in the IGALL database as described in Table 2.
— IGALL number: The sequential number of the line item (or row) in the AMR table assigned to each area and numbered as described in Table 2. A combination of table number and IGALL number creates a unique ID number for each line item.
— System: The systems to which the structure or component subject to AMR belongs. For electrical and I&C plant equipment, this column only indicates whether the equipment concerned is environmentally qualified or not.

- Structure/component: The structure or component subject to AMR, listed in alphabetical order in Appendix IV (see Table 5).
- Critical location/part: The location or part within a given structure or component that is susceptible to the degradation mechanism.
- Material: The material of construction, listed in alphabetical order in Appendix IV (see Table 6).
- Environment: The environment to which the structure or component is exposed. Internal or external service environments are indicated as applicable, listed in alphabetical order in Appendix IV (see Table 7). Applicable environmental stressors (e.g. temperature, radiation level, concentration of chemicals) are identified in the AMR tables in the IGALL database.
- Ageing effect/degradation mechanism: The applicable ageing effects and degradation mechanisms. Ageing effects and degradation mechanisms are listed in alphabetical order in Appendix IV (see Tables 8 and 9, respectively). The ageing effect/degradation mechanism entries are ‘No ageing effects identified’ for some of the combinations of system, structure/component, critical location/part, material and environment. In these cases, neither prior evaluations of the combinations of system, structure/component, critical location/part, material and environment, operating experience nor research and development results have identified ageing effects requiring management at the time they were created. Plant specific use of these items confirms that these conclusions are valid for the plant.
- Ageing management programme: The AMP used to manage the ageing effects. AMPs are addressed in Section 3 and are listed in Appendix I.
- Time limited ageing analysis (TLAA): The TLAA used to manage ageing effects. TLAAs are addressed in Section 3 and are listed in Appendix II.
- Design: Pressurized water reactor (PWR) (including water cooled water moderated power reactor, WWER), boiling water reactor (BWR), Canada deuterium–uranium (CANDU) reactor/pressurized heavy water reactor (PHWR).

TABLE 1. EXAMPLE OF AGEING MANAGEMENT REVIEW TABLE FOR PRESSURIZED WATER REACTOR (PWR) MECHANICAL COMPONENTS

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

TABLE 1. EXAMPLE OF AGEING MANAGEMENT REVIEW TABLE FOR PRESSURIZED WATER REACTOR (PWR) MECHANICAL COMPONENTS (cont.)

Table No.	IGALL No.	System	Structure/ component	Critical location/ part	Material	Environment	Ageing effect/ degradation mechanism	Ageing Management Programme (AMP)	Time Limited Ageing Analysis (TLAA)	Design
101	284	Reactor pressure vessel, internals, reactor coolant system	Reactor pressure vessel, internals (PWR)	Core barrel outlet nozzle	Stainless steel	Reactor coolant	Cumulative fatigue damage due to fatigue	AMP101 Low Cycle Fatigue Monitoring	TLAA101 Low Cycle Fatigue Usage TLAA106 Environmentally Assisted Fatigue	PWR
104	218	Engineered safety features	Emergency core cooling systems (PWR)	Piping, piping component, piping element, tank	Stainless steel	Air, outdoor	Loss of material due to pitting corrosion, crevice corrosion	AMP134 External Surfaces Monitoring of Mechanical Components	Environmental conditions need to be evaluated	PWR
101	44	Reactor pressure vessel, internals, reactor coolant system	Reactor pressure vessel (PWR)	Nozzle: inlet, outlet, safety injection	Low alloy steel with stainless steel or nickel alloy cladding	Reactor coolant	Loss of fracture toughness due to thermal ageing	A plant specific AMP	TLAA116 Thermal Ageing of Low Alloy Steels	PWR

TABLE 2. NUMBERING OF AMR TABLES

Area	Structures and components	Table No.
Mechanical	PWR class 1	101
	BWR class 1	102
	CANDU/PHWR class 1	103
	PWR non-class 1	104
	BWR non-class 1	105
	CANDU/PHWR non-class 1	106
	Generic cross-cutting[a]	107
	Generic non-class 1[b]	108
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 containment[c]	302, 303
	Anchors and supports for equipment, piping and components	304

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

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

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

Each plant performs a plant specific AMR. Figure 1 provides a flow chart for using IGALL and other IAEA guidance for AMR and review of plant specific AMPs. An example of implementation of the plant specific AMR process, input information and specific guidance is given in Fig. 1. The plant can use AMR:

(a) To identify potential ageing effects: The approach is to review in-scope SSCs and to identify potential ageing effects and degradation mechanisms. These can be compared with the AMR table to identify any missing ageing effects and degradation mechanisms applicable to the SSCs.
(b) To close gaps between a plant's existing programmes and IGALL: AMR tables can be used to determine whether new AMPs or TLAAs need to be developed. AMPs and TLAAs can be used if existing programmes need to be modified.

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

TABLE 3. NOTE COLUMN DESIGNATION

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

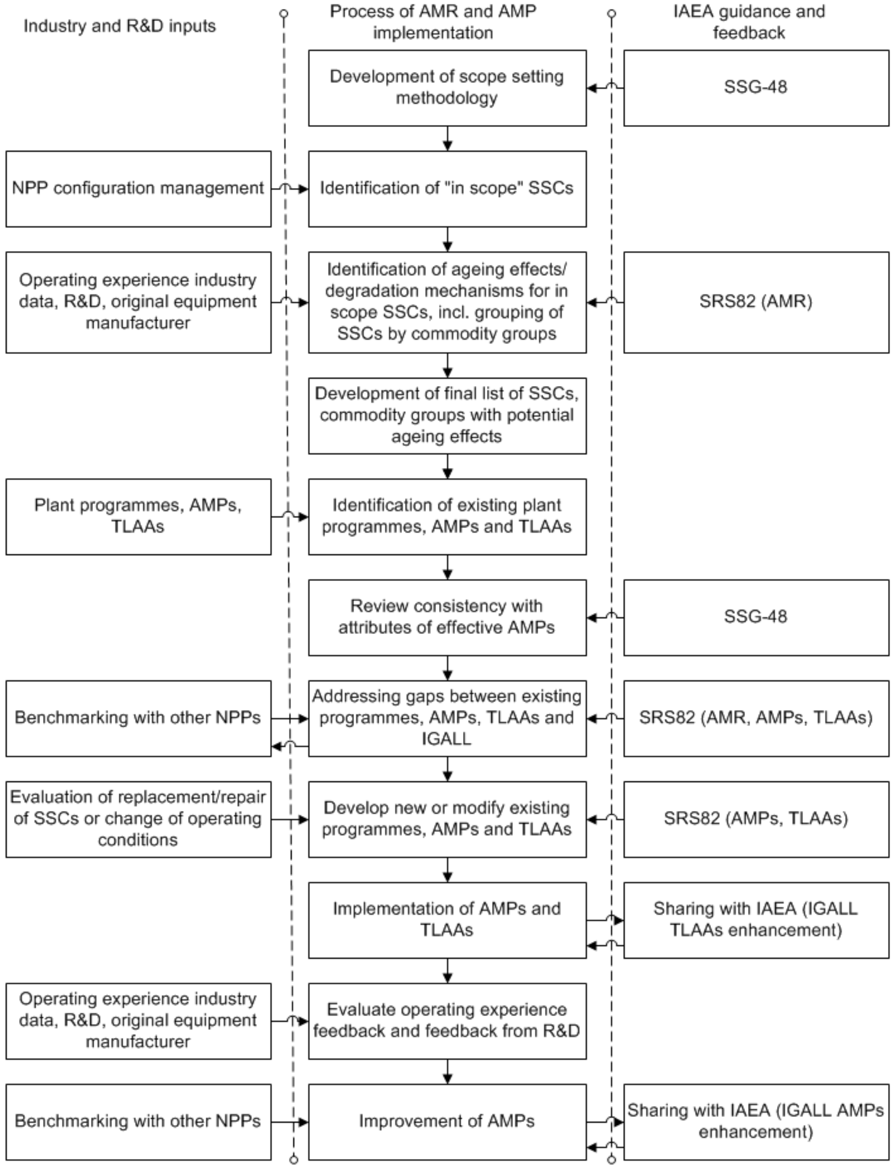

FIG. 1. Implementation of the plant specific AMR process, input information and specific guidance.

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

3. AGEING MANAGEMENT PROGRAMMES

An AMP is a set of plant activities relating to the 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 technical support programmes. Paragraph 5.54 of SSG-48 [3] states:

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

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

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

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

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

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

The approach used to establish ageing management priorities — specifically the balancing and integration of AMPs and maintenance, in-service inspection, testing and surveillance — depends on the regulatory requirements in each Member State and also on operators' targets for plant load factors and outage duration. In some Member States, the focus of ageing management for LTO is on passive structures and components only, since the reliability of active structures and components is addressed by current requirements in the maintenance regulations (see Ref. [28] for United States of America), which provide a performance based approach to ensure component reliability and include maintenance, testing and surveillance. In other Member States, ageing management deals with both active and passive structures and components.

Although this publication is concerned with the development and implementation of AMPs and does not provide specific guidance for maintenance, in-service inspection, testing and surveillance, 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 plant specific AMPs, like all other plant programmes and processes, be documented and prioritized in the quality management system and that they are included in the safety analysis report of the plant [29]. The list of AMPs for mechanical components, electrical and I&C components, and civil structures is provided in Appendix I. The collection of full AMPs, which are based on input from participating Member States, is provided in the IGALL database. The AMPs are structured according to the nine generic attributes of an effective AMP, against which each plant specific AMP is evaluated (see table 2 of SSG-48 [3]):

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

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

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

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

3.2. PREVENTIVE ACTIONS TO MINIMIZE AND CONTROL AGEING EFFECTS

This attribute includes:

(a) Specification of preventive actions. These activities are defined as those that are necessary to prevent or minimize the initiation of degradation:
    (i) The actions for prevention programmes are described in the way that they contribute to preventing ageing degradation;

(ii) Condition or performance monitoring programmes that do not rely on preventive actions need not be provided;
(iii) Condition or performance monitoring programmes that rely on preventive actions are specified (e.g. maintenance of water chemistry or use of appropriate lubrication).

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

3.3. DETECTION OF AGEING EFFECTS

This attribute includes:

(a) Specification of parameters to be monitored or inspected:
(i) This programme element identifies the ageing effects that the programme manages and provides a link between the parameters to be monitored and how the monitoring will ensure adequate ageing management.
(ii) In an effective condition monitoring programme, the parameter monitored or inspected will be capable of detecting the presence and extent of ageing effects, for example measurements of wall thickness and detection and sizing of cracks.
(iii) In an effective performance monitoring programme, a link will be established between the degradation of the intended function or functions of the particular structure or component and the parameters being monitored. An example of linking the degradation of the intended function of a passive component with the performance being monitored is linking the fouling of heat exchanger tubes with the heat transfer function. This could be monitored by periodic heat balances. Since this example deals only with one intended function of the tubes (heat transfer), additional programmes may be necessary to manage other intended functions of the tubes (i.e. pressure boundary). Thus, an effective performance monitoring programme ensures that the structures and components can perform their intended functions by using a combination of performance monitoring and evaluation (if outside acceptable limits are specified in the acceptance criteria) that

demonstrate that a change in performance characteristics is a result of an age related degradation mechanism.

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

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

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

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

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

(iv) In an effective performance monitoring programme, the detection of 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.

(v) 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.

3.4. MONITORING AND TRENDING OF AGEING EFFECTS

This attribute includes:

(a) 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 industry wide operating experience may be considered in evaluating the appropriateness of the technique and frequency.

(b) Description when, where, and how programme data are collected (i.e. all aspects of activities to collect data as part of the programme).

(c) Data to be collected to facilitate the assessment of structure or component ageing.

(d) Assessment methods (including data analysis and trending). A description of how the collected data are evaluated is provided and may also include trending (i.e. a comparison of the current monitoring results with previous monitoring results to make predictions for the future). The description includes an evaluation of the results against the acceptance criteria, and a prediction with regard to the rate of degradation, to confirm that the next scheduled inspection will occur before a loss of the intended function of the structure or component. Although ageing indicators may be quantitative or qualitative, ageing indicators are quantified, to the extent possible, to allow trending. The parameter or indicator trended is described. The methodology for analysing the inspection or test results against the acceptance criteria is described.

3.5. MITIGATION OF AGEING EFFECTS

This attribute includes:

(a) Actions that mitigate further degradation when degradation has been observed but the condition of the structure or component is still within the limits of the acceptance criteria.
(b) Operation, maintenance, repair and replacement actions to mitigate detected ageing effects and/or degradation of the structure or component. The activities for programmes are described which mitigate ageing degradation. An example is the coolant dissolved oxygen level that is being controlled in a water chemistry programme to mitigate pipe corrosion.

3.6. ACCEPTANCE CRITERIA

This attribute includes:

(a) Acceptance criteria against which the need for corrective action is evaluated:
    (i) The quantitative or qualitative acceptance criteria of the programme, and their bases, are described. The acceptance criteria against which the need for corrective actions is evaluated ensure that the intended function or functions of the structure or component are consistently maintained under all CLB 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 as a result of flow accelerated corrosion.

An effective AMP for flow accelerated corrosion may consist of periodically measuring the pipe wall thickness and comparing that with a specific minimum wall thickness acceptance criterion. Corrective action, such as piping replacement, is taken before the acceptance criterion is exceeded, and this acceptance criterion is appropriate to ensure that the thinned piping would be able to carry CLB design loads (i.e. deadweight, seismic and other loads). This acceptance criterion provides for timely corrective action before the loss of intended function under these CLB design loads.

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

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

3.7. CORRECTIVE ACTIONS

This attribute includes:

(a) Corrective actions if a structure or component fails to meet the acceptance criteria:

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

(ii) If corrective actions permit analysis without repair or replacement, the analysis ensures that the intended function or functions of the structure or component are maintained consistent with the CLB.
(iii) Corrective actions are prioritized and scheduled as a part of the plant's AMPs according to their safety importance.
(iv) For safety related components, a plant quality assurance programme confirms that the corrective actions are performed in accordance with applicable code requirements or regulatory body approved standards. In the United States of America, for example, for a plant specific condition monitoring programme that is based on American Society of Mechanical Engineers Section XI requirements, the implementation of appendix B to 10 CFR Part 50 [28] ensures that the corrective actions are performed in accordance with applicable code requirements or regulatory body approved code cases.

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

This attribute includes:

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

because the feedback from operating experience should have resulted in appropriate programme enhancements or new programmes, if needed. This information can show where an existing programme has succeeded and where (or if) it has failed in intercepting ageing degradation in a timely manner. This information should provide objective evidence to support the conclusion that the effects of ageing will be managed adequately so that the intended function or functions of the structure or component will be maintained during the period of extended operation.

(iii) For new plant specific AMPs that have yet to be implemented and have therefore not generated any operating experience, other relevant plant specific operating experience or generic operating experience in the industry that is relevant to the AMP's elements should be considered. Thus, to ensure the effectiveness of a new plant programme, the plant operator considers the impact of relevant operating experience that results from the past implementation of its existing plant specific AMPs, and the impact of relevant generic operating experience, when developing the programme elements. Therefore, operating experience applicable to new programmes will be discussed.

(iv) Significant international and domestic research and development activities relevant to the plant specific AMP are identified. Findings from these activities are evaluated to determine the need either to revise the existing plant specific AMPs or to develop new plant specific AMPs, as appropriate.

3.9. QUALITY MANAGEMENT

This attribute includes:

(a) Administrative controls that document the implementation of the plant specific AMP and actions taken:

(i) The administrative controls of the programme include comprehensive actions and procedures to guarantee fulfilment of the safety and performance goals of the plant operator.

(ii) Administrative controls provide a formal review and approval process. In the United States of America, for example, any AMPs to be relied on for licence renewal should have regulatory and administrative controls. It is the basic requirement of 10 CFR 54.21(d) [23] that the final safety analysis report 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 supplement of the safety analysis report.

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

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

(d) Record keeping practices to be followed.

4. TIME LIMITED AGEING ANALYSES

The 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 criteria as defined in para. 5.64 of SSG-48 [3]. This publication includes, among the list of TLAAs, other safety analyses that do not meet the criterion they be contained or incorporated by reference in the CLB 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 para. 7.28 of SSG-48 [3], “Time limited ageing analyses should be reviewed to determine the continued acceptability of the analysed structure or component for the planned period of long term operation”. Paragraph 7.18 of SSG-48 [3] states that the programme for LTO should include a:

> “(d) Demonstration that the time limited ageing analyses have been revalidated and that the evaluation includes: ...Revalidation of

> each identified time limited ageing analysis in accordance with the recommendations provided in para. 7.28 to demonstrate that the intended function(s) of the structure or component will be maintained throughout the planned period of long term operation in a manner that is consistent with the current licensing basis."

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

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

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

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

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

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

The plant's safety analysis report can be supplemented to include a summary description of the plant specific TLAAs concerned and their evaluation for the LTO period. Generic TLAAs typically include the following [25]:

— 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 include the following [25]:

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

Analyses that are not regarded as TLAAs include population projections and cost–benefit analyses for plant modifications. A sample process for identifying potential plant specific TLAAs and a basis for disposition are provided in Table 4 [24].

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.

In some cases, plant technical specifications have operational restrictions, but the plant designer has not provided to the plant operator a full design basis

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

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

including a safety analysis, which is a basis for the restriction. For such cases, TLAA118 is one approach through which the plant operator could develop a new safety analysis to evaluate the operational restriction. Because these cases are plant specific and could involve several different components, there are no specific AMR line items that identify TLAA118. This situation is unique within the AMPs and TLAAs. Lists of TLAAs for mechanical components, electrical and I&C components, and civil structures are provided in Appendix II.

5. DEFINITIONS

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

Table 5 defines structures and components used in the nuclear industry. It is important to compare carefully the structures and components used in different reactor types and the structures and components used in the tables before reaching any conclusion. Treatment of external or internal surfaces should consider that surface conditions of SSCs are monitored through visual examinations and leakage inspections to determine the existence of external and internal corrosion or deterioration. For some environments, such as ‘air, indoor controlled’, ‘air, indoor uncontrolled’, ‘air, outdoor’, ‘condensation’ or ‘air, indoor uncontrolled >35°C’, the component description 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 has to 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 with the materials in the table before reaching any conclusions.

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

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

Appendix I

LIST OF 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 AMPs can be found in the IGALL database.

I.1. AGEING MANAGEMENT PROGRAMMES FOR MECHANICAL COMPONENTS

AMP101	Low Cycle Fatigue Monitoring
AMP102	In-service Inspection/Periodic Inspection
AMP103	Water Chemistry
AMP104	Reactor Head Closure Stud Bolting
AMP105	BWR Vessel ID Attachment Welds
AMP106	BWR Feedwater Nozzle
AMP107	BWR Stress Corrosion Cracking in Coolant Pressure Boundary Components
AMP108	BWR Penetrations
AMP109	BWR 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 and Erosion
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 (Relating to Refuelling) Handling Systems
AMP128	Compressed Air Monitoring
AMP129	BWR Reactor Water Cleanup System
AMP130	Fire Protection
AMP131	Fire Water System
AMP132	Above Ground Metallic Tanks
AMP133	Fuel Oil Chemistry
AMP134	External Surfaces Monitoring of Mechanical Components
AMP135	Inspection of Internal Surfaces in Miscellaneous Piping and Ducting Components
AMP136	Lubricating Oil Analysis
AMP137	Monitoring of Neutron Absorbing Materials other than Boraflex
AMP138	Reactor Coolant Pump
AMP139	CANDU/PHWR Fuel Coolant Channels
AMP140	CANDU/PHWR Feeder Piping
AMP141	CANDU/PHWR Reactor Assembly
AMP142	CANDU/PHWR Fuel Handling
AMP143	Safety Related Valves
AMP144	Safety Related Pumps
AMP145	CANDU/PHWR Moderator and Moderator Purification Heat Exchangers
AMP146	CANDU/PHWR Inspection Programmes
AMP147	Containment Bellows
AMP148	CANDU/PHWR Reactor Shutdown Systems
AMP149	CANDU/PHWR Heavy Water Management
AMP150	CANDU/PHWR Annulus Gas System
AMP151	CANDU/PHWR Primary Heat Transport Instrument Tubing
AMP152	WWER Reactor Vessel Surveillance
AMP153	WWER Main Gate Valves
AMP154	PWR Pressurizer
AMP155	PWR Residual Heat Removal Heat Exchangers
AMP156	PWR Main Coolant Piping
AMP157	Internal Coatings and Linings
AMP158	(Reserved for future use)
AMP159	(Reserved for future use)
AMP160	Neutron Fluence Monitoring
AMP161	High Cycle Fatigue Monitoring

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

AMP201	Electrical Insulation for Electrical Cables and Connections Not Subject to Environmental Qualification Requirements
AMP202	Electrical Insulation for Electrical Cables and Connections Not Subject to Environmental Qualification Requirements Used in Instrumentation Circuits
AMP203	Electrical Insulation for Inaccessible Instrumentation and Control and Low and Medium Voltage Power Cables Not Subject to Environmental Qualification Requirements
AMP204	Metal Enclosed Bus Not Subject to Environmental Qualification Requirements
AMP205	Fuse Holders Not Subject to Environmental Qualification Requirements
AMP206	Electrical Cable Connections Not Subject to Environmental Qualification Requirements
AMP207	Environmental Qualification of Electrical and I&C Equipment
AMP208	High Voltage Insulators and Transmission Conductors
AMP209	Reassessment Qualification of Electrical and I&C Equipment Relevant to an Environmental Qualification
AMP210	Condition Monitoring of Electrical and I&C Cables Subject to Environmental Qualification Requirements
AMP211	Power Transformers Not Subject to Environmental Qualification Requirements
AMP212	Electrical Enclosures Not Subject to Environmental Qualification Requirements
AMP213	Whiskers and Capacitors with Liquid Electrolyte
AMP214	Electrical Insulation of Motors, Motor Operated Valves Actuators and Generators Not Subject to Environmental Qualification Requirements
AMP215	Switchgears, Breakers, Distribution Panels, Contactors, Protection Relays and Relays Not Subject to Environmental Qualification Requirements
AMP216	Lead Batteries Not Subject to Environmental Qualification Requirements
AMP217	Sensors and Transmitters Not Subject to Environmental Qualification Requirements

AMP218	Electronic Equipment Not Subject to Environmental Qualification Requirements
AMP219	Fuses Not Subject to Environmental Qualification Requirements
AMP220	Lightning Protection and Grounding Grid Not Subject to Environmental Qualification Requirements

I.3. AGEING MANAGEMENT PROGRAMMES FOR CIVIL STRUCTURES

AMP301	In-service Inspection for Containment Steel Elements
AMP302	In-service Inspection for Concrete Containment
AMP303	Safety Class 1, 2 and 3 Piping and Metal Containment Components Supports
AMP304	Containment Leak Rate Test
AMP305	Masonry Walls
AMP306	Structures Monitoring
AMP307	Water Control Structures
AMP308	Protective Coating Monitoring and Maintenance Programme
AMP309	Non-metallic Liner
AMP310	Ground Movement Surveillance
AMP311	Containment Monitoring System
AMP312	Concrete Expansion Detection and Monitoring System
AMP313	Containment Prestressing System

Appendix II

LIST OF 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 TLAAs are provided in the IGALL database.

II.1. TIME LIMITED AGEING ANALYSES FOR MECHANICAL COMPONENTS

TLAA101	Low Cycle Fatigue Usage
TLAA102	RPV Neutron Embrittlement
TLAA103	Crack Growth Analyses for Flaws Detected in Service
TLAA104	Corrosion Allowances
TLAA105	CANDU/PHWR Fuel Channel Creep
TLAA106	Environmentally Assisted Fatigue
TLAA107	High Cycle Fatigue for Steam Generator Tubes
TLAA108	Fatigue of Cranes
TLAA109	PWR RPV Internals Swelling
TLAA110	Thermal Ageing of Cast Austenitic Stainless Steels
TLAA111	CANDU/PHWR Hydrogen Embrittlement and Delayed Hydride Cracking in Pressure Tubes
TLAA112	Main Circulation Pump Flywheel
TLAA113	(Reserved for future use)
TLAA114	(Reserved for future use)
TLAA115	Fatigue and Thermal Ageing Analysis of Manufacturing Flaws and Flow Tolerance
TLAA116	Thermal Ageing of Low Alloy Steels
TLAA117	Underclad Cracking
TLAA118	Components with Operational Restrictions that Have No Documented Safety Analysis
TLAA119	High Cycle Thermal Fatigue
TLAA120	PWR RPV Internals Vibrations
TLAA121	IASCC Fluence Limit for Stainless Steel
TLAA122	Thermal Ageing of Martensitic Stainless Steels
TLAA123	CANDU/PHWR Calandria Internals Vibrations

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

TLAA201	Environmental Qualification of Electrical and I&C Components

II.3. TIME LIMITED AGEING ANALYSES FOR CIVIL STRUCTURES

TLAA301	Concrete Containment Tendon Prestress
TLAA302	Effects of Creep and Shrinkage on Performance of Concrete Structures
TLAA303	Cumulative Fatigue Damage of Containment Liners and Penetrations
TLAA304	Foundation Settlement due to Soil Movement

Appendix III

LIST OF OTHER PLANT PROGRAMMES

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

TOP401	Technological Obsolescence Programme

Appendix IV

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

Many of the definitions are based on Ref. [26].

TABLE 5. STRUCTURES AND COMPONENTS

Term	Definition as used in AMR tables
Anchorages	Used to join components to the structure.
Antiseismic devices	Bearings that are able to isolate a component or a building from vibration due to earthquakes.
Bolting	Structural bolting, closure bolting or all other bolting. Bolted closures are necessary for the pressure boundary of the components being joined or closed. Closure bolting in high pressure or high temperature systems is defined as that in which the pressure exceeds a certain level, for example 2 MPa (1.896 MPa in USA), or in which the temperature exceeds a certain level, for example 100°C (93°C in USA). Closure bolting is used to join pressure boundaries or where a mechanical seal is required.
Chimney made of fibre reinforced polymer	Comprises composite material in which both polymer and fibres are included.
Concrete submitted to high temperature during setting	Concrete elements for which high temperature can occur during setting: the temperature limit is usually 65°C.
Containment	Structures and associated components that perform a confinement function, namely preventing or controlling the release of radioactive substances and their dispersion in the environment. The containment refers, depending on the design, to the concrete or steel structure and associated metallic parts, such as liners and penetrations, which separate the confinement atmosphere from the outside environment.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in AMR tables
Electrical enclosures	Passive mechanical supporting components of active electrical and I&C equipment that are mounted onto or inside electrical enclosures. An enclosure is a surrounding case or housing used to protect the contained conductors and prevent personnel from accidently making contact with live parts.
Electrical penetration	The leaktight passage device by which the cables go through the containment wall.
Encapsulation components/valve chambers	Airtight enclosures that function as a secondary containment boundary to completely enclose containment sump lines and isolation valves. Encapsulation components and features (in systems such as the emergency core cooling system, containment spray system, containment isolation system and refuelling water storage tank) can include encapsulation vessels, piping and valves.
End fittings	The out-of-core extensions of pressure tubes. The end fittings provide a flow path for the primary coolant between the pressure tube and the rest of the CANDU primary heat transport system by having a bolted connection to carbon steel inlet feeders and outlet feeders.
External surfaces	The external surfaces of structures and components, such as tanks, that are not specifically listed elsewhere.
Feeders	In CANDU/PHWR systems, 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 the inlet/outlet headers of the primary heat transport system.
Fuel coolant channels	In CANDU or PHWR systems, a horizontal array of zirconium tubing containing the reactor fuel and primary heat transport coolant through the calandria vessel. The fuel coolant channel consists of the pressure tube, annulus spacers, end fittings and their associated hardware.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in AMR tables
Fuelling machine	The CANDU system employs a unique, on-power refuelling system. Two identical fuelling machines rise from a fuelling duct under the reactor and latch onto opposite ends of a designated fuel channel. Each machine is operated remotely from the control room. With both machines latched on and brought up to system pressure, the ends of the fuel channel are opened and new fuel is exchanged for used fuel — one machine discharges new fuel and the other accepts used fuel.
Heat exchanger components	A device that transfers heat from one fluid to another without the fluids coming into contact with each other. This includes air handling units and other devices that cool or heat fluids. Heat exchanger components include air handling unit cooling and heating coils, piping, shell, tube sheets, tubes, valves and bolting. Although tubes are the primary heat transfer components, heat exchanger internals, including tube sheets and fins, contribute to heat transfer and may be affected by the reduction of heat transfer due to fouling.
High voltage insulators	An insulator is an insulating material in a configuration designed to physically support a conductor and separate the conductor electrically from other conductors or objects. High voltage insulators are those insulators used to support and insulate high voltage electrical components in switchyards, switching stations and transmission lines.
HVAC duct	Heating, ventilation and air-conditioning (HVAC) duct and its components. Examples include ductwork, ductwork fittings, access doors, closure bolts, equipment frames and housing, housing supports (including housings for valves), dampers (including louvres and gravity dampers), mesh, filters and fire dampers, and ventilation fans (including exhaust fans, intake fans, purge fans). In some cases, this also includes HVAC closure bolts or HVAC piping.
Masonry walls	Construction parts made of concrete blocks or bricks. The masonry wall can be reinforced by rebars. Stability can be required to prevent interaction with SSCs, for fire area separation or for other safety reasons.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in AMR tables
Metal enclosed bus	Term used in electrical and industry standards (Institute of Electrical and Electronics Engineers and American National Standards Institute) for electrical buses installed on electrically insulated supports, constructed with all phase conductors enclosed in a metal enclosure.
Piping elements (glass)	Components made of glass, such as sight glasses and level indicators. The ‘piping elements’ designation is used in the AMR tables only when the material is defined as glass.
Piping, piping components, piping elements	A category that includes features of the piping system within the scope of the AMR; specific features included in this category may vary in different countries. Examples include piping, fittings, tubing, flow elements and indicators, demineralizers, nozzles, orifices, flex hoses, pump casings and bowls, safe ends, spray heads, strainers, thermowells, and valve bodies and bonnets. For reactor coolant pressure boundary components that are subject to cumulative fatigue damage, this category also can include flanges, nozzles and safe ends, penetrations, instrument connections, vessel heads, shells, welds, weld inlays and weld overlays, stub tubes, and miscellaneous Class 1 components (e.g. pressure housings). Buried piping is in direct contact with soil or concrete (e.g. a wall penetration). Underground piping is below grade but is contained within a tunnel or vault such that it is in contact with air and located where access for inspection is restricted.
Prestressed cables and rods of retaining wall	Designed to support the retaining wall and to limit its deformation.
Pressure housings	Refers only to pressure housing for the control rod drive mechanisms (for PWR reactor vessels).
Pressure tubes and calandria tubes	Pressure tubes, which contain the high pressure, high temperature coolant, form part of the fuel channel assembly and are isolated from the cold, low pressure moderator by the carbon dioxide filled annulus spacer between the pressure tubes and calandria tubes of the CANDU/PHWR.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in AMR tables
Primary heat transport system	The reactor coolant pressure boundary of the CANDU/PHWR. Primary heat transport system boundary components include the fuel coolant channels, steam generators, primary heat transport system pumps, inlet headers, outlet headers, feeders and interconnecting piping.
Reactor assembly (CANDU/PHWR)	Components include calandria vessel, end shield, shield tank (or water filled, steel lined calandria vault), guide tubes and the fuel coolant channels: — 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. — 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. — 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 waterfilled calandria vault is lined with carbon steel to provide a leaktight seal for containment of the shield cooling system demineralized light water. — 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	Components include reactor pressure vessel, piping, piping components, piping elements, flanges, nozzles and safe ends, pressurizer vessel, heater sheaths and sleeves, penetrations and thermal sleeves.
Seals, gaskets, and moisture barriers (caulking, flashing and other sealants)	Elastomer components used as sealants or as gaskets, including metal reinforced sealing materials.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in AMR tables
Spillway	A structure located inside the river dedicated to maintaining a minimum water level so that the pumping system is fed with sufficient water under all circumstances.
Steel and stainless steel elements (liner, liner anchors, integral attachments)	Steel and stainless steel liners used in the suppression pool, spent fuel pool, reactor pool and fuel transfer channel.
Switchyard bus	The uninsulated, unenclosed, rigid electrical conductor or pipe used in switchyards and switching stations to connect two or more elements of an electrical power circuit, such as active disconnect switches and passive transmission conductors.
Tanks	Large reservoirs used as hold-up volumes for liquids or gases. Tanks may have an internal liquid or vapour space and may be partially buried or in close proximity to soils or concrete. Tanks are treated separately from piping due to their potential need for different AMPs. One example is AMP132 Above Ground Metallic Tanks, for tanks partially buried or in contact with soil or concrete that experience general corrosion as the ageing effect at the soil–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	Uninsulated, stranded electrical cables used in switchyards, switching stations and transmission lines to connect two or more elements of an electrical power circuit, such as active disconnect switches, power circuit breakers, transformers and passive switchyard buses.
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 to support components prone to vibration.

TABLE 5. STRUCTURES AND COMPONENTS (cont.)

Term	Definition as used in AMR tables
Water control structures	Integral parts of the systems that provide plant cooling water and residual heat removal.

TABLE 6. MATERIALS

Term	Definition as used in AMR tables
ACSR	Aluminium conductor steel reinforced transmission conductor.
Boraflex	Composed of 46% silica, 4% polydimethyl siloxane polymer and 50% boron carbide. It is a neutron absorbing material used as a neutron absorber in spent fuel storage racks. Degradation of Boraflex panels under gamma radiation can lead to loss of the ability to absorb neutrons in spent fuel storage pools (e.g. AMP126 Boraflex Monitoring).
Boral	Comprises aluminium–boron carbide sandwiched between aluminium. Boral refers to patented aluminium–boron master alloys, which can contain up to 10% boron as aluminium–boron carbide composite.
Boron steel	Steel with ^{10}B content ranging from one to several per cent. Boron steel absorbs neutrons and hence often used to make control rods to help to control neutron flux.
Cast austenitic stainless steel (CASS)	A family of steels, including CF-3, CF-8, CF-3M and CF-8M, that have been widely used in water moderated reactors. These CASS alloys are similar to wrought grade Types 304L, 304, 316L and 316, except that CASS typically contains 5–25% ferrite. CASS is susceptible to loss of fracture toughness due to thermal and neutron irradiation embrittlement.
Coatings	Paint or other material applied to structures and components to protect the external surfaces from the environment.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in AMR tables
Concrete and cementitious material	When used generally, a category of concrete applies to concrete in many different configurations (e.g. block, cylindrical) 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. 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	Used for electrical contacts and usually made of materials with good contact resistance (e.g. gold, silver).
Copper alloy (>15% Zn or >8% Al)	Critical alloying elements are above certain thresholds that make it susceptible to ageing effects. Copper–zinc alloys >15% zinc are susceptible to 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 (brass), tin (bronze), nickel, silicon, aluminium (aluminium bronze), cadmium and beryllium. Additional copper alloys may be susceptible to ageing effects above the threshold for the critical alloying element.
Ductile iron	An iron alloy, similar to grey cast iron, made by adding larger amounts of carbon to molten iron than would be used to make steel. Most steels have less than 1.2% carbon, while cast irons typically have 2.5–4%. Ductile iron contains spherical graphite nodules, as opposed to graphite flakes for grey cast iron, resulting in increased strength and ductility compared with grey cast iron. Ductile iron is susceptible to selective leaching, resulting in a loss of iron from the microstructure, leaving a porous matrix of graphite. In some environments, ductile iron is categorized with steel.
Elastomers	Natural or synthetic polymers that have elastic properties, such as rubber, EPT, EPDM, viton, vitril, neoprene, PVC, LDPE, HDPE and silicone elastomer.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in AMR tables
Electrolyte	A substance that ionizes in solution. Electrolytes conduct electricity: in batteries, they are instrumental in producing electricity by chemical action; in capacitors, paper saturated with electrolyte is used to separate aluminium foil strips.
Electronic components	Basic electronic elements, usually packaged in a discrete form with two or more connecting leads or metallic pads. Components are connected together, usually by soldering to a printed circuit board, to create an electronic circuit with a particular function.
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 the component or structure.
Galvanized steel	Steel coated with zinc, usually by immersion or electrodeposition. The zinc coating protects the underlying steel because the corrosion rate of the zinc coating in dry, clean air is very low and the zinc acts as a sacrificial anode to the steel. In the presence of moisture, galvanized steel is classified under the category ‘steel’.
Glass	A hard, amorphous, brittle, super cooled liquid made by fusing together one or more of the oxides of silicon, boron or phosphorous with certain basic oxides (e.g. calcium, magnesium, potassium, sodium) and cooling the product rapidly to prevent crystallization or devitrification.
Graphitic tool steel	Steels (such as AISI O6, which is oil hardened, and AISI A10, which is air hardened) with excellent non-seizing properties. The graphite particles provide self-lubricity and hold applied lubricants.
Grease	A semisolid lubricant of a soap emulsified with mineral or vegetable oil. The characteristic feature of grease is that it possesses a high initial viscosity, which upon the application of shear, drops to give the effect of an oil lubricated bearing of approximately the same viscosity as the base oil used in the grease. Grease hardening due to, for example, elevated temperature may lead to loss of function.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in AMR tables
Grey cast iron	An iron alloy used in nuclear plants. Cast iron is made by adding larger amounts of carbon to molten iron than would be used to make steel. Most steels have less than 1.2% carbon, while cast irons typically have 2.5–4%. Grey cast iron has flat graphite flakes, which reduce its strength and act as crack formers, potentially initiating mechanical failures. They also cause the metal to behave in a nearly brittle fashion, rather than experiencing the elastic, ductile behaviour of steel. Fractures in this type of metal tend to take place along the flakes, which give the fracture surface a grey colour, hence the name of the metal. Grey cast iron is susceptible to selective leaching, resulting in a significant reduction of the material's strength due to the loss of iron from the microstructure, leaving a porous matrix of graphite.
High density polyethylene	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 (aluminium oxide, magnesium oxide) could exhibit reduced insulation resistance due to moisture intrusion or elevated temperature.
Low alloy steel, actual measured yield strength ≥1034 MPa	High strength iron–chromium–nickel–molybdenum low alloy steel bolting materials with maximum tensile strength <1172 MPa may be subject to SCC if the actual measured yield strength ≥1034 MPa. Examples of high strength alloy steel designations in this category include SA540-Gr. B23/24, SA193-Gr. B8 and Grade L43 (AISI 4340). 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 ≥1034 MPa) low alloy steel SA193-Gr. B7 is susceptible to SCC.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in AMR tables
Lubrite	A patented, self-lubricating bearing technology in which the bearing substrate (bronze is commonly used, but in unusual environments other materials ranging from stainless steel and nodular iron to tool steel are used) is fastened to lubricant. Lubrite is often defined as bronze attached to ASTM B22, alloy 905, with G10 lubricant. Even though Lubrite bearings are characterized as maintenance free, because of the differences in installation, fineness of the surfaces and lubricant characteristics, they can be subjected to mechanical wear and fretting. Though experience has not shown adverse conditions relating to the use of Lubrite, the unique environment and tight installation tolerances required for installing the bearings would require bearing specific examinations. Literature from the general vendor (Lubrite Technologies) shows ten lubricant types used in the bearings, ranging from G1 (general duty) to AE7 (temperature and radiation tested) lubricants. Depending on the plant specific specification, lubricants of various requirements may be used. Any deviation from the 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
Lubrite	malfunction, distortion, dirt accumulation and fatigue effects under vibratory and cyclic thermal loads. The potential ageing effects could be managed by incorporating periodic examination in an appropriate AMP.
Metal	An element, compound or alloy with good mechanical strength and a good conductor of electricity and heat. For electrical and I&C components, the main focus is oxidation of the metal, which leads to an increase of ohmic resistance in metal used as a conductor. For metal connections, loosening of the connection due to various ageing effects also leads to an increase in ohmic resistance.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in AMR tables
Nickel alloys	Nickel–chromium–iron (molybdenum) alloys such as alloys 600/690. Examples of nickel alloy designations that comprise this category include alloys 82, 182, 600, 690, 800, Gr. 688 (X-750), SB-166, SB-167, SB-168 and X-750.
Non-metallic liner	An organic coating to enhance leaktightness for containment.
Oil (pressure transmitter)	Pressure transmitter oil is of a special quality and has good properties, such as thermal stability, radiation damage resistance and a low coefficient of expansion.
Paper	Used as electrical insulation in many applications because pure cellulose has outstanding electrical properties. Cellulose is a good insulator, having a dielectric constant significantly greater than one. It is used for many functions, including the insulation of wiring in transformers.
Polymer	This category generally includes flexible polymeric materials (rubber) and rigid polymers (HDPE). These materials are used in mechanical components such as gaskets, seals and service water pipes. Polymers used in electrical applications include EPR, silicone rubber, EPDM and XLPE. XLPE is a cross-linked polyethylene thermoplastic resin, such as polyethylene and polyethylene copolymers. EPR and EPDM are in the category of thermosetting elastomers.
Polyvinyl chloride	Used in the piping of some plants, PVC pipe has been found to have high corrosion and chemical resistance.
Porcelain	Hard quality porcelain is used as an insulator to support high voltage electrical insulators. Porcelain is a hard, fine grained ceramic that essentially consists of kaolin, quartz and feldspar fired at high temperatures.
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.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in AMR tables
Stainless steel	Wrought or forged austenitic, ferritic, martensitic, precipitation hardened martensitic or duplex stainless steel (chromium content >11%) are grouped for AMRs under 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 long term operation, when the recommended AMP is the same for precipitation hardened stainless steel or CASS as for stainless steel, precipitation hardened stainless steel or CASS are in some cases 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 in this category include A-286, Gr. 660, SA193-6, SA193-Gr, B8 or B-8M, SA453, Types 304, 304NG, 308, 308L, 309, 309L, 316, 347, 403 and 416. Examples of CASS designations include CF-3, CF-8, CF-3M and CF-8M.
Steel	For a given environment, carbon steel, alloy steel, cast iron, grey cast iron, malleable iron, and high strength, low alloy steel are vulnerable to general, pitting and crevice corrosion, even though the rates of ageing may vary. Consequently, these metal types are generally grouped for AMRs under the broad term ‘steel’. Note that this does not include stainless steel. However, grey cast iron is also susceptible to selective leaching, and high strength, low alloy steel is susceptible to SCC. Therefore, when these ageing effects are being considered, these materials are specifically called out. Galvanized steel (zinc coated carbon steel) is also included in this category of ‘steel’ when exposed to moisture. Examples of steel designations in this category include ASTM A36, ASTM A285, ASTM A759, SA36, SA106-Gr. B, SA155-Gr. KCF70, SA193-Gr. B7, SA194-Gr. 7, SA302-Gr. B, SA320-Gr. L43 (AISI 4340), SA333-Gr. 6, SA336, SA508-64, Class 2, SA508-Cl 2 or Cl 3, SA516-Gr. 70, SA533-Gr. B, SA540-Gr. B23/24 and SA582.

TABLE 6. MATERIALS (cont.)

Term	Definition as used in AMR tables
Superaustenitic stainless steel	Has the same structure as the common austenitic alloys but with enhanced levels of elements such as chromium, nickel, molybdenum, copper and nitrogen, which give the alloys superior strength and corrosion resistance. Compared to conventional austenitic stainless steels, superaustenitic materials have superior resistance to pitting and crevice corrosion in environments containing halides. For example, several nuclear power plants have installed superaustenitic stainless steel (AL-6XN) buried piping.
Titanium	Unalloyed titanium (e.g. ASTM grades 1–4) and various related alloys (e.g. ASTM grades 5, 7, 9 and 12). The corrosion resistance of titanium is a result of the formation of a continuous, stable, highly adherent protective oxide layer on the metal surface. Titanium and titanium alloys may be susceptible to crevice corrosion in saltwater environments at elevated temperatures (>70°C). Titanium grades 5 and 12 are resistant to crevice corrosion in sea water at temperatures as high as 260°C. SCC of titanium and its alloys is considered applicable in sea water or brackish raw water systems if the titanium alloy contains more than 5% aluminium, more than 0.20% oxygen or any amount of tin. For example, ASTM grades 1, 2, 7, 11 and 12 are not susceptible to SCC in sea water or brackish raw water.
Water proofing membranes	Material to prevent the ingress of water.
Wood	Wooden piles or sheet piles exposed to flowing or standing water are subject to loss of material or changes in material properties due to weathering, chemical degradation, insect infestation, repeated wetting and drying or fungal decay.

TABLE 6. MATERIALS (cont.)

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

TABLE 7. ENVIRONMENTS

Term	Definition as used in AMR tables
Adverse localized environment	An environment limited to the immediate vicinity of an electrical component that is hostile to the component material, thereby leading to potential ageing effects. This can be due to moisture, radiation, voltage, oxygen or heat, particularly >60 year service limiting temperature (temperatures exceeding the temperature below which the material has a ≥60 year service lifetime).
Aggressive environment	An environment that affects steel embedded in concrete with (e.g. in USA) a water pH <5.5, chloride concentration >500 ppm or sulphate concentration >1500 ppm.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in AMR tables
Air	Any indoor or outdoor air environment where the cited ageing effects could occur regardless of the particular air environment (e.g. ‘air, indoor uncontrolled’, ‘air outdoor’). For example: (a) hardening or loss of strength of elastomeric components occurs in many different air environments depending on environmental parameters such as temperature, ozone, ultraviolet light and radiation; and (b) loss of preload for closure bolting can occur in a variety of air environments. The term ‘air’ was incorporated to allow the AMR line items to be more succinct with regard to citing environments. This term does not encompass the air environment downstream of instrument air dryers, air-dry or the underground environment. The potential for leakage from bolted connections (e.g. flanges, packing) impacting in-scope components exists when citing the air environment.
Air with borated water leakage	Air and untreated borated water leakage in indoor or outdoor systems with temperatures above or below the dew point. The water from leakage is considered to be untreated, due to the potential for water contamination at the surface (relevant 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 or steam.
Air with metal temperature up to 288°C	Synonymous with the more commonly used phrase ‘system temperature up to 288°C’.
Air with reactor coolant leakage	Air and reactor coolant or steam leakage in high temperature systems (relevant 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.

TABLE 7. ENVIRONMENTS (cont.)

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

TABLE 7. ENVIRONMENTS (cont.)

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

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in AMR tables
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 condensation 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.
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 or soil environment can be vulnerable to an increase in porosity and permeability, cracking, loss of material (spalling, scaling) or aggressive chemical attack, such as from chlorides and sulphates. Other materials with prolonged exposure to groundwater or moist soils are subject to the same ageing effects as those systems and components exposed to raw water.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in AMR tables
Lubricating oil	Low to medium viscosity hydrocarbons that can contain contaminants or moisture. This definition also functionally encompasses hydraulic oil (non-water based). These oils are used for bearing, gear and engine lubrication. AMP136 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. Lubricating oil (waste oil) and lubricating oil are different environments. Lubricating oil (waste oil) is oil that has been collected as it leaks from a component (e.g. reactor coolant pumps) and, as such, contains potential contaminants such as water and dirt. Lubricating oil is unlikely to contain contaminants due to the testing of the oil and corrective actions when contaminants are detected. As a result, one-time inspections for components exposed to these environments are treated as two separate populations.
Moderator (D_2O)	The CANDU/PHWR design uses heavy water (D_2O) as the moderator. It is kept at relatively low pressure and temperature (about 70°C) to take advantage of the neutron economy provided by deuterium. While many of the physical properties of heavy water are somewhat different than those of light water, they are similar in terms of environmental effects relating to ageing. The most important difference is that heavy water does not readily absorb neutrons. This makes heavy water one of the most effective neutron moderators available.
Neutron flux/fluence	The neutron flux corresponds to the total length travelled by all neutrons per unit of time and volume. This is approximately equivalent to the number of neutrons travelling through unit area in unit time. The neutron fluence is defined as the neutron flux integrated over a certain time period.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in AMR tables
Primary coolant (D_2O)	The CANDU/PHWR design uses heavy water (D_2O) as the primary heat transport coolant to transfer heat generated from the reactor fuel to the steam generators. Primary heat transport coolant heavy water is at or near full operating pressure (8–10 MPa) and temperature (249–310°C). While many of the physical properties of heavy water are somewhat different than those of light water, they are similar in terms of environmental effects related to ageing.
Raw water	Comprises untreated surface or groundwater, whether fresh, brackish or saline in nature. This includes water for use in open cycle cooling water systems and may include potable water (see also ‘condensation (internal/external)’).
Reactor coolant	Treated water in the reactor coolant system and connected systems at or near full operating temperature, including steam associated with BWRs.
Reactor coolant >250°C	Treated water above the thermal embrittlement threshold temperature for CASS.
Reactor coolant >250°C and neutron flux	Treated water above the thermal embrittlement threshold temperature for CASS and neutron flux exceeding a certain limit.
Reactor coolant and high fluence ($>1 \times 10^{21}$ n/cm^2, $E > 0.1$ MeV)	Reactor coolant subjected to a high fluence ($>1 \times 10^{21}$ n/cm^2, $E > 0.1$ MeV).
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 (AMP103 Water Chemistry).

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in AMR tables
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 (AMP103Water Chemistry).
Sodium pentaborate solution	Treated water that contains a mixture of borax and boric acid.
Soil	A mixture of inorganic materials produced by the weathering of rock and clay minerals and organic material produced by the decomposition of vegetation. Voids containing air and moisture occupy some amount of the soil volume. Properties of soil that can affect degradation kinetics include moisture content, pH, ion exchange capacity, density and hydraulic conductivity. The soil category includes components at the air–soil interface, buried in the soil or exposed to groundwater in the soil (see also ‘groundwater/soil’).
Steam	The steam environment is managed by the BWR water chemistry programme or PWR/CANDU/PHWR secondary water chemistry programme (AMP103 Water Chemistry). Defining the temperature of the steam is not considered necessary for analysis.
System temperature up to 288°C	Consists of a metal temperature of BWR components <288°C.
System temperature up to 340°C	Consists of a maximum metal temperature <340°C.
Treated borated water	Borated (PWR) water is a controlled water system. The chemical and volume control system maintains the proper water chemistry in the reactor coolant system while adjusting the boron concentration during operation to match long term reactivity changes in the core.

TABLE 7. ENVIRONMENTS (cont.)

Term	Definition as used in AMR tables
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.
Treated water	Water whose chemistry has been altered and is maintained (as evidenced by testing) in a state which differs from that of water from naturally occurring sources so as to meet a desired set of chemical specifications. Treated water generally falls into one of two categories. The first category is demineralized water which, with the possible exception of boric acid (for PWRs only), generally contains minimal amounts of any additions. This water is generally characterized by high purity, low conductivity and very low oxygen content. This category of treated water is generally used as BWR coolant and PWR primary and secondary water. The second category may, but need not necessarily, be based on demineralized water. It contains corrosion inhibitors and also may contain biocides or other additives. This water will generally be comparatively higher in conductivity and oxygen content than the first category of treated water. This category of treated water is generally used in HVAC systems, auxiliary boilers and diesel engine cooling systems. Closed cycle cooling water is a subset of this category of treated water.
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 AMR tables
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 offset point	Periodic deterioration in the calibration (input to output relation) of a sensor or instrument.
Change in colour	In a polymeric material, a change in colour is indicative of either water absorption (see ‘water absorption’) or degradation by thermal or photooxidation. The chemical reactions involved in oxidation degradation lead to physical and optical property changes relative to the initially specified properties. If an elevated temperature is applied to a polymer in the presence of an aggressive chemical agent (often oxygen), this may increase the rate of chemical reactions. During both thermal oxidation and photooxidation, chain scission occurs with the releasing of molecular chain segments from entanglements, facilitating conformational rearrangements. The material is changed irreversibly by the scission events. In addition to colour changes, other typical property changes due to oxidation degradation include reduced ductility and embrittlement, chalking, cracking or general reduction in most other desirable physical properties.
Change in dimensions	Irreversible changes in dimension can result from various phenomena, such as void swelling, creep and, on 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 and repeatability, accuracy, threshold, drift, zero drift, resolution, hysteresis, range and span, input impedance and loading effect. These characteristics may undergo change due to various degradation mechanisms.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in AMR tables
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.
Contact sticking	Contact sticking due to electrical causes occurs when excessive current flows through contacts, the heat generated causes the contacts to melt and then stick together inseparably.
Corrosion of steel plates of 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.
Cracking	Synonymous with the crack initiation and growth in metallic substrates. Cracking in concrete can be caused by restraint shrinkage, creep, settlement and aggressive environment.
Cracking due to expansion from reaction with aggregate	Alkali–aggregate reaction is an irreversible chemical reaction. There are two 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.

TABLE 8. AGEING EFFECTS (cont.)

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

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in AMR tables
Elastomer degradation	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.
Expansion and cracking	Can result within concrete structures, expansion and cracking from reaction with aggregates.
Fretting or lockup	Fretting wear due to accelerated deterioration at the interface between tight fitting surfaces as a result of extremely small amplitude relative motion of the two surfaces and, possibly, contributions of corrosion. In essence, both fretting and 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 the 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 AMR tables
Increased friction	Increase of the force that resists relative motion between two bodies in contact and that can lead to thermal effects and mechanical deformation.
Increased resistance of connection	Ageing effect that can be caused by the loosening of bolts resulting from thermal cycling and ohmic heating. Increased resistance of connection is also caused by the following degradation mechanisms: — Chemical contamination, corrosion and oxidation (in an air, indoor controlled environment, increased resistance of connection due to chemical contamination, corrosion and oxidation does not apply); — Thermal cycling, ohmic heating, electrical transients, vibration, chemical contamination, corrosion and oxidation; — Fatigue caused by frequent manipulation or vibration; — Corrosion of connector contact surfaces caused by intrusion of borated water; — Oxidation or loss of preload.
Ingress of deleterious substances	Penetration of substances that can cause degradation of material properties.
Ligament cracking	Steel tube support plates can experience ligament cracking due to corrosion. Tube support plate signal anomalies found during eddy current testing of steam generator tubes may be indicative of support plate damage or ligament cracking.
Loss of coating integrity	The disbondment of a coating from its substrate, 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, reduction in heat transfer).
Loss of conductor strength	Transmission conductors can experience loss of conductor strength due to corrosion.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in AMR tables
Loss of dielectric strength — electrical insulation	Reduction in electrical potential gradient voltage (breakdown voltage) that can be applied to the insulating material without causing the breakdown of the material (e.g. and an associated decrease in the effectiveness of the electrical insulation). Loss of dielectric strength is an ageing effect associated with the following ageing mechanisms: — Thermal and thermoxidative degradation of organics and thermoplastics; — Radiation induced oxidation; — Moisture and debris intrusion; — Ohmic heating; — Presence of salt deposits or surface contamination; — Radiolysis and photolysis (ultraviolet sensitive materials only) of organics.
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	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 the gasket or seal 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 can result from erosion, settlement, sedimentation, frost action, waves, currents, surface runoff and seepage.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in AMR tables
Loss of mechanical function	In Class 1 piping and components (e.g. constant and variable load spring hangers, guides, stops, sliding surfaces, vibration isolators) fabricated from steel or other materials can occur through the combined influence of a number of degradation mechanisms. Such degradation mechanisms can include corrosion, distortion, dirt, overload, fatigue due to vibratory and cyclic thermal loads, or elastomer hardening. Clearances being lower than the design requirements can also contribute to a loss of mechanical function.
Loss of mechanical function (electrical components)	In electrical components fabricated from steel or other materials can occur through the combined influence of a number of degradation mechanisms. Such degradation mechanisms can include corrosion, distortion, dirt, overload, fatigue due to vibratory and cyclic thermal loads, or elastomer or lubricant hardening.
Loss of mechanical properties	Loss of strength or change of stiffness due to thermal ageing elevated temperature, exposure to ozone, oxidation, photolysis (due to ultraviolet light) and radiation. Degradation may include ageing effects such as cracking, crazing and fatigue breakdown.
Loss of preload	Can be due to gasket creep, thermal effects (including differential expansion and creep or stress relaxation) and self-loosening (includes vibration, joint flexing, cyclic shear loads, thermal cycles).
Loss of prestress	In structural steel anchorage components 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, 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 AMR tables
Movement or shifting	In CANDU/PHWRs, the annulus spacers (garter springs), which are positioned along the length of the pressure tube to prevent it from making contact with the calandria tube, can potentially shift from their initial design position during operation due to fuel channel vibrations. This is of most concern for loose fitting or detensioned spacers.
No ageing effect identified	Certain material–environment combinations might not be subject to significant degradation mechanisms; thus, there are no relevant ageing effects that require management.
Plate bulging	Evolution in the shape of the containment liner due to temperature change and concrete creep.
Reduced insulation resistance	An ageing effect used exclusively for electrical components resulting from the following degradation mechanisms: — Thermal and thermoxidative degradation of organics and thermoplastics (which can be accelerated by the presence of salt deposits or surface contamination); — Radiation induced oxidation; — Moisture and debris intrusion; — Ohmic heating; — Radiolysis and photolysis (ultraviolet sensitive materials only) of organics.
Reduction in concrete anchor capacity due to local concrete degradation	Can result from service induced cracking or other concrete degradation mechanisms.
Reduction in 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	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 AMR tables
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	Can result from degradation of neutron absorbing materials.
Reduction of strength and modulus	Can be attributed in concrete to elevated temperatures (>65°C general, >90°C local).
Reduction or loss of isolation function	Reduction or loss of isolation function in polymeric vibration isolation elements can result from elastomers being exposed to radiation hardening, high temperature, humidity or sustained vibratory loading.
Silting up of intake canal	Deposit of sediment near the intake canal may prevent the pumping system from collecting enough cooling water.
Spalling	A fragment usually in the shape of a flake, detached from a larger mass and can be produced by a mechanical blow, weathering, pressure or expansion within the large mass.
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	Can occur due to lack of electrical continuity, mechanical dislocation, corrosion, component rupture or excess concrete strain.

TABLE 8. AGEING EFFECTS (cont.)

Term	Definition as used in AMR tables
Wall thinning	A specific type of loss of material due to general corrosion, flow accelerated corrosion, and erosion mechanisms, including cavitation, flashing, droplet impingement or solid particle impingement.
Welding defect propagation in stainless steel	Can occur when subjected to an environment with treated water or treated borated water.
Winding/coil failure	Breaking of winding/coil results in loss of function of the associated instrument or equipment. Associated degradation mechanisms include sustained vibratory loading, mechanical loading and ohmic heating.

TABLE 9. DEGRADATION MECHANISMS

Term	Definition as used in AMR tables
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 come into the contact with the concrete. Exposed surfaces of Class 1 structures may be subject to sulphur based acid rain degradation (e.g. minimum thresholds causing concrete degradation in USA are 500 ppm chlorides and 1500 ppm sulphates).

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Biological attack	Concrete structures can undergo biodeterioration when exposed to lichens, mosses, algae, roots of plants and trees, marine molluscs, sponges, soil, water, sewage, food, agricultural products and waste materials. Biodeterioration can occur in foundations, walls, dams, harbour and maritime structures, bridges, tanks, pipelines, cooling towers and silos. Organisms colonize material surfaces and their pores, capillaries and microcracks, causing concrete damage resulting in aesthetic, functional or structural problems. Increased roughness as surfaces age facilitates the colonization of microbes. Microorganisms mainly affect the concrete by contributing to erosion of the exposed concrete surface, reducing protective cover depth, increasing concrete porosity and increasing transport into the concrete of degrading materials that can accelerate cracking, spalling and other damage and reduce the service life of the structure.
Blistering	Localized loss of adhesion and lifting of the coating, lining or surfaces of polymer piping.
Boraflex degradation	May involve gamma radiation induced shrinkage of Boraflex and the potential to develop tears or gaps in the material. A more significant potential degradation is the gradual release of silica and the depletion of boron carbide from Boraflex, following gamma irradiation and long term exposure to the wet pool environment. The loss of boron carbide from Boraflex is characterized by slow dissolution of the Boraflex matrix from the surface of the Boraflex and a gradual thinning of the material. The boron carbide loss can result in a significant increase in the reactivity within the storage racks. An additional consideration is the potential for silica transfer through the fuel transfer canal into the reactor core during refuelling operations and its effect on the fuel clad heat transfer capability.
Borated water intrusion	Influx of borated water.
Boric acid corrosion	Can occur where there is borated water leakage in an environment described as air with borated water leakage.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Cavitation	Formation and instantaneous collapse of tiny voids or cavities within a liquid subjected to rapid and intense pressure changes resulting in pitting. Cavitation caused by severe turbulent flow can lead to cavitation damage.
Chemical contamination	Presence of chemicals that do not occur under normal conditions at concentrations that could result in the degradation of the component.
Chemical degradation	Alteration or deterioration of the material through chemical reaction.
Cladding/lining degradation	Due to the loss of material because of the pitting and crevice corrosion of piping, piping components and piping elements fabricated from steel, with elastomer lining or stainless steel cladding.
Component rupture or excess concrete strain	Sensor stops measuring or is damaged by strain of concrete exceeding sensor's measuring range.
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 aggregate, and the moisture content.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Corrosion of embedded steel (without spalling, scaling and loss of concrete material)	This type of corrosion (also known as black or green rust due to the colour) can be found in submerged concrete structures with lack of oxygen. Typical for this kind of corrosion is no indication of cracking, spalling or scaling of concrete. This is because of the small expansion of the oxide Fe_3O_4, which means that the volume of the black rust is only slightly larger than the original steel (in contrast to corrosion in an oxygen rich environment, where the volume of the products from rust is two to five times larger than the original steel). The reinforcement may therefore be severely affected before corrosion is detected. Anyway, visual signs of rust deposits on concrete surfaces is a common sign of degradation (see also 'corrosion of embedded steel').
Creep	For a metallic material, a time dependent continuous deformation process under constant stress. It is an elevated temperature process and is not a concern for low alloy steel below 370°C, for austenitic alloys below 540°C, or for nickel based alloys below 982°C. Creep, in concrete, is related to the loss of absorbed water from the hydrated cement paste. It is a function of the modulus of elasticity of the aggregate. It 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 and lining degradation.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Cyclic loading	One source of cyclic loading is the periodic application of pressure loads and forces due to thermal movement of piping transmitted through penetrations and structures to which penetrations are connected. The typical result of cyclic loads on metal components is fatigue cracking and failure; however, cyclic loads also 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. 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	A chemical sulphate reaction where the source of sulphate ions happens to be internal, likely to occur 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).
Deposit of sediment material	Suspended particles through water settling on the bottom of channels causing greater flow resistance.
Deterioration of seals, gaskets and moisture barriers (caulking, flashing and other sealants)	Subject to loss of sealing and leakage due to containment caused by ageing degradation of these components.
Differential settlement	Uneven settlement of the soil beneath the foundation of a structure that may cause cracks and other structural problems.
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.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Dynamic strain ageing	A phenomenon associated with post-yielding plastic deformation in metals as a result of interactions between mobile dislocations and the dissolved interstitial solute atoms (e.g. carbon, nitrogen) which leads to unsteady flow phenomena at the macroscopic scale, appearing as a serrated stress-strain response and deformation banding and reduced ductility. There are five major factors that affect the extent of dynamic strain ageing: amount of interstitial nitrogen and carbon atoms, temperature, strain rate, extent of prestrain (i.e. initial dislocation density) and stress state.
Electrical transients	Stressors caused by a voltage spike that can contribute to ageing degradation. Certain types of high energy electrical transient can contribute to electromechanical forces, ultimately resulting in fatigue or loosening of bolted connections. Transient voltage surges are a major contributor to the early failure of sensitive electrical components.
Electrostatic discharge	A sudden flow of electricity between two objects caused by contact, an electrical short or dielectric breakdown, which can be caused by a buildup of static electricity by tribocharging or by electrostatic induction and cause a range of harmful effects, including failure of solid state electronic components such as integrated circuits, which can suffer permanent damage.
Elevated temperature	Temperature rise above a given threshold defined by manufacturer or by analysis.
Emergence of whiskers	Metal whiskering is a crystalline metallurgical phenomenon involving the spontaneous growth of tiny filiform hairs from a metallic surface. The effect is primarily seen on elemental metals but also occurs with alloys. The mechanism behind metal whisker growth is not well understood but seems to be encouraged by compressive mechanical stresses including: — Residual stresses caused by electroplating; — Mechanically induced stresses; — Stresses induced by diffusion of different metals; — Thermally induced stresses.
Environmentally assisted fatigue	Also called corrosion fatigue, a reduction in fatigue life in the reactor water environment compared to the fatigue life in ambient air.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Erosion	The progressive loss of material from a solid surface due to mechanical interaction between the surface and a moving fluid, a multicomponent fluid or solid particles carried by the fluid, attributed to cavitation, flashing, droplet impingement or solid particle impingement.
Erosion settlement	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. Synonymous with erosion of the porous concrete subfoundation.
Fatigue	A phenomenon leading to fracture under repeated or fluctuating stresses having a maximum value less than the tensile strength of the material. Fatigue fractures are progressive and grow under the action of the fluctuating stress. Fatigue due to vibratory and cyclic thermal loads is defined as the structural degradation that can occur from repeated stress/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.
Flaking	Lifting of the coating from the underlying surface in the form of flakes or scales.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Flow accelerated corrosion	A corrosion mechanism which results in wall thinning in susceptible materials. An example is carbon steel piping exposed to moving, high temperature, low oxygen water, such as PWR/CANDU/PHWR primary and secondary water, and BWR reactor coolant. Flow accelerated corrosion is the result of dissolution of the surface film of the steel, which is transported away from the site of dissolution by the movement of water.
Flow induced vibration	The dynamic response of structures immersed in or conveying fluid flow. Fluid flow is a source of energy that can induce structural and mechanical oscillations. Flow induced vibrations best describe the interaction that occurs between the fluid's dynamic forces and a structure's inertial, damping and elastic forces.
Fouling	An accumulation of deposits on the surface of a component or structure. This term includes accumulation and growth of aquatic organisms on a submerged metal surface or the accumulation of deposits (usually inorganic) on heat exchanger tubing and surfaces. Biofouling, a subset of fouling, can be caused by either macroorganisms (e.g. barnacles, various types of clams and mussels, and others found in fresh and salt water) or microorganisms (e.g. algae). Fouling also can be categorized as particulate fouling from sediment, silt, dust and corrosion products, marine biofouling or macrofouling (e.g. peeled coatings, debris). Fouling in a raw water system can occur on the surfaces of piping, valves and heat exchangers. Fouling can result in a reduction of heat transfer or loss of material.
Freeze–thaw, frost action	Repeated freezing and thawing can cause severe degradation of concrete, characterized by scaling, cracking and spalling, caused by water freezing within the pores of the concrete, creating hydraulic pressure. If unrelieved, this pressure will lead to freeze–thaw degradation. If the temperature cannot be controlled, other factors that enhance the resistance of concrete to freeze–thaw degradation include: — Adequate air content (i.e. within ranges specified in American Concrete Institute specification 301-84); — Low permeability; — Protection until adequate strength has developed; — Surface coating applied to frequently wet–dry surfaces.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Fretting	Wear due to accelerated deterioration at the interface between tight fitting surfaces as the result of extremely small amplitude relative motion of the two surfaces and, possibly, contributions of corrosion.
Fungal decay	Species of fungus that digests moist wood, causing it to rot and degrade. High moisture content is a prerequisite for the wood to be attacked by various fungi.
Galvanic corrosion	Accelerated corrosion of a metal because of an electrical contact with a more noble metal or non-metallic conductor in a corrosive electrolyte. It is also called bimetallic corrosion, contact corrosion, dissimilar metal corrosion or two-metal corrosion. Galvanic corrosion is an applicable degradation mechanism for steel materials coupled to more noble metals in heat exchangers; galvanic corrosion of copper is of concern when coupled with the nobler stainless steel.
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 effect and 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 AMR tables
Hydraulic pressure fluctuation	Induced by liquid flow irregularity, the fluctuations are usually permanent and, depending on their intensity, create specific pressure differences. The fluctuations can be caused by temperature distribution irregularity in pipelines, unequal density of liquid or mechanical eccentricity of pumps. Significant hydraulic fluctuations could be generated when more than one pump is operated on a common collector with amplitude addition of the pressure fluctuations at or behind the output of the pumps.
Hydrogen assisted stress cracking	Occurs when hydrogen generated during corrosion is absorbed and diffused into metals. The hydrogen gets trapped at the sites of dislocations, grain boundaries and inclusions, which leads to the brittle behaviour of metals that are normally ductile.
Hydrogen/deuterium uptake	Refers to hydrogen (or its isotope deuterium) ingress in zirconium alloy pressure tubes during CANDU/PHWR operation. The sources of hydrogen/deuterium are corrosion (the reaction of heavy water (D_2O) and zirconium), the dissociation of heavy water on the oxidized surface of the pressure tube, and the radiolytic decomposition of water. High hydrogen concentration (the sum of the initial hydrogen content before operation and the deuterium uptake during operation) in the pressure tube material can make them susceptible to delayed hydride cracking.
Increased stress levels from settlement	Uneven settlement causes unexpected stresses which may exceed a component’s tensile strength, resulting in cracks.
Insect infestation	Pervasive influx and development of insects or parasites, affecting materials.
Intergranular attack	In austenitic stainless steels and nickel alloys, the precipitation of chromium carbides, usually at grain boundaries, on exposure to temperatures of about 450–850°C (during manufacture and repair), leaves the grain boundaries depleted of chromium and therefore susceptible to preferential attack (intergranular attack) by a corroding (oxidizing) medium.

TABLE 9. DEGRADATION MECHANISMS (cont.)

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

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
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.
Material depletion/ changing material properties	Depletion in material mass and natural changes in material properties over time. Over long periods of time, changes in material properties 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 dislocation	A loss of bond between sensor and concrete causing inadequate transfer of strain from concrete to the sensor.
Mechanical loading	Applied loads of mechanical origins rather than from other sources (e.g. thermal).
Mechanical vibration	Repetitive and periodic oscillations of parts of components and structures.
Microbiologically influenced corrosion	Any of the various forms of corrosion influenced by the presence and activities of such microorganisms as bacteria, fungi and algae and the products produced in their metabolism. Degradation of material that is accelerated due to conditions under a biofilm or microfouling tubercle, 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.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Moisture intrusion	Influx of moisture through any viable process.
Neutron irradiation embrittlement	Embrittlement of carbon and low alloy steels, austenitic stainless steel, nickel alloys and zirconium alloys. It 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	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, and is especially significant for power circuit penetrations.
Oil mist	Micro size oil droplets suspended or distributed in the air, which can form with the evaporation of fuel oil, grease, synthetic lubricants and hydraulic oil. When mixed with dust in the air and rests on a part, equipment or component, it may have a negative impact on operation or cause material degradation.
Outer diameter stress corrosion cracking	Intergranular SCC which occurs on the outer diameter (secondary side) of steam generator tubes.
Overload	One of the degradation mechanisms that can cause loss of mechanical function in Class 1 piping and components, such as constant and variable load spring hangers, guides, stops, sliding surfaces, design clearances and vibration isolators, fabricated from steel or other materials, such as Lubrite.
Oxidation	Involves one of two types of reaction: an increase in valence resulting from a loss of electrons or a corrosion reaction in which the corroded metal forms an oxide.
Peeling	Disbonding of particles of a coating from substrate in the form of strips, due to loss of adhesion.
Photolysis	Chemical reactions induced or assisted by light.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
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.
Preferential weld attack	Arises because weld metal compositions tend to be slightly anodic to the parent metal, and therefore the weld metal corrodes at a higher rate than the parent material. It can occur for a number of reasons, for example differences in chemical composition and microstructure, and work hardening between the weld metal and the parent metal.
Primary water stress corrosion cracking	An intergranular cracking mechanism that requires the presence of high applied or residual stress, susceptible microstructures (few intergranular carbides), a primary water environment and high temperatures. This degradation mechanism is most likely a factor for nickel alloys and welds in the PWR environment.
Radiation damage	A general term used to describe various mechanisms by which ionizing radiation may affect materials and devices in deleterious ways, including: — Nuclear transmutation of the elements within the material, which can in turn alter the mechanical properties of the materials and cause swelling and embrittlement; — Radiolysis (breaking chemical bonds) within the material, which can weaken it, cause it to swell, polymerize, promote corrosion, promote cracking or otherwise change its desirable mechanical or electronic properties; — Formation of reactive compounds, affecting other materials; — Ionization, causing electrical breakdown, particularly in semiconductors employed in electronic equipment, with subsequent currents introducing operation errors or even permanently damaging the devices.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
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 reaction caused by radiation are an increase in valence resulting from a loss of electrons and a corrosion reaction in which the corroded metal forms an oxide (this is a very limited form of oxidation and applies to metal enclosed bus insulation).
Radiolysis	A chemical reaction induced or assisted by radiation. Radiolysis and photolysis degradation mechanisms can occur in ultraviolet sensitive organic materials.
Reaction with 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, seawater penetration or solutions of de-icing salts. These reactions include alkali–silica reactions, cement–aggregate reactions and aggregate–carbonate reactions. These reactions may lead to expansion and cracking.
Relaxation	Loss of force in time at constant deformation.
Restraint shrinkage	Can cause cracking in concrete transverse to the longitudinal construction joint.
Selective leaching	Also known as de-alloying (e.g. dezincification, graphitic corrosion) 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.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Settlement	Settlement of structures may occur due to changes in the site conditions (e.g. water table, soil settlement, heaving). The amount of settlement depends on the foundation material.
Shrinkage	Decrease in either length or volume of a material resulting from changes in moisture content or chemical changes.
Significant moisture	Long term wetting or submergence over a continuous period that if left unmanaged could have an adverse effect on operability or lead to failure of the cable insulation system.
Soil erosion	The displacement of soil due to the action of wind or water.
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)	Cracking that requires the presence of a susceptible metal, a corrosive environment and a sufficiently high tensile stress (applied and residual). SCC is highly chemically specific, in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments under certain temperature ranges. SCC includes intergranular SCC, transgranular SCC, primary water SCC and low temperature crack propagation as degradation mechanisms. High strength bolting materials with yield strength in excess of 1034 MPa exposed to corrosive lubricant such as molybdenum and humidity or water are also susceptible to SCC.
Stress relaxation	Many of the bolts and other fastener components (e.g. keys, springs) in reactor internals are stressed to a cold initial preload. When subject to high operating temperatures, over time these fasteners may loosen and the preload may be lost. Radiation can also cause stress relaxation in highly stressed members.

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Sulphate attack	Sulphates can damage concrete by causing excessive expansion, delamination, cracking and loss of strength. Attacks come from exposure to excessive amounts of sulphate from internal sources (soluble sulphate sources incorporated into concrete at the time of mixing, or gypsum or pyrite being naturally present in the aggregate or admixtures) or from external sources. External attack sources include magnesium, sodium, calcium and potassium sulphates present in soils, groundwater and sea water. Delayed ettringite formation is a special case of internal sulphate attack.
Surface contamination	Contamination of the surfaces by corrosive constituents or fouling.
Surge or voltage spike	A voltage surge is a sudden rise in voltage lasting one and a half cycles or more that damages the electrical equipment of an installation. A voltage spike is a voltage pulse of extremely short duration, with damaging effect less than that of a voltage surge.
Sustained vibratory loading	Vibratory loading over time.
Thermal ageing embrittlement	A time and temperature dependent degradation mechanism that decreases material toughness also termed thermal ageing or thermal embrittlement. At operating temperatures of 260–343°C, CASS exhibits a spinodal decomposition of the ferrite phase into ferrite rich and chromium rich phases. This 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 irradiation enhanced stress relaxation	Observed decrease in preload in response to the same amount of strain generated in the structure, dependent on temperature and which can be enhanced by high irradiation.
Thermal and mechanical loading	Loads (stress) due to mechanical or thermal (temperature) sources.

TABLE 9. DEGRADATION MECHANISMS (cont.)

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

TABLE 9. DEGRADATION MECHANISMS (cont.)

Term	Definition as used in AMR tables
Thermoxidative degradation of organics/ thermoplastics	Degradation of organics or 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	Most often occurs in components made of stainless steel as a result of chloride contamination (e.g. from insulation, ocean aerosols, tapes) if the surfaces are wetted. It initiates on the outside surfaces of components mainly due to lack of attention to adequate cleanliness (also known as external chloride SCC). It can also initiate on the inner surfaces, mainly in pipe sections containing stagnant two phase coolant, where evaporation and concentration of chlorides can occur.
Underclad cracking	Cracking that occurs in base metal (pressure vessel and 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 and low temperature, which leads subsequently to loss of elasticity of the insulation. Due to the volatilization of the plasticizer and the decay products, the weight of plastic (insulation) declines and its volume 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 AMR tables
Water absorption	Can decrease the yield strength of the polymer materials and cause significant reductions in the strengths of glass fibre composites. In the presence of environmental moisture, most polymers absorb some moisture through diffusion in high humidity environments. The extent of moisture absorption in each polymer will be a function of its hydrophilicity or chemical compatibility with water. Water absorption is of special concern in the case of glass fibre reinforced polymer matrix composites, since glass is known to be subject to permanent hydrolytic damage, especially when simultaneously exposed to stress. The nature of the water induced damage is not well understood since its effect is often, but not always, reversible on drying.
Water trees	Occur when the insulating materials are exposed to long term electrical stress and moisture. These trees eventually result in breakdown of the dielectric and ultimate failure. The growth and propagation of water trees is somewhat unpredictable. Water treeing is a degradation and long term failure phenomenon.
Wear	The removal of surface layers due to relative motion between two surfaces or under the influence of hard, abrasive particles. Wear occurs in parts that experience intermittent relative motion or frequent manipulation, or in clamped joints where relative motion is not intended, but may occur due to a loss of the clamping force.
Weathering	The mechanical or chemical degradation of external surfaces of materials when exposed to an outside environment.
Wind induced abrasion	The fluid carrier of abrading particles is wind rather than water and liquids (see also ‘abrasion’).

Appendix V

GROUPING OF CIVIL STRUCTURES EXCEPT FOR CONTAINMENT

The civil structures in AMR tables AMP302 and AMP303 are grouped as follows:

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

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Design, IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), IAEA, Vienna (2016).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Commissioning and Operation, IAEA Safety Standards Series No. SSR-2/2 (Rev. 1), IAEA, Vienna (2016).

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

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Surveillance and In-service Inspection in Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.6, IAEA, Vienna (2002).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Periodic Safety Review for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-25, IAEA, Vienna (2013).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Aspects of Nuclear Power Plant Ageing, IAEA-TECDOC-540, IAEA, Vienna (1990).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Methodology for the Management of Ageing of Nuclear Power Plant Components Important to Safety, Technical Reports Series No. 338, IAEA, Vienna (1992).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Steam Generators, 2011 Update, IAEA-TECDOC-1668, IAEA, Vienna (2011).

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

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: CANDU Pressure Tubes, IAEA-TECDOC-1037, IAEA, Vienna (1998).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: PWR Pressure Vessels, 2007 Update, IAEA-TECDOC-1556, IAEA, Vienna (2007).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: PWR Vessel Internals, 2007 Update, IAEA-TECDOC-1557, IAEA, Vienna (2007).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Metal Components of BWR Containment Systems, IAEA-TECDOC-1181, IAEA, Vienna (2000).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: In-containment Instrumentation and Control Cables, IAEA-TECDOC-1188, 2 vols, IAEA, Vienna (2000).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: CANDU Reactor Assemblies, IAEA-TECDOC-1197, IAEA, Vienna (2001).
[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Primary Piping in PWRs, IAEA-TECDOC-1361, IAEA, Vienna (2003).
[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: BWR Pressure Vessels, IAEA-TECDOC-1470, IAEA, Vienna (2005).
[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: BWR Pressure Vessel Internals, IAEA-TECDOC-1471, IAEA, Vienna (2005).
[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Aspects of Long Term Operation of Water Moderated Reactors: Recommendations on the Scope and Content of Programmes for Safe Long Term Operation, IAEA, Vienna (2007).
[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Plant Life Management for Long Term Operation of Light Water Reactors: Principles and Guidelines, Technical Reports Series No. 448, IAEA, Vienna (2006).
[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Power Plant Life Management Processes: Guidelines and Practices for Heavy Water Reactors, IAEA-TECDOC-1503, IAEA, Vienna (2006).
[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Safe and Effective Nuclear Power Plant Life Cycle Management Towards Decommissioning, IAEA-TECDOC-1305, IAEA, Vienna (2002).
[23] NUCLEAR REGULATORY COMMISSION, Requirements for Renewal of Operating Licenses for Nuclear Power Plants, 10 CFR 54, US Govt Printing Office, Washington, DC.
[24] NUCLEAR REGULATORY COMMISSION, Standard Format and Content for Applications to Renew Nuclear Power Plant Operating Licenses, Regulatory Guide 1.188, Rev. 1, Office of Nuclear Regulatory Research, Washington, DC (2005).
[25] NUCLEAR REGULATORY COMMISSION, Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants, NUREG-1800, Rev. 2, Office of Nuclear Reactor Regulation, Washington, DC (2010).
[26] NUCLEAR REGULATORY COMMISSION, Generic Aging Lessons Learned (GALL) Report, NUREG-1801, Rev. 2, Office of Nuclear Reactor Regulation, Washington, DC (2010).
[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Approaches to Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL) Final Report, IAEA-TECDOC-1736, IAEA, Vienna (2014).
[28] NUCLEAR REGULATORY COMMISSION, Domestic Licensing of Production and Utilization Facilities, 10 CFR 50, US Govt Printing Office, Washington, DC.
[29] INTERNATIONAL ATOMIC ENERGY AGENCY, Format and Content of the Safety Analysis Report for Nuclear Power Plants, IAEA Safety Standards Series No. GS-G-4.1, IAEA, Vienna (2004).

ABBREVIATIONS

AISI	American Iron and Steel Institute
AMP	ageing management programme
AMR	ageing management review
ASTM	American Society for Testing and Materials
BWR	boiling water reactor
CANDU	Canada deuterium–uranium reactor
CASS	cast austenitic stainless steel
CLB	current licensing basis
EPDM	ethylene propylene diene monomer
EPR	ethylene propylene rubber
HDPE	high density polyethylene
HVAC	heating, ventilation and air-conditioning
I&C	instrumentation and control
IASCC	irradiation assisted stress corrosion cracking
IGALL	International Generic Ageing Lessons Learned
LDPE	low density polyethylene
LTO	long term operation
PHWR	pressurized heavy water reactor
PVC	polyvinyl chloride
PWR	pressurized water reactor
RPV	reactor pressure vessel
SCC	stress corrosion cracking
SSCs	structures, systems and components
TLAA	time limited ageing analysis
WWER	water cooled water moderated power reactor

CONTRIBUTORS TO DRAFTING AND REVIEW

Ahlstrand, R.	Joint Research Centre Petten, European Commission
Alvermann, S.	RWE Power, Germany
do Amaral, J.A.R	Angra Nuclear Power Plant, Brazil
Antonacio, E.	National Atomic Energy Commission, Argentina
Arai, K.	Japan Nuclear Energy Safety Organization, Japan
Bausk, A.	Prydniprovska State Academy of Civil Engineering and Architecture, Ukraine
Berezanin, A.	Rosenergoatom, Russian Federation
Beusekom, J.F.V.R. van	Borssele nuclear power plant, Netherlands
Bieth, M.	Joint Research Centre Petten, European Commission
Bishnoi, L.R.	Atomic Energy Regulatory Board, India
Bletz, B.	Philippsburg nuclear power plant, Germany
Borák, J.	Slovenské elektrárne, Slovakia
Calatayud, M.	Iberdrola, Spain
Cepcek, S.	Nuclear Regulatory Authority of the Slovak Republic, Slovakia
Changhuai, X.	Research Institute of Nuclear Power Operation, China
Chigusa, N.	Kansai Electric Power, Japan
Chun, G.	Research Institute of Nuclear Power Operation, China
Costa Filho, P.A.	Angra Nuclear Power Plant, Brazil
Crombez, S.	French Nuclear Safety Authority, France
Cueto-Felgueroso García, C.	Tecnatom, Spain
De Smet, M.	Tractebel Engineering, Belgium

Doutt, C.	Nuclear Regulatory Commission, United States of America
Duchac, A.	Joint Research Centre Petten, European Commission
Erickson, A.	Nuclear Regulatory Commission, United States of America
Esteban López, G.	Idom, Spain
Faidy, C.	Électricité de France, France
Fernandez-Cernuda, J.	Nuclear Safety Council, Spain
Fernandéz, G.	Laguna Verde nuclear power plant, Mexico
Figueras, J.	Nuclear Safety Council, Spain
Fornero, A.	Nuclear Regulatory Authority, Argentina
Freitas Cardoso, T.	Electrobras Electronuclear, Brazil
Gallardo, I.	Federal Electricity Commission, Mexico
Gallitre, E.	Électricité de France, France
Germerdonk, K.	Swiss Federal Nuclear Safety Inspectorate, Switzerland
Getman, A.	All-Russian Research Institute for Nuclear Power Plant Operation, Russian Federation
Givaudan, B.	Électricité de France, France
Gris Cruz, M.M.	Laguna Verde nuclear power plant, Mexico
Grisy, L.	Électricité de France, France
D'Haeyer, P.	Electrabel, Belgium
Hala, P.	ČEZ, Czech Republic
Harikumar, S.	Atomic Energy Regulatory Board, India
Hashimoto, A.	Tokyo Electric Power Company, Japan
Havel, R.	RESCO, Czech Republic
Heldt, J.	Leibstadt nuclear power plant, Switzerland

Hiser, A.L.	Nuclear Regulatory Commission, United States of America
Hnát, V.	Nuclear Research Institute Řež, Czech Republic
Holian, B.	Nuclear Regulatory Commission, United States of America
Holm, T.	Oskarshamn nuclear power plant, Sweden
Honma, A.	JANUS, Japan
Huerta, A.	OECD Nuclear Energy Agency
Hüttner, F.	Vattenfall, Germany
Ignatov, G.	Kozloduy nuclear power plant, Bulgaria
Ikeuchi, T.	Kansai Electric Power, Japan
Jung, C.	Canadian Nuclear Safety Commission, Canada
Jurco, V.	Slovenské elektrárne, Slovakia
Kanno, M.	Japan Nuclear Energy Safety Organization, Japan
Karwoski, K.	Nuclear Regulatory Commission, United States of America
Kastelijn, E.	Tractebel Engineering, Belgium
Katona, T.	Paks Nuclear Power Plant, Hungary
Kirkhope, K.	Canadian Nuclear Safety Commission, Canada
Kiryukhin, A.	Rosenergoatom, Russian Federation
Klochko, V.	National Nuclear Energy Generating Company “ENERGOATOM”, Ukraine
Kohutovic, P.	Slovenské elektrárne, Slovakia
Krivanek, R.	International Atomic Energy Agency
Leberecht, M.	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Germany
Linder, J.	Swedish Radiation Safety Authority, Sweden

Lindholm, P.	Ringhals nuclear power plant, Sweden
Liszka, E.	Swedish Radiation Safety Authority, Sweden
Lopes de Araújo, J.	Eletronuclear, Brazil
López, T.	Empresarios Agrupados, Spain
Lubinski, J.	Nuclear Regulatory Commission, United States of America
Marchena, M.	National Atomic Energy Commission, Argentina
Martin, O.	Joint Research Centre Petten, European Commission
Mathew, R.	Nuclear Regulatory Commission, United States of America
Mäkelä, K.	Radiation and Nuclear Safety Authority, Finland
Medina Almazan, A.L.	National Institute for Nuclear Research, Mexico
Medvedev, P.	Rosenergoatom, Russian Federation
Michel, F.	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Germany
Minakawa, T.	Japan Nuclear Energy Safety Organization, Japan
Miyama, S.	Kansai Electric Power, Japan
Mok, J.	Canadian Nuclear Safety Commission, Canada
Nakamura, R.	JANUS, Japan
Nakano, M.	Japan Nuclear Energy Safety Organization, Japan
Narada, K.	Japan Nuclear Technology Institute, Japan
Naryzhna, R.	Kharkov Certification Center of I&C Systems, Ukraine
Nilsson, P.	Ringhals nuclear power plant, Sweden
Nishiyama, T.	Tokyo Electric Power Company, Japan
Noser, V.	Beznau nuclear power plant, Switzerland

Park Jinseok	KEPCO Engineering & Construction Company, Republic of Korea
Patel, E.	Consultant, United States of America
Ping, H.	Research Institute of Nuclear Power Operation, China
Polyakov, O.	International Atomic Energy Agency
Popov, Vl.	Kozloduy nuclear power plant, Bulgaria
Puchkov, V.	Rosenergoatom, Russian Federation
Ranalli, J.	National Atomic Energy Commission, Argentina
Rao Srinivasa, Ch.	Nuclear Power Corporation of India Limited, India
Ratkai, S.	Paks Nuclear Power Plant, Hungary
Ryden, A.	Swedish Radiation Safety Authority, Sweden
Sabater, J.	Ascó-Vandellós II Nuclear Association, Spain
Sabransky, M.	Nucleoeléctrica Argentina, Argentina
Sánchez, J.	Cofrentes nuclear power plant, Spain
Sano, T.	Hamaoka nuclear power plant, Japan
Santander Cruz, L.	Federal Electricity Commission, Mexico
Sekimura, N.	University of Tokyo, Japan
Sergiienko, V.	Kharkov Certification Center of I&C Systems, Ukraine
Shatskikh, T.	Novovoronezh nuclear power plant, Russian Federation
Shaydetsky, O.	National Nuclear Energy Generating Company “ENERGOATOM”, Ukraine
Sheikh, A.	Nuclear Regulatory Commission, United States of America
Shimamoto, R.	Chubu Electric Power, Japan
Singh, P.K.	Bhabha Atomic Research Centre, India

Streibig, L.	French Nuclear Safety Authority, France
Svensson, B.	Ringhals nuclear power plant, Sweden
Tanaka, H.	Kansai Electric Power, Japan
Ternon-Morin, F.	Électricité de France, France
Thoma, K.	Beznau nuclear power plant, Switzerland
Torano, N.	Nuclear Regulatory Authority, Argentina
Toth, P.	Paks Nuclear Power Plant, Hungary
Ueyama, I.	Nuclear Regulatory Authority, Japan
Uhrik, P.	Nuclear Regulatory Authority of the Slovak Republic, Slovakia
Usanov, A.	All-Russian Research Institute for Nuclear Power Plant Operation, Russian Federation
Usui, T.	Chubu Electric Power, Japan
Vaucher, R.	French Nuclear Safety Authority, France
Vesely, J.	State Office for Nuclear Safety, Czech Republic
Vincour, D.	ČEZ, Czech Republic
Vuorio, P.	Radiation and Nuclear Safety Authority, Finland
Wang, Y.	Canadian Nuclear Safety Commission, Canada
Weisz, P.	Paks Nuclear Power Plant, Hungary
Wullaert, P.	Électricité de France, France
Zamboch, M.	Nuclear Research Institute Řež, Czech Republic
Zander, R.-M.	Gundremmingen nuclear power plant, Germany
Zarate, S.	Nuclear Regulatory Authority, Argentina
Zarazovskii, M.	IPP-Centre, Ukraine
Zeng, Z.	Canadian Nuclear Safety Commission, Canada
Zorrilla, J.	National Atomic Energy Commission, Argentina

Contributors to drafting and review for Revision 1

Ab Azar, N.	Atomic Energy Organization of Iran, Islamic Republic of Iran
Agnes, J.B.	Veiki E+, Hungary
do Amaral, J.A.R.	Angra Nuclear Power Plant, Brazil
Anisonyan, G.	Armenian Nuclear Power Plant, Armenia
Antonaccio, E.	National Atomic Energy Commission, Argentina
Arif Javaid, M.	Pakistan Nuclear Regulatory Authority, Pakistan
Arora, P.	Bhabha Atomic Research Centre, India
Austin, J.	Eskom, South Africa
Baghdasaryan, H.	Armenian Nuclear Power Plant, Armenia
Ballesteros, A.	Joint Research Centre, Institute for Energy and Transport, European Commission
Bausk, A.	Prydniprovska State Academy of Civil Engineering and Architecture, Ukraine
Bernhoft, S.	Electric Power Research Institute, United States of America
Bishnoi, L.R.	Atomic Energy Regulatory Board, India
Bizek, J.	ČEZ Company, Czech Republic
Blahoianu, A.	Canadian Nuclear Safety Commission, Canada
Blom, F.	NRG, Netherlands
Borák, J.	Slovenské elektrárne, Slovakia
Bouril, V.	ČEZ Company, Czech Republic
Brandin, U.	Oskarshamn nuclear power plant, Sweden
Brenna, P.	National Atomic Energy Commission, Argentina
Brocko, P.	Rolls-Royce, Czech Republic

Brumovský, M.	Nuclear Research Institute Řež, Czech Republic
Buford, A.	Nuclear Regulatory Commission, United States of America
Calatayud, M.A.	Iberdrola, Spain
Carneiro Monteath Caldas, F.	Angra Nuclear Power Plant, Brazil
de Castro Justino, M.	Eletrobras Eletronuclear, Brazil
Chan, P.	CANDU Owners Group, Canada
Chang Liu, Y.	Canadian Nuclear Safety Commission, Canada
Choon-Suk, P.	Korea Hydro & Nuclear Company, Republic of Korea
Chuanli, Z.	China National Nuclear Corporation, China
Chun, G.	China National Nuclear Power Company, China
Colangelo, N.	ENGIE, Belgium
Cueto-Felgueroso García, C.	Tecnatom, Spain
Delhaye, C.	ENGIE, Tihange Nuclear Power Plant, Belgium
De Smet, M.	Tractebel, Belgium
Dimova, G.	Kozloduy Nuclear Power Plant, Bulgaria
Doutt, C.	Nuclear Regulatory Commission, United States of America
Droesbeke, M.	ENGIE, Belgium
Duchac, A.	International Atomic Energy Agency
Dusek, L.	ČEZ Company, Czech Republic
Dvouletý, K.	Nuclear Research Institute Řež, Czech Republic
Dyle, R.	Electric Power Research Institute, United States of America
Elmas, M.	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Germany
Fernandez-Cernuda, J.M.	Consejo de Seguridad Nuclear, Spain

Fernandez de Triana, N.	IDOM, Spain
Ferreira Pinto, A.L.	Eletrobras Eletronuclear, Brazil
Fornero, A.	Nuclear Regulatory Authority, Argentina
Gallitre, E.	Électricité de France, France
Garcia, J.	Federal Electricity Commission, Mexico
Getman, A.	All-Russia Research Institute of Automatics, Russian Federation
Geukens, B.	ENGIE, Belgium
Givaudan, B.	Électricité de France, France
Goicea, L.	National Commission for Nuclear Activities Control, Romania
Gorrochategui Sánchez, I.	IDOM, Spain
Gris Cruz, M.M.	Laguna Verde nuclear power plant, Mexico
Grisy, L.	Électricité de France, France
Guimaraes, M.	Electric Power Research Institute, United States of America
Gulab, A.	Pakistan Nuclear Regulatory Authority, Pakistan
Gupta, S.K.	Bhabha Atomic Research Centre, India
Hala, P.	ČEZ Company, Czech Republic
Hayashi, K.	Kansai Electric Power, Japan
Heldt, J.	Leibstadt nuclear power plant, Switzerland
Hiser, A.	Nuclear Regulatory Commission, United States of America
Hnát, V.	Nuclear Research Institute Řež, Czech Republic
Holm, T.	Oskarshamn nuclear power plant, Sweden
Hovanec, C.	Nuclear Regulatory Commission, United States of America

Hovhannisyan, L.	Armenian Nuclear Regulatory Authority, Armenia
Hyun-Gyu, S.	Korea Hydro & Nuclear Company, Republic of Korea
Ibas, G.	Nucleoeléctrica Argentina, Argentina
Ignatov, G.	Kozloduy nuclear power plant, Bulgaria
Imran, M.	Pakistan Atomic Energy Commission, Pakistan
Iqbal, J.	Pakistan Atomic Energy Commission, Pakistan
Jae Ki, L.	Korea Hydro & Nuclear Company, Republic of Korea
Jendrich, U.	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Germany
Jiangang, T.	Tianwan nuclear power plant, China
Jiangtao, Z.	China National Nuclear Corporation, China
de Jong, A.	Borssele nuclear power plant, Netherlands
Jurčo, V.	Slovenské elektrárne, Slovakia
Kazymyrska, O.	National Nuclear Energy Generating Company “ENERGOATOM”, Ukraine
Khan, T.	Nuclear Power Corporation of India, India
Kirkhope, K.	Canadian Nuclear Safety Commission, Canada
Kitagawa, T.	Kansai Electric Power, Japan
Kitamura, Y.	Kansai Electric Power, Japan
Klasson, J.	Ringhals nuclear power plant, Sweden
Klochko, V.	National Nuclear Energy Generating Company “ENERGOATOM”, Ukraine
Kozlov, V.	National Nuclear Energy Generating Company “ENERGOATOM”, Ukraine
Krivanek, R.	International Atomic Energy Agency
Kumar, S.	Bhabha Atomic Research Centre, India
Kunito, S.	International Atomic Energy Agency

Kwang Ho, J.	Korea Hydro & Nuclear Company, Republic of Korea
Kyoung-Soo, L.	Korea Hydro & Nuclear Company, Republic of Korea
Leberecht, M.	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Germany
Lee, K.-S.	Korea Hydro & Nuclear Company, Republic of Korea
Libosvar, K.	Slovenské elektrárne, Slovakia
Liendo, M.	Nucleoeléctrica Argentina, Argentina
Lievense, S.	Elektriciteits-Productiemaatschappij Zuid-Nederland, Netherlands
Lima, L.	Eletrobras Eletronuclear, Brazil
Linder, J.	Swedish Radiation Safety Authority, Sweden
Ljung, H.	Oskarshamn nuclear power plant, Sweden
López, G.M.	IDOM, Spain
Lucan, D.	Institutul de Cercetari Nucleare Piteşti, Romania
Mantey, A.J.	Electric Power Research Institute, United States of America
Marchena, M.	National Atomic Energy Commission, Argentina
Marshall, J.	Nuclear Regulatory Commission, United States of America
Martin, O.	Joint Research Centre, Institute for Energy and Transport, European Commission
Masman, F.	Forsmark Nuclear Power Plant, Sweden
Mäkelä, K.	International Atomic Energy Agency
Medlik, J.	ČEZ Company, Czech Republic
Michel, F.	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Germany
Minakawa, T.	Nuclear Regulation Authority, Japan

Mocanu, C.	Cernavodă nuclear power plant, Romania
Moroka, K.	Koeberg nuclear power plant, South Africa
Munir, A.	Pakistan Atomic Energy Commission, Pakistan
Naito, K.	Chugoku Electric Power Co., Japan
Nakamura, R.	JANUS, Japan
Naryzhna, R.	System Certification Center, Ukraine
Nasir, O.	Pakistan Nuclear Regulatory Authority, Pakistan
Nevander, O.	OECD Nuclear Energy Agency
Nhleko, S.	National Nuclear Regulator, South Africa
Nozdrovický, J.	JUNOZ & Partners Engineering, Slovakia
Nushaj, T.	Ontario Power Generation, Canada
Okubo, Y.	JANUS, Japan
Olofsson, P.	Ringhals nuclear power plant, Sweden
Pinczes, J.	Paks Nuclear Power Plant, Hungary
Polyakov, O.	International Atomic Energy Agency
de Prekel, P.	Electrabel, Belgium
Qingquan, L.	Tianwan nuclear power plant, China
Qureshi, S.	CANDU Owners Group, Canada
Radoslavov, B.	Kozloduy nuclear power plant, Bulgaria
Ranalli, J.	National Atomic Energy Commission, Argentina
Ratkai, S.	Paks nuclear power plant, Hungary
Ribas, J.O.	Eletrobras Eletronuclear, Brazil
Rong, P.	Nuclear and Radiation Safety Center, China
Sabater, J.	Ascó-Vandellós II Nuclear Association, Spain

Saberi, R.	Iranian Nuclear Regulatory Authority, Islamic Republic of Iran
Sacko, F.	Nuclear Regulatory Commission, United States of America
Sadiq, M.	Pakistan Nuclear Regulatory Authority, Pakistan
Sadollah, M.	Nuclear Regulatory Commission, United States of America
Santoro, R.	Rolls-Royce, United States of America
Sato, Y.	JANUS, Japan
Schubert, A.	Energie Baden-Württemberg, Germany
Serbanescu, D.	Nuclearelectrica, Romania
Sergiienko, V.	System Certification Center, Ukraine
Sevikyan, E.	Armenian Nuclear Power Plant, Armenia
Se-Youl, W.	Korea Hydro & Nuclear Company, Republic of Korea
Sfirlea, I.	Cernavodă nuclear power plant, Romania
Shale, G.	National Nuclear Regulator, South Africa
Singh, P.K.	Bhabha Atomic Research Centre, India
Sircar, M.	Nuclear Regulatory Commission, United States of America
Škodlar, J.	Slovenian Nuclear Safety Administration, Slovenia
Soeres Futuro, F.L.	Angra Nuclear Power Plant, Brazil
Spekkens, P.	Ontario Power Generation, Canada
Stappaerts, C.	Electrabel, Belgium
Stewart, S.	Southern Nuclear, United States of America
Stoyanov, G.	Canadian Nuclear Safety Commission, Canada
Suchard, D.	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Germany

Svensson, B.	Ringhals nuclear power plant, Sweden
Synak, D.	Slovenské elektrárne, Slovakia
Tabish, Y.	Pakistan Atomic Energy Commission, Pakistan
Tadevosyan, A.	Armenian Nuclear Regulatory Authority, Armenia
Takht Ardeshir, A.	Atomic Energy Organization of Iran, Islamic Republic of Iran
Talebi, M.	Nuclear Power Production and Development, Islamic Republic of Iran
Tamboli, P.	Nuclear Power Corporation of India, India
Tao Ge	China National Nuclear Corporation, China
Tarasov, O.	South Ukraine Nuclear Power Plant, Ukraine
Tarren, P.	International Atomic Energy Agency
Uesaka, M.	Tokyo Electric Power Company, Japan
Van Rompuy, J.	ENGIE, Belgium
Vaucher, R.	French Nuclear Safety Authority, France
Vermeulen, S.	ENGIE, Belgium
Vitelaru, I.	Cernavodă nuclear power plant, Romania
Voica, I.	Cernavodă nuclear power plant, Romania
Volkanovski, A.	Joint Research Centre, Institute for Energy and Transport, European Commission
Vuorio, P.	Radiation and Nuclear Safety Authority, Finland
Wada, H.	Chubu Electric Power Company, Japan
Weisz, P.	Paks Nuclear Power Plant, Hungary
Willey, B.	Électricité de France, France
Won, S.-Y.	Korea Hydro & Nuclear Company, Republic of Korea
Wong, E.	Electric Power Research Institute, United States of America

Xu, F.	China National Nuclear Power Company, China
Xu Sheng, M.	Shanghai Nuclear Engineering Research and Design Institute, China
Yizhou, Z.	Research Institute of Nuclear Power Operation, China
Yoneyama, K.	Japan Atomic Power Company, Japan
Zamboch, M.	Nuclear Research Institute Řež, Czech Republic
Zamora Gutierrez, I.	Federal Electricity Commission, Mexico
Zamudio, A.	Laguna Verde nuclear power plant, Mexico
Zander, R.-M.	ZandCon, Germany
Zarate, S.	Nuclear Regulatory Authority, Argentina
Zeng, Z.	Canadian Nuclear Safety Commission, Canada
Zhi, S.	International Association for Measurement and Evaluation of Communication, United Kingdom

Technical Meeting

Vienna, Austria: 11–12 November 2015

Steering Committee Meetings

Vienna, Austria: 18–19 December 2014, 9–10 November 2015, 13–15 December 2016, 12–14 December 2017

Mechanical Components Working Group Meetings

Vienna, Austria: 19–22 April 2016
Ottawa, Canada: 6–9 September 2016
Budapest, Hungary: 3–6 April 2017

WWER Mechanical Components Working Group Meetings

Paks, Hungary: 7–9 October 2014
Bratislava, Slovakia: 17–20 February 2015
Prague, Czech Republic: 4–7 August 2015

CANDU Mechanical Components Working Group Meetings

Ottawa, Canada: 24–27 November 2014
Vienna, Austria: 5–8 May 2015
Daejeon, Republic of Korea: 11–14 August 2015

Electrical and I&C Components Working Group Meetings

Vienna, Austria: 22–23 May 2014, 20–23 October 2014, 21–24 June 2016
Oskarshamn, Sweden: 30 June–3 July 2015
Cofrentes, Spain: 8–11 November 2016
Ljubljana, Slovenia: 7–10 March 2017

Civil Structures Working Group Meetings

Vienna, Austria: 17–20 May 2016
Lyon, France: 15–18 November 2016
Prague, Czech Republic: 23–26 May 2017

Obsolescence Working Group Meetings

Vienna, Austria: 20–21 May 2014
Birmingham, AL, United States of America: 19–21 November 2014

Consultants Meeting

Vienna, Austria: 25–29 September 2017

IAEA
International Atomic Energy Agency

No. 26

ORDERING LOCALLY

IAEA priced publications may be purchased from the sources listed below or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA. The contact details are given at the end of this list.

NORTH AMERICA

Bernan / Rowman & Littlefield
15250 NBN Way, Blue Ridge Summit, PA 17214, USA
Telephone: +1 800 462 6420 • Fax: +1 800 338 4550
Email: orders@rowman.com • Web site: www.rowman.com/bernan

REST OF WORLD

Please contact your preferred local supplier, or our lead distributor:

Eurospan Group
Gray's Inn House
127 Clerkenwell Road
London EC1R 5DB
United Kingdom

Trade orders and enquiries:
Telephone: +44 (0)176 760 4972 • Fax: +44 (0)176 760 1640
Email: eurospan@turpin-distribution.com

Individual orders:
www.eurospanbookstore.com/iaea

For further information:
Telephone: +44 (0)207 240 0856 • Fax: +44 (0)207 379 0609
Email: info@eurospangroup.com • Web site: www.eurospangroup.com

Orders for both priced and unpriced publications may be addressed directly to:

Marketing and Sales Unit
International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530 • Fax: +43 1 26007 22529
Email: sales.publications@iaea.org • Web site: www.iaea.org/publications

20-01234E-T

AGEING MANAGEMENT AND DEVELOPMENT OF A PROGRAMME FOR LONG TERM OPERATION OF NUCLEAR POWER PLANTS
IAEA Safety Standards Series No. SSG-48
STI/PUB/1814 (65 pp.; 2018)
ISBN 92–0–104318–4 Price: €43.00

SAFETY OF NUCLEAR POWER PLANTS: DESIGN
IAEA Safety Standards Series No. SSR-2/1 (Rev. 1)
STI/PUB/1715 (71 pp.; 2016)
ISBN 978–92–0–109315–8 Price: €50.00

SAFETY OF NUCLEAR POWER PLANTS: COMMISSIONING AND OPERATION
IAEA Safety Standards Series No. SSR-2/2 (Rev. 1)
STI/PUB/1716 (47 pp.; 2016)
ISBN 978–92–0–109415–5 Price: €48.00

PERIODIC SAFETY REVIEW FOR NUCLEAR POWER PLANTS
IAEA Safety Standards Series No. SSG-25
STI/PUB/1588 (106 pp.; 2013)
ISBN 978–92–0–137410–3 Price: €37.00

This publication provides a technical basis and practical guidance based on proven practices on managing ageing of mechanical, electrical and instrumentation and control components and civil structures of nuclear power plants important to safety to support the application of the IAEA safety standards on design, commissioning and operation, ageing management and long term operation and periodic safety review.

It presents a common, internationally recognized basis on what constitutes an effective ageing management programme and time limited ageing analysis, as well as a knowledge base on ageing management for design of new plants, design reviews and safety reviews.

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA