European Nuclear Safety Regulator's Group

ENSREG

1st Topical Peer Review Report

"Ageing Management"

October 2018

EXECUTIVE SUMMARY AND MAIN RECOMMENDATIONS

Background

In 2014, the European Union (EU) Council adopted directive 2014/87/EURATOM[1] amending the 2009 Nuclear Safety Directive to incorporate lessons learned following the accident at the Fukushima Daiichi nuclear power plant in 2011. Recognizing the importance of peer review in delivering continuous improvement to nuclear safety, the revised Nuclear Safety Directive introduced a European system of Topical Peer Review (TPR) commencing in 2017 and every six years thereafter. The purpose is to provide a mechanism for EU Member States to examine topics of strategic importance to nuclear safety, to exchange experience and to identify opportunities to strengthen nuclear safety. The process provides for participation, on a voluntary basis, of States neighbouring the EU with nuclear power programmes.

The 30th Meeting of the European Nuclear Safety Regulators Group (ENSREG[2]) in July 2015 identified ageing management of nuclear power plants as the topic for the first Topical Peer Review. This selection was informed by a technical assessment performed by the Western European Nuclear Regulators Association (WENRA[3]) in recognition of the age profile of the European nuclear reactor fleet and the safety significance of the topic. The Terms of Reference (ToR)[4] and the Technical Specification (TS)[5] of the first Topical Peer Review, as well as the Stakeholder Engagement Plan[6], were approved by ENSREG in January 2017 and published on the ENSREG Website in February 2017.

Scope, Objectives and Organisation of the first Topical Peer Review

According to the Terms of Reference and Technical Specification, the peer review focused on the Ageing Management Programmes (AMPs) at Nuclear Power Plants (NPPs) and Research Reactors (RRs) above 1 MWth. On a voluntary basis, participating countries extended the scope of their national assessment to encompass other Research Reactors. Several countries reported on specific aspects of ageing management related to long-term operation (LTO) of NPPs although LTO was not specifically required by technical specifications. In addition to reviewing the programmatic part of ageing management, the peer review process examined the application of the AMPs to the selected systems, structures and components (SSCs) in four thematic areas, namely; electrical cables, concealed piping, reactor pressure vessels, or equivalent structures, and concrete containment structures.

The objective of the first Topical Peer Review was to examine how well Ageing Management Programmes in participating countries meet international requirements on ageing management (in particular WENRA Safety Reference Levels – (SRLs) and the IAEA Safety Standards). Moreover, the objectives of the Topical Peer Review were to:

- Enable participating countries to review their provisions for ageing management, to identify good practices and to identify areas for improvement.
- Undertake a European peer review to share operating experience and identify common issues faced by Member States.
- Provide an open and transparent framework for participating countries to develop appropriate follow-up measures to address areas for improvement.

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.219.01.0042.01.ENG
[2] http://www.ensreg.eu/
[3] http://www.wenra.org/
[4] http://www.ensreg.eu/sites/default/files/attachments/ensreg_tpr_terms_of_reference_-_january_2017.pdf
[5] http://www.ensreg.eu/sites/default/files/attachments/wenra_tpr_technical_specification_-_january_2017_1.pdf
[6] http://www.ensreg.eu/sites/default/files/attachments/ensreg_tpr_stakeholders_plan_-_january_2017_1.pdf

The review process consisted of three phases:

In the first phase national self-assessments were conducted against the WENRA Technical Specification. Results of the self-assessments were documented in the **National Assessment Reports (NARs)**, published at the end of 2017.

The second phase started in January 2018 when the National Assessment Reports were made available for questions and comments from stakeholders. As an indication of the commitment to the Peer Review and the importance of the selected topic, this phase resulted in more than 2300 questions and comments. Subsequently, in May 2018, ENSREG organized a one-week workshop to discuss the results of the self-assessments, the questions and comments on the National Assessment Reports, as well as the replies to the questions, with a goal to identify and discuss both generic and country-specific findings on Ageing Management Programmes.

In the third and final phase of the Topical Peer Review, a Topical Peer Review Report and country specific findings have been compiled to provide input for national action plans and ENSREG work.

The 16 European Union countries with Nuclear Power Plants and / or Research Reactors as well as Norway, Switzerland and Ukraine participated in the peer review. The regulators of the participating countries nominated more than 50 experts and rapporteurs to work on the different thematic areas of the National Assessment Reports. In the May workshop, there were about 140 participants, including experts and observers from non-EU countries (Switzerland, Norway, South Africa and Ukraine) as well as the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD). The peer review process was overseen by the Topical Peer Review Board, comprised of seven senior regulators from EU Member States, a senior manager from the European Commission (EC) and an EC Technical Secretariat.

Main results of the first Topical Peer Review

The main conclusion of the peer review is that Ageing Management Programmes exist in all countries for Nuclear Power Plants. In all countries, regulation of the Ageing Management Programmes is in line with the IAEA Safety Standards and WENRA Safety Reference Levels on ageing management. The review did not identify any major deficiencies in European approaches to regulate and implement Ageing Management Programmes at Nuclear Power Plants. However, this is not the situation for Research Reactors. Ageing Management Programmes are neither regulated nor implemented as systematically and comprehensively, and therefore require further attention from both regulators and licensees.

To further enhance the implementation of Ageing Management Programmes in European countries the review highlights the utilization of Peer Review Services such as the International Atomic Energy Agency Safety Aspects of Long Term Operation (IAEA SALTO) and Operational Safety Review Team (OSART) missions (with the module on LTO) as a good practice. The review also sets an expectation to all countries to review and implement the revised IAEA safety guide on ageing management (Ref DS485 / SSG-48), once it has been published, to ensure a more consistent scope of Ageing Management Programmes. Furthermore, countries would benefit by resolving the challenge to evaluate the effectiveness of AMPs for instance with performance indicators. In addition to reviewing the implementation of Overall Ageing Management Programmes (OAMPs), the practical implementation of ageing management on four thematic areas was also reviewed. There were findings in all thematic areas, providing opportunities for improvement in all countries (see Annex II). These are presented in more detail in this report.

Self-assessment results constitute the basis for countries to enhance their Ageing Management Programmes. The peer review allocated good practices and expectations to enhance ageing management in the participating countries. There is already evidence based on the National

Assessment Reports and their peer review that improvements have already been made or are ongoing as a result of the Topical Peer Review. Countries need to establish National Action Plans to address the findings from self-assessments and from this peer review. Delivery of National Action Plans will further improve the ageing management of both Nuclear Power Plants and Research Reactors.

Recommendations to the Countries and to the European Nuclear Safety Regulators Group

The scope of this peer review was Nuclear Power Plants in operation and under construction and Research Reactors with thermal power of 1 MW or above. The generic outcome of the Topical Peer Review was that the regulation and implementation of the Ageing Management Programmes is more systematic and comprehensive for Nuclear Power Plants compared to Research Reactors. There are also other nuclear installations in operation in the EU which were not covered by the peer review. The Board recommends that countries explore the regulation and implementation of Ageing Management Programmes of other risk significant nuclear installations while developing and implementing National Action Plans to ensure they exist and are effective.

According to the Directive "*Member States should establish national action plans for addressing any relevant findings and their own national assessment*". The countries' National Action Plans should address the results of the self-assessment and respond to the country specific findings allocated to them for reaching the Topical Peer Review expected level of performance. Furthermore, the Board encourages countries to explore all generic findings of this peer review and to study their applicability to improve the regulation and implementation of Ageing Management Programmes at each Nuclear Power Plant and Research Reactor.

The challenges identified by the Topical Peer Review are Europe-wide and difficult to resolve for individual countries. The Board recommends the European Nuclear Safety Regulators Group (ENSREG) to ask the Western European National Regulators Association (WENRA) to address identified challenges in collaboration with European Technical Safety Organisation Network (ETSON) when applicable.

The Board recommends the European Nuclear Safety Regulators Group to ask the International Atomic Energy Agency and Western European National Regulators Association to consider addressing Topical Peer Review findings in their safety standards or SRL documents. This could ensure more consistent implementation and application of Ageing Management Programmes and further improvement of nuclear safety globally.

As per the Directive these Topical Peer Reviews will be conducted every six years. Conducting the first peer review has been a challenge and has required significant resources from the participating countries and the European Commission. The Board recommends the European Nuclear Safety Regulators Group to ask its Working Group 1 to collect feedback from the countries and from the Board to draw lessons learned from this peer review to ensure efficiency and effectiveness in the future peer reviews

Transparency

The Topical Peer Review process has included opportunities for public involvement since the beginning. The Terms of Reference, Technical Specification and Stakeholders Engagement Plan as well as National Assessment Reports were made available for public consultation. On 3 May 2018, a Public Event was organized to present and discuss the Topical Peer Review process. Another Public Event is planned for late 2018 to present and discuss the results of the first Topical Peer Review.

In Conclusion

The Topical Peer Review met the generic goals and objectives set out in the Directive and in the ENSREG Terms of Reference. The peer review enabled countries to review their Ageing Management Programmes, share information and experience, and provided an open and transparent framework for participating countries to develop appropriate follow-up measures to further enhance safety with more effective Ageing Management Programmes.

Contents

1. INTRODUCTION

1.1. Presentation of Council Directive 2014/87/Euratom

Nuclear safety is of the utmost importance to the EU citizens. On 25 June 2009, the Council adopted Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations, which provides binding legal force to the main international nuclear safety principles. The Directive aims to maintain and promote the continuous improvement of nuclear safety.

The EU amended the Nuclear Safety Directive in 2014 (Council Directive 2014/87/Euratom[7]) "*in view of the technical progress achieved through the provisions of the IAEA and by the Western European Nuclear Regulators Association ('WENRA') and responding to the lessons learnt from the stress tests8, carried out in 2011 and 2012, and the Fukushima nuclear accident investigations*," (Directive recital 15).

The amended Directive requires EU countries to give the highest priority to nuclear safety at all stages of the lifecycle of nuclear installations. This includes carrying out safety assessments regularly, identifying and implementing reasonably practicable safety improvements in a timely manner.

1.2. General overview of the Article 8e – Peer Reviews

Recognizing the importance of peer reviews in delivering continuous improvement to nuclear safety, the revised Nuclear Safety Directive introduced a European system of topical peer reviews commencing in 2017 and every six years thereafter. The TPR process provides for participation, on a voluntary basis, of States neighbouring the EU with nuclear installations.

The amended Directive requires (Recital 23, 2nd paragraph) that "*Member States, through their competent regulatory authorities making relevant use of ENSREG, and building on the expertise of the WENRA, should every six years define a methodology, Terms of Reference and a time frame for Peer Reviews on a common specific technical topic related to the nuclear safety of their nuclear installations. The common specific technical topic to be considered should be identified among the WENRA safety reference levels or on the basis of operating experience feed-back, incidents and accidents and technological and scientific developments. Member States should perform a national self-assessment and make arrangements for common peer reviews by other Member States' competent regulatory authorities of their national self-assessment.*"

Details regarding this Topical Peer Review mechanism are included in the Article 8e "Peer Reviews" of the amended nuclear safety directive where it is stated:
"1. ….

2 Member States shall ensure that, on a coordinated basis:

(a) a national assessment is performed, based on a specific topic related to nuclear safety of the relevant nuclear installations on their territory;

(b) all other Member States, and the Commission as observer, are invited to peer review the national assessment referred to in point (a);

(c) appropriate follow-up measures are taken of relevant findings resulting from the peer review process;

(d) relevant reports are published on the above mentioned process and its main outcome when results are available.

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[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.219.01.0042.01.ENG
[8] EU stress tests: http://ec.europa.eu/energy/node/102, http://www.ensreg.eu/EU-Stress-Tests.

3. Member States shall ensure that arrangements are in place to allow for the first topical peer review to start in 2017, and for subsequent topical peer reviews to take place at least every six years thereafter".

According to the Directive (Recital 23, 3rd paragraph)"*Reports on the findings of those peer reviews should be produced. Member States should establish national action plans for addressing any relevant findings and their own national assessment, taking into account the results of those peer review reports. The peer review reports should also form the basis of any summary report of the outcome of the Union-wide topical peer review exercise prepared collectively by the competent regulatory authorities of the Member States. The summary report should not aim to rank the safety of nuclear installations but rather focus on the process and technical findings of the topical peer review so that the knowledge gained from the exercise can be shared*."

The main benefits of the peer reviews are to have in-depth examination of safety significant topics enabling common understanding on nuclear safety issues and, where appropriate, to result in concrete recommendations to enhance nuclear safety, including appropriate follow-up of actions. Additional benefits are to share knowledge and experience at a European level and to enhance transparency on nuclear safety issues.

1.3. Objectives of the 1st Topical Peer Review (TPR)

In 2015, at the invitation of ENSREG, WENRA drew up a list of possible topics for the first TPR. At its **30th meeting[9] in July 2015,** ENSREG identified **"ageing management" as the topic for the first TPR**. This choice was made in recognition of both the safety significance of the topic as well as the age profile of the European nuclear reactor fleet and considering their potential long term operation. The generic objectives for the Topical Peer Reviews are defined in the Directive (see above). In addition, the ToR for the first TPR sets the following objectives:

- Enable participating countries to review their provisions for ageing management to identify good practices and to identify areas for improvement.
- Undertake a European peer review to share operating experience and identify common issues faced by Member States.
- Provide an open and transparent framework for participating countries to develop appropriate follow-up measures to address areas for improvement.

1.4. Purpose of the summary report

The results of the peer review on ageing management are summarised in this report. The purpose of this report is to provide Member States with the outcome of the peer review process, in particular by presenting the main findings in terms of good practices, expected levels of performance, challenges, and to present some identified measures already taken at the national level.

The process of this Topical Peer Review is presented in chapter 2.

2. DESCRIPTION OF THE PEER REVIEW PROCESS

2.1. Topic and scope of the 1st TPR

The ToR for the TPR and the Technical Specification for the NARs were developed in 2016, by ENSREG and WENRA respectively. A Stakeholder Engagement Plan was also developed by ENSREG in response to comments received during the public consultation on the ToR (see 2.4).

[9] http://www.ensreg.eu/document/minutes-30th-ensreg-meeting-30th-june-and-1st-july-2015

The ToR presents all elements related to the process, organisation and expected output for the peer review while the TS presents all technical areas to be covered. The key aspects of the WENRA Technical Specification were the following:

- The first TPR is mandatory for nuclear power reactors and research reactors (with a power of 1 MWth or more) (other research reactors and other nuclear installations may be included on a voluntary basis)
- The scope includes reactors in operation and under construction
- Plants in final shutdown are not included
- Obsolescence is not included

The scope includes OAMPs and how these programmes are applied to the four thematic areas: electrical cables; concealed pipework; Reactor Pressure Vessels (RPV) (or equivalent structures) and concrete containment structures.

2.2. Project organization

2.2.1. Topical Peer Review Board

ENSREG coordinated the preparatory activities on the topical peer review process until the appointment of the Topical Peer Review Board. The Board was established at the 34th meeting[10] of ENSREG in June 2017, to provide leadership and to supervise the peer review process. The composition of the Board is as follows:

Position	**Organisation**	**Name**
Chair	STUK (FI)	Petteri TIIPPANA
Vice- Chair	ASN (FR)	Sylvie CADET-MERCIER
European Commission official	DG ENER	Massimo GARRIBBA
Project Manager 1: Overall Ageing Management Programmes (OAMPs)	UJD (SK)	Mikulas TURNER
Project Manager 2: Reactor Pressure Vessel (RPV) and Calandria	ASN (FR)	Laurent STREIBIG
Project Manager 3: Electrical cables	BMLFUW (AT)	Bojan TOMIC
Project Manager 4: Concrete Containment Structures and Pre-stressed Concrete Pressure Vessels (PCPVs)	CSN (ES)	Carlos ANTA
Project Manager 5: Concealed Pipework	ONR (UK)	Ian BRAMWELL
Secretariat	DG ENER	Ghislain PASCAL

2.2.2. Review teams

In June 2017 ENSREG asked participating countries to nominate experts that would perform an in-depth technical review of the countries' NARs according to the following:

- Each Member State and participating neighbouring countries had the right to nominate experts for each of the different topics;
- The qualifications of the experts were decided by the nominating countries; information on the experts background was provided to facilitate the composition of balanced teams;
- In nominating their experts, countries also indicated whether they could serve as Project Managers or Rapporteurs;
- The appointment of Project Managers and Rapporteurs was agreed jointly by ENSREG and the Commission.

[10] http://www.ensreg.eu/document/minutes-34th-meeting-ensreg

Five teams of experts were created as follows:

- Ageing Management Programmes
- Electrical cables
- Concealed Pipework
- RPV and Calandria
- Concrete Containment Structures and PCPVs

The experts reviewed the NARs under the guidance of their respective Project Managers. The experts and Board Members represented altogether a group of 55 experts from 21 different countries (EU and non EU).

2.2.3. European Commission support

According to Directive 2014/87/Euratom, the EC has the role of observer in the Topical Peer Reviews. It also has the role of facilitator in providing secretariat support for all phases of the process. The Commission was represented in the TPR Board and Commission observers participated in each team.

2.3. Project implementation

2.3.1. Technical Specification, Terms of Reference and stakeholder engagement plan

The final versions of the Technical Specification, ToR and Stakeholder Engagement Plan were approved by ENSREG and published on its website in January 2017[11], thereby launching the peer review process.

2.3.2. Preparation of National Assessment Reports

The peer review exercise is a requirement under Article 8e of the Nuclear Safety Directive for EU Member States, but several non-EU countries also participated on a voluntary basis. Based on the nuclear installations covered by the technical specification, the final list of countries that submitted a report for this peer review was established in autumn 2017, and approved at the 35th ENSREG meeting in December 2017[12].

Most of the countries reported on NPPs and on research reactors. Countries reporting only on Research Reactors were Italy, Poland and Norway.

Belgium (NPPs and RRs)	Italy (RRs)	Sweden (NPPs)
Bulgaria (NPPs)	The Netherlands (NPPs and RRs)	United Kingdom (NPPs)
Czech Republic (NPPs and RRs)	Poland (RRs)	Norway (RRs)
Finland (NPPs)	Romania (NPPs and RRs)	Switzerland (NPPs)
France (NPPs and RRs)	Slovak Republic (NPPs)	Ukraine (NPPs)
Germany (NPPs and RRs)	Slovenia (NPPs)	
Hungary (NPPs and RRs)	Spain (NPPs)	

[11] http://www.ensreg.eu/background
[12] http://www.ensreg.eu/document/minutes-35th-meeting-ensreg

The NARs were prepared by the nuclear safety regulators based on the WENRA Technical Specification. The reports were published on the ENSREG Website in January 2018[13] [14].

2.3.3. Desktop review

From January until May 2018, participating countries performed a desktop review of the NAR. In addition, the nominated experts reviewed the NARs under the guidance of their Project Managers. Questions were also submitted by the public and the EC. Written questions were submitted to the EC Secretariat, collated and transmitted to each country, which then provided their responses.

In total, more than 2300 questions (including 19 questions from the public) were received in preparation of the TPR workshop in May 2018 (see Annex III). The questions and replies were published on the ENSREG website end of April 2018.

While reviewing the NARs and the questions/answers, the nominated experts identified a list of preliminary generic findings and areas to be explored during the workshop. This list was distributed to the participating countries prior to the workshop.

2.3.4. Topical Peer Review workshop in May 2018

The Topical Peer Review workshop took place in Luxembourg on 14-18 May 2018, with more than 140 representatives from the participating countries. Observers also attended from the EC, IAEA, OECD-NEA, WENRA and non EU Regulatory Authorities representatives from South Africa. All the sessions were webstreamed on a secured network to allow participation of additional representatives from Regulatory Authorities, TSOs, utilities, etc.

Each session of the workshop was organised in two steps. Firstly, countries presented their self-assessment results on their AMP and for the thematic areas, and in particular presented the findings from their self-assessment (good practices, challenges and areas for improvement). Secondly, the preliminary generic findings resulting from the peer review were presented by the experts and discussed with the participants. These generic findings were categorised during the workshop as good practices, good performance, areas of improvement and challenges and allocated to countries based on the NAR and the discussions during the workshop. The last day of the workshop was devoted to the presentations and discussions on preliminary generic findings and their categorisation. Preliminary country-specific findings were presented. Following the workshop, countries were asked to provide feedback on the preliminary generic and country-specific findings.

2.3.5. Process to finalise the report

A workshop was organised on 6-7 June 2018 for TPR Board members and rapporteurs to continue to draft the report and finalise the findings addressing the feedback provided by the countries.

During this phase, the TPR Board finalised the different categories of findings and defined three categories. The definitions for these categories are provided below and are used throughout the different chapters of this report.

Good Practice

A good practice is an aspect of ageing management which is considered to go beyond what is required in meeting the appropriate international standard.

[13] http://www.ensreg.eu/country-specific-reports/EU-Member-States
[14] http://www.ensreg.eu/country-specific-reports/Other-Countries

TPR expected level of performance

A "TPR expected level of performance" for ageing management is the level of performance that should be reached to ensure consistent and acceptable management of ageing throughout Europe.

Challenge

Challenges are common to many or all countries and are areas where action at a European level could help to increase available knowledge or drive consistency or produce beneficial new techniques or technology to assist in specific aspects of ageing management.

Additional TPR Board meetings were necessary to finalise the draft report and to conclude on the country specific findings. Countries were asked to provide feedback on this draft report and country specific findings before submitting them to ENSREG members.

The final report and the country specific findings were then submitted to ENSREG for endorsement in the meeting on 4th of October 2018.

2.4. Public information and interaction

In accordance with the ToR and the ENSREG Guidance for National Regulatory Organisations — Principles for Openness and Transparency[15], a Stakeholder Engagement Plan was developed[16], identifying activities to ensure the peer review process and outcomes are visible to the public and other interested parties, e.g. publication of national assessment reports on the ENSREG website, organisation of public meetings.

2.4.1. Information on the ENSREG Website

Dedicated webpages were created on the ENSREG website, for public information. These were updated throughout the peer review process.

NARs were published by national regulators on their websites and were also made available through the ENSREG website from the beginning of 2018[17]. In addition, the questions and answers on the National Assessment Reports were published on the ENSREG Website.

The TPR Summary Report and country specific findings, after approval by ENSREG Members, were published on the ENSREG Website.

ENSREG and participating countries will prepare National Action Plans that will also be published on the ENSREG website.

2.4.2. Public consultations

The ToR and the Technical Specification were made available for public consultation on the ENSREG and WENRA Websites for two months in 2016. The comments received have been taken into account. Based on the comments received a stakeholder engagement plan was also developed.

The NARs were open to public consultation between 8 January and 28 February 2018[18].

[15] http://www.ensreg.eu/document/guidance-nro-principles-openness-and-transparency
[16] http://www.ensreg.eu/sites/default/files/attachments/ensreg_tpr_stakeholders_plan_-_january_2017_1.pdf
[17] http://www.ensreg.eu/country-specific-reports

2.4.3. Public events

The TPR process was presented by the Board members to the public and European Stakeholders at a public event which took place in Brussels on 3 May 2018. This event was also webstreamed via the ENSREG website.

The results of the peer review will be presented to the public and European Stakeholders during a 2nd public event which will take place in Brussels in late 2018. This event will also be webstreamed via the ENSREG website.

3. GENERAL QUALITY OF NATIONAL ASSESSMENT REPORTS

This chapter reviews the overall consistency of the National Assessment Reports (NARs) with the WENRA Topical Peer Review (TPR) Technical Specification (TS) as agreed by ENSREG. Initially intended for nuclear power plants, the scope of this TPR on Ageing Management was extended to research reactors with a power equal to or above 1MWth. The findings and comments below apply to both types of installation, unless specified.

3.1. Compliance of the national reports with the topics defined in the WENRA TPR technical specification

The TPR TS defined the structure and content of the NAR. Although there were differences in the level of detail and presentation, all the NARs addressed the topics defined by the TPR Technical Specification and provided a sufficient overview of the AMPs for the purposes of the TPR. Several NARs also provided information on research reactors beyond the TPR technical specifications, although this was not mandatory.

The NARs outlined the essential technical, procedural and organisational provisions required for effective ageing management. Several countries reported on specific aspects of ageing management related to long-term operation (LTO) of NPPs although LTO was not specifically required by technical specifications.

The NARs covered experience and lessons learned from regulating and implementing AMPs. As a result of the self-assessment, countries have also identified and reported areas of improvement in their AMPs.

3.2. Adequacy of the information provided, consistency with the guidance provided by ENSREG and WENRA

The information in the NARs was based on the licensees' documentation and on other relevant regulatory requirements.

The assessment of ageing management focussed on assessing the AMPs, covering:

- Overall ageing management programme (OAMP);
- SSCs specific ageing management programme (AMPs).

The NARs described the application of international standards in developing the OAMP including relevant WENRA safety reference levels, IAEA Safety Standards and other guidance documents, and where relevant, the proven practices described in the IAEA International Generic Ageing Lessons Learned (IGALL) programme and other international guidance.

Countries reported on their relevant nuclear installations, addressing a variety of reactor designs, different generations of designs and plants operated by different licensees. Countries having multiple units of the same type typically opted for a design-specific assessment, grouping several units, rather than site-specific assessment and analysis, using the possibility of a "commonalities structure" as mentioned in the TPR Technical Specification.

The information in the NARs, together with the answers provided to questions, and the national presentations provided an adequate level of information for the purpose of the peer review.

3.3. Compliance with licensing basis and international standards

Participating countries have established specific requirements for ageing management and implemented them in national legislation consistent with the WENRA SRLs[19] and IAEA Safety Standards. The IAEA Safety Standards reflect an international consensus on what constitutes a high level of safety. In addition, the objective of WENRA is to develop a harmonized approach to nuclear safety and regulation, aiming for continuous improvement in particular within the European Union. The application of the WENRA SRLs and IAEA Safety Standards on ageing management over the last decade has contributed towards a greater consistency amongst the European countries.

Where minor deviations from national regulatory requirements were identified and described in NARs, standard regulatory practices were applied in line with national regulations and international standards to remediate the situation.

The review of NARs demonstrated that, despite countries using different approaches, all reports provided evidence that ageing management programmes at NPPs support compliance with their current licensing basis.

In several cases, the NARs state that the AMP of research reactors is neither systematically implemented by the research reactor licensees, nor sufficiently formalised in the legal framework.

3.4. Conclusion

The WENRA TPR Technical Specification for the NARs was generally addressed with an adequate level of quality, although the level of detail varied. The NARs outlined the essential technical, procedural and organisational provisions required for effective ageing management. The information in the NARs, together with the answers provided to questions, and the national presentations enabled a desktop peer review exercise to be conducted.

[19] Mainly issue I of the SRL document, WENRA Safety Reference Levels for Existing Reactors, September 2014

4. EUROPEAN PLANTS ASSESSMENT RELATIVE TO OVERALL AGEING MANAGEMENT PROGRAMME REQUIREMENTS AND IMPLEMENTATION

The WENRA Safety Reference Levels for Existing Reactors Issue I describes the expectations for ageing management for NPPs. According to WENRA definition "*Ageing is considered as a process by which the physical characteristics of a SSC change with time (ageing) or use (wear-out)*". In addition, ageing management is defined as the design, engineering, operations and maintenance actions undertaken to prevent or to control ageing degradation of SSCs within acceptable limits. With regards to safety, the aim of ageing management is to ensure the availability of required safety functions throughout the operational life of the plant, with account taken of changes that occur with time and use and by considering all operating conditions.

WENRA RL I1.1 requires: *The operating organisation shall have an Ageing Management Programme (AMP) to identify all ageing mechanisms relevant to safety significant SSCs, determine their possible consequences, and determine necessary activities in order to maintain the operability and reliability of these SSCs.*

This chapter summarises the results of the ENSREG Topical Peer Review on the OAMP, in particular its programmatic aspects, its implementation and subsequent experience of its application amongst European countries, including the safety significant SSCs to which a specific AMP is applied, i.e.:

- Safety significant SSCs that are necessary to fulfil the fundamental safety functions;
- Other SSCs whose failure may prevent safety significant SSCs from fulfilling their intended functions.

4.1. Description of present situation of plants across Europe

4.1.1. Regulatory basis for assessment and regulatory oversight of Overall Ageing Management Programme

In general, the participating countries have developed regulatory requirements for ageing management in line with the IAEA Safety Standards and WENRA SRLs. The IAEA Safety Standards and WENRA SRLs are regularly reviewed and updated. Their transposition into national legal frameworks is an ongoing and continuous process. The level of implementation differs from country to country.

Differences in regulatory framework and plant design result in differences in the evaluated OAMP. Regulatory requirements for ageing management are continuously updated with an aim of improving the effectiveness of the overall ageing management programme of the licensees.

The regulatory basis for the assessment and regulatory oversight is typically provided by primary legislation (e.g. Atomic act, Environment code, etc.) and on subsequent secondary acts (e.g. regulations, etc.), license requirements and non-legally binding documents such as guides as described in Chapter 2 of each NAR:

- **<u>For NPPs</u>**, the regulatory framework of each country for ageing management is mainly based on the IAEA Safety Guide NS-G-2.12 "Ageing management"[20] and on the IAEA safety report SRS No. 57 "Safe Long Term Operation of Nuclear Power Plants"[21], as well as on the relevant WENRA SRLs[22] and internationally applied national practices.

[20] https://www-pub.iaea.org/MTCD/publications/PDF/Pub1373_web.pdf
[21] https://www-pub.iaea.org/MTCD/publications/PDF/Pub1340_web.pdf
[22] http://www.wenra.org/media/filer_public/2016/07/19/wenra_safety_reference_level_for_existing_reactors_september_2014.pdf

The majority of countries recognize that the IAEA Safety Standards with their comprehensive system of safety objectives, basic safety goals and safety requirements, provide a good basis for the design and implementation of an OAMP for the SSCs of their NPPs. There are national differences in practical application within specific areas, such as safety classification of SSCs according to the specific national requirements and approaches applied, usually based on the historical development of the country’s nuclear activities and on the specific NPP design.

- **For the research reactors**, the IAEA specific safety guide SSG-10 "Ageing Management for Research Reactors"[23] is relevant and is used by several countries.

In many cases, the countries refer to sharing of best practices and exchange of experiences amongst regulators and licensees. In addition, national and worldwide operational experience and the results of research projects, studies and programmes on ageing management topics are used in formulating national regulatory requirements, more particularly for SSC-specific AMPs rather than for OAMPs.

The regulators have established requirements for the OAMP. As a usual practice, licensees submit their OAMP to the regulator for review or approval, as appropriate. These OAMPs usually contain the following aspects:

- Coordination, responsibilities and duties,
- Measurement of effectiveness,
- Utilisation of operational experience and research data,
- Graded approach
- Data of each SSC or commodity group within licensee’s ageing management,
- Provisions for management of obsolescence (out-of-scope for this TPR).

The regulators assess these programmes and verify their implementation at NPPs to ensure compliance with the relevant national requirements. Assessments of the OAMPs are carried out within the licensing processes, periodic safety reviews and other regulatory activities.

The frequency and scope of inspections are intended to verify that the licensee’s oversight and other processes and capabilities are in place to implement an effective OAMP and in case of any deficiencies to require appropriate remedial action. A number of countries reported that the activities of regulators focus on monitoring the current condition and lifetime assessment of safety-significant SSCs. In the framework of regulators' inspection activities, particular attention is paid to the results of in-service inspections and maintenance practices. Assessments and inspections are carried out by the regulator's staff, supported where appropriate by e.g. technical support organisations. In a number of countries, the regulatory activities in ageing management are also supported by IAEA expert services.

4.1.2. Overall approach to ageing management

All the countries have implemented or are gradually introducing a proactive AMP to cover design, construction, commissioning and operation and where relevant supporting the LTO.

Licensees have generally demonstrated that the ageing of NPPs is being clearly identified and incorporated in the relevant safety documentation. The recommendations of the plant vendor and equipment suppliers are taken into account in the implementation of the OAMP by the licensees.

Ageing management is a cross-cutting process within the management systems of the licensees (e.g. with participation of engineering management, asset management and safety management as appropriate). Within these management areas, the fundamental principles and strategies for ageing management are defined, together with responsibilities, obligations and competencies to implement the process.

[23] https://www-pub.iaea.org/MTCD/publications/PDF/Pub1447_web.pdf

The specific structure of an OAMP depends on the organisational structure of each licensee and could be overseen in a number of ways e.g. by an ageing management coordinator or ageing management groups or committees. A dedicated manager is generally responsible for the establishment of, and compliance with, the processes as well as for the implementation of remedial actions to ensure the continuous improvement of the processes, in cooperation with other departments concerned. Information relevant to the ageing management is collected and usually status reports are drawn up on a regular basis. For example, the person responsible for the system and/or the component provides information to the ageing manager (or group) to ensure that the OAMP is implemented.

Effective ageing management is accomplished in practice through the coordination of the existing programmes (including maintenance, in-service inspection and surveillance) as well as through technical support programmes (including analysis of any ageing mechanisms), and external programmes such as research and development. The OAMP is also coordinated with other relevant processes and programmes, e.g. the PSR or safety upgrade programmes. More thorough OAMP are implemented for NPPs in countries where LTO is, or may be relevant.

The regulatory framework in several countries requires application of ageing management to both active and passive SSCs in accordance with WENRA SRL and IAEA Safety Standards. Others require application of ageing management principally to passive SSCs, considering that the ageing degradation of active SSCs is managed via maintenance or other surveillance processes (e.g. consistent with US regulation 10 CFR 54[24]). In this regard, countries have adopted different approaches to determine which SSCs are subject to ageing management. Despite such differences, the final objective of all reported AMPs is to ensure that the SSCs continuously perform the required safety functions throughout the lifetime of the plant, and to determine necessary activities in order to maintain the operability and reliability of these SSCs.

Concerning the majority of research reactors, their ageing management is currently based mainly on maintenance programmes and periodic inspections and tests. In some cases the compliance with requirements is also verified during the periodic safety reviews (PSR). The overall scope of AMPs for the research reactors is limited in comparison to NPPs and significant differences in the national approaches exist. The variability in approaches to ageing management for research reactors was considered to be an inevitable feature for this diverse range of reactors. Some countries reported on international peer reviews conducted, invited or to be invited to review the OAMPs and on the on-going development of a more comprehensive approach to ageing management.

4.1.3. Review and update of the OAMPs

The Nuclear Safety Directive[25], in its Article 8c, requires "*the licence holder, under the regulatory control of the competent regulatory authority, to re-assess systematically and regularly, at least every 10 years, the safety of the nuclear installation*".

WENRA RL I2.3 specifies: "*The Periodic Safety Reviews shall be used to confirm whether ageing and wear-out mechanisms have been correctly taken into account and to detect unexpected issues*."

WENRA RL I2.5 also stipulates: "*The AMP shall be reviewed and updated as a minimum with the PSR, in order to incorporate new information as it becomes available, to address new issues as they arise, to use more sophisticated tools and methods as they become accessible and to assess the performance of maintenance practices considered over the life of the plant*."

Countries reported that OAMPs are reviewed and regularly updated, at least within the PSR ten year period, in order to incorporate new information, to address new objectives and evaluate the results of maintenance activities. In addition to PSRs, regular reviews are used to confirm whether ageing

[24] https://www.nrc.gov/reading-rm/doc-collections/cfr/part054/
[25] Directive 2009/71/Euratom as amended by Directive 2014/87/Euratom

and wear-out effects have been correctly taken into account and unexpected behaviours have been detected in a timely manner.

In addition to the PSR, an AMP is usually updated in the following cases e.g.:

- Changes in legal/regulatory requirements,
- Changes in the methodology or criteria for the assessment of ageing degradation,
- Experience from AMP implementation,
- Operational experience,
- Audit findings,
- Design changes,
- Changes in the organizational structure,
- Newly qualified test methods etc.

National activities and international cooperation in science and technology in such as materials and structural ageing, as well as in new diagnostic technologies are an important input for the review of the AMP. In addition, licensees and regulators are members of different fora and contribute to event databases (e.g. IAEA's International Reporting System (IRS), IRS Research Reactors, IGALL, WANO, EPRI)) for the purpose of exchange of operating experience and practices, including those related to degradation due to ageing.

In several countries, findings of peer reviews performed by the IAEA are used to improve the existing AMPs.

The process of an AMP review and update is subject to regulatory oversight in accordance with national requirements.

4.1.4. Licensees' AMP experience and application practice

The NARs described the organisational structure of an OAMP, which depends on the organisational arrangements of the licensee. An appointed manager is generally responsible for managing the activities of relevant ageing management groups, units or committees with multidisciplinary features. These groups/units have a close relation with other organisational units responsible for other functions such as maintenance, operations, engineering etc.

A systematic assessment of preventive and remedial actions in ageing management is an important activity that needs to be documented and continuously evaluated. Ageing management has been developed from an approach consisting of individual maintenance, surveillance and inspection programmes, into an integrated SSC-oriented ageing management process in which coordination, traceability and experience feedback are important.

Licensees carry out monitoring, testing, sampling and internal oversight to assess ageing effects and to identify unexpected behaviour and degradation during the service life of SSCs. Using lessons learned, the OAMPs have been gradually upgraded. Based on this, existing internal oversight and test programmes, especially preventive maintenance, are being regularly reviewed by the licensees to determine whether an ageing-induced degradation can be avoided or detected at an early stage. Any findings revealed by the review are followed up by the licensees and in some cases also by the regulators.

Several countries reported on the licensee´s systematic approach in reviewing the AMPs based on operating experiences gained from internal and external sources. The relevant information from operating experience is evaluated by the responsible departments of the licensee and implemented as appropriate through plant modifications and/or changes in the operational characteristics. Subsequently the AMPs are reviewed and updated based on the performed plant modifications and/or changes in the operational characteristics. In general, amongst lessons learned from ageing management is that the licensees recognise the need to replace or modify SSCs, which are reaching the limits of their functionality, in a timely manner.

A number of countries are using vendor design documentation. Some countries reported that their licensees periodically update this documentation based on the outputs from operation, maintenance programmes and experience.

In countries where NPPs are operated, or planned to be operated, longer than originally envisaged, the licensees reviewed the existing AMPs to verify that they will be effective to manage the effects identified also for the entire planned period of operation. This review usually resulted in more thorough AMPs (updates or in new AMPs) to ensure that the SSCs will be able to perform their intended function for the planned period. For example, time-limited ageing analyses are reviewed to determine the continued validity of the analyses, and therefore the capability of the concerned SSC to perform its intended function for the planned period of operation. The relevant updates or new programmes are documented by the licensee in accordance with national requirements and in several countries reviewed and/or approved by the regulatory body.

According to the NARs, the OAMPs for NPPs can be considered sufficiently comprehensive and meeting the requirements of national regulations and international standards, and are therefore considered adequate.

Several countries state that a comprehensive AMP for their research reactors is still not available or is under development and that work on the implementation of an AMP will continue. Some countries are more advanced in the implementation of AMP for RR and use the external peer review services such as those under the umbrella of the IAEA

4.1.5. Regulators' assessment of the overall AMPs

The regulators reviewed information provided by the licensee(s) concerning OAMPs together with information obtained from their assessment and inspection activities. One of the main goals of the regulators in all countries is to stimulate the continuous improvement of AMPs according to international safety standards and best practices. Depending on the regulatory requirements, the licensees notify the regulator about updates and extensions to an existing AMP.

In general, the regulators in all countries state that all the information provided by licensees on OAMPs is satisfactory, and are in line with the internationally applicable safety standards, such as the WENRA SRLs and IAEA Safety Standards. However, the NARs of several countries identified shortcomings such as deficiencies in updating drawings of SSCs and the ageing management database to reflect the actual status of SSCs.

With regards to research reactors, several regulators consider that the management of ageing needs to be more formalised. Some of the regulators consider that the licensees of research reactors should develop and implement an appropriate OAMP in accordance with the IAEA Safety Standards.

Countries reported in NARs the following generic good practices:

- Preparation of annual reports on the implementation of an AMP by the licensee and the submission thereof to the regulator,
- Regular update of the scope of SSCs subject to the OAMP, at least within the PSR (or whenever necessary e.g. for example when new relevant information is available),
- Participation in international activities (e.g. IAEA IGALL) in support of national activities.

4.1.6. Measures (including further studies) already decided or implemented by operators and/or follow-up measures required to be undertaken by the regulators

A range of improvement measures have been identified by the licensees and regulators for NPPs and research reactors, some during regular PSRs, others during the preparation of the NARs.

Several countries reported on ongoing reviews and updates, either under development or implementation. For example, some of these measures are related to concealed pipes, cables after years in operation and results from surveillance programmes for RPVs etc.

Several regulators are focusing their efforts on OAMPs in order to make sure that all safety significant SSCs are included and covered by suitable inspection and maintenance programmes.

In many countries, further harmonisation of reporting among the licensees is considered by the regulator to be of benefit (e.g. overview of the updated factsheets, evaluation of the international operating experience, and assessment of the AMP effectiveness based on the outputs from maintenance findings).

In the NARs, almost all countries reported findings (good practices, challenges and areas for improvement) on OAMPs, some of which were presented during the workshop. Identified areas for improvement or challenges included:

- Improvement of existing performance indicators in support of an effective OAMP,
- Harmonisation of AMPs between licensees (where more than one licensee exists),
- Regular update and where necessary expansion of the scope of the licensee´s information systems/databases for AM,
- Implementation of an AMP at NPPs under construction,
- To develop a more comprehensive AMP for research reactors in accordance with international safety standards e.g. IAEA Safety Standards.

These improvements have been identified by the licensees or regulators during the preparation of their NARs. Some countries already reported on the progress achieved in the implementation of some of these findings.

4.2. Assessment of the Overall Ageing Management Programmes

4.2.1. Consistency of approaches used in the European countries and the international requirements (IAEA, WENRA)

For NPPs, the OAMPs of all reviewed countries are based on requirements set out in a national legal framework and other relevant documents such as guides. The international safety standards such as IAEA and WENRA SRLs represent a basis for the development of AMPs in most of the countries; in addition some countries are applying other regulations such as the US NRC regulation. These guidelines were incorporated into the maintenance strategies and ageing management practices to an extent deemed appropriate to ensure safety and operability of SSCs at the NPPs.

In establishing an AMP, the general approach is that the licensees developed an overall approach to ageing management, which is further developed as specific SSCs AMPs.

International cooperation represents an important tool for establishing a common approach for participating countries. In several countries, the licensees are members of the IAEA IGALL Project, which provides a common, internationally agreed basis on what constitutes an acceptable OAMP. The project aims to develop a common practical manual for the ageing management of NPP safety significant SSCs, including recommendations for effective management of AMPs.

Licensees of many countries have access to the EPRI (Electric Power Research Institute) databases and its materials related to ageing management. In addition, several regulators and their TSOs participate in OECD NEA ageing-related research activities.

The outcomes of the self-assessment constitute the bases to enhance OAMPs in the participating countries. The NARs of almost all countries reported on a number of findings (good practices, challenges and areas for improvement) on OAMPs, which were also presented and discussed during the workshop as part of the national presentation.

During the preparation of the workshop, while reviewing the NARs and the questions and answers, the experts identified fourteen preliminary generic findings for discussion during the workshop. These findings were presented by the experts and discussed in the plenary session of the workshop.

Based on the outcome of the discussions and their importance, six of them were categorised as, good practice, TPR expected level of performance or challenge and described below or included in the conclusions of this chapter (see section 4.3).

4.2.2. Good practice

The peer review identified the following good practices.

External peer review services

Several countries are arranging peer reviews of the licensee´s AMPs by external entities to obtain an independent assessment of whether the OAMPs are consistent with IAEA Safety Standards and generally accepted practices, and to identify areas for improvement.

Good practice: External peer review services (e.g. SALTO, OSART-LTO, INSARR-Ageing) are used to provide independent advice and assessment of licensees' ageing management programmes.

4.2.3. TPR Expected level of performance

The topics below were recognised as the expected level of performance during this TPR and therefore considered as a good performance for those countries which already meet this expectation and as an area for improvement for the others.

Data collection, record keeping and international cooperation

Document management is part of the licensees' integrated management system. Several countries highlighted the importance of maintaining the availability of design and manufacturing/vendor documentation to support operability and reliability of the SSC for the entire lifetime of the NPP.

Peer reviews conducted in recent years at NPPs have highlighted the importance of keeping records of baseline data (design, manufacturer, equipment qualification and commissioning), operational histories (operating performance, process/system and environmental conditions, etc.) and maintenance histories of plant components. Data from the AMP contribute to an effective plant configuration management, and vice versa. Usually the databases containing data relating to SSCs are part of the licensee´s integrated information system that provides a coherent source of information in support of operation, configuration management, maintenance and engineering functions.

The NPPs licensee´s AMPs are usually based on the vendor documentation. A continuous update of the documentation is identified as important. For this purpose, countries use internal and external operating experience databases e.g. reports from WANO, IAEA - IRS system, etc and participate in relevant networks, users groups and projects (i.e. FRAmatome REGulators association, VVER Regulator´s Forum or IAEA IGALL etc.). In particular, countries were encouraged to share results of their R&D and to use existing R&D instruments available within the Euratom research programme.

Expected level of performance: Participation in international R&D projects, experience exchange within groups of common reactor design and the use of existing international databases are used to improve the effectiveness of the NPPs OAMP.

Methodology for scoping the SSCs subject to ageing management

The regulatory framework in several countries requires the application of ageing management processes to both active and passive SSCs in accordance with WENRA SRL and IAEA Safety Standards. In some countries, ageing management is applied mostly to passive SSCs, whereas ageing of active SSCs is managed via maintenance or other surveillance processes.

The peer review noted that countries have different approaches to determine which SSCs are subject to ageing management

The peer review concluded that OAMP should apply to all safety significant SSCs including:

- SSCs necessary to fulfil the fundamental safety functions
- Other SSCs whose failure may prevent previous SSCs from fulfilling their intended safety functions.

For selecting the SSCs subject to ageing management, some countries consider SSCs credited in the safety analyses (deterministic and probabilistic) for other events such as external or internal hazards, Station Black Out and Design Extension Conditions.

During the workshop, the representative of the IAEA explained that there is work ongoing to clarify guidance in this area of scoping of SSCs (DS485 to supersede NS-G-2.12 in the near future). Therefore, after this new IAEA Safety Standard (Specific Safety Guide on Ageing and Development of a Programme for Long term Operation of Nuclear Power Plants) is published, countries should analyse whether their approach to scoping of SSCs complies with the new IAEA Safety Standard.

<u>Expected level of performance</u>: The scope of the OAMP for NPPs is reviewed and, if necessary, updated, in line with the new IAEA Safety Standard after its publication.

Delayed NPP projects and extended shutdown

The time period from start of construction to operation may be relatively long, in particular if unexpected delays occur in the project. A few countries emphasised the importance of raising awareness of this possibility and implementing an effective OAMP during construction for ensuring the original capabilities of safety significant SSCs are preserved for future operation.

This is also valid in the case of extended shutdown at operating NPPs. An extended outage can be unplanned, but also planned outages may be significantly extended beyond their intended duration. Both circumstances can lead to the need to manage ageing including new or different ageing mechanisms or effects.

Some countries faced prolonged duration of construction or extended shutdown and implemented an effective OAMP to address ageing management issues.

<u>Expected level of performance</u>: During long construction periods or extended shutdown of NPPs, relevant ageing mechanisms are identified and appropriate measures are implemented to control any incipient ageing or other effects.

Overall Ageing Management Programmes of research reactors

The NARs covered research reactors with a power equal to 1 MWth or more. Some countries reported, on a voluntary basis, on research reactors with a power below 1 MWth.

Each research reactor covered by the NARs is specific and unique by the design, age, purpose etc. The overall scope of AMPs for the research reactors is limited in comparison to NPPs. In several cases the NARs stated that the OAMP is not systematically implemented by the research reactor licensees, nor sufficiently formalised. However, when such a programme exists, the requirements have been developed for example on the basis of the IAEA Specific Safety Guide No. SSG-10: Ageing Management for Research Reactors[26] and IAEA-TECDOC-792: Management of research reactor

[26] https://www-pub.iaea.org/books/IAEABooks/8412/Ageing-Management-for-Research-Reactors

ageing[27]. WENRA has already initiated activities to establish SRLs for research reactors, including their ageing management. The TPR supports the WENRA effort to define SRLs for research reactors.

<u>Expected level of performance</u>: A systematic and comprehensive OAMP is implemented for research reactors, in accordance with the graded approach to risk, the applicable national requirements, international safety standards and best practices.

4.2.4. Challenges

Effectiveness of the OAMP and use of performance indicators

There are a variety of approaches in countries to evaluate the effectiveness of the OAMPs including the use of indicators and other tools such as internal audits. The effectiveness of the OAMPs could be measured by means of specific indicators through tracking and assessment of the activities defined in the AMPs. Some countries reported on development and the use of performance indicators such as:

- Material condition with respect to acceptance criteria
- Data trends relating to degradation / failure
- Comparison of preventive and corrective maintenance efforts (e.g. in terms of person-years or cost)
- Number of recurrent failures and occurrences of degradation, etc.

Such performance indicators might be established at component level, system level and plant level. Indicators are considered important for the evaluation of the effectiveness of the OAMPs.

<u>Challenge</u>: Indicators are considered important for the evaluation of the effectiveness of the OAMPs but no unified approach is available. Further development of improved performance indicators or other appropriate tools would enable consistent evaluation of the effectiveness of the OAMPs among NPPs.

4.3. Conclusion

The participating countries demonstrated that they have taken steps to ensure that an effective overall OAMP is implemented at the NPPs, in order to guarantee the availability of required safety functions throughout the service life of the plant.

The regulators of the participating countries have established specific requirements for ageing management and implemented them in national legislation or guidance, in line with the IAEA Safety Standards and WENRA SRLs. Therefore, the application of the IAEA Safety Standards and WENRA SRLs on ageing management contributed towards a greater consistency amongst the European countries. WENRA RLs might be more demanding than international standards (e.g. IAEA, US NRC): the European national regulators made the commitment to improve and harmonize their national regulatory system by implementing those.

The OAMP is accomplished in practice through the coordination of existing programmes (including maintenance, in-service inspection and surveillance) as well as through technical support programmes (including analysis of any ageing mechanisms), and external programmes such as research and development. Moreover, in several countries, findings of peer reviews performed by external organisations (e.g. IAEA) are also used to improve the existing AMPs.

According to the NARs, the OAMPs for NPPs can be considered sufficiently comprehensive and meeting the requirements of national regulations and international standards, and are therefore

[27] https://www-pub.iaea.org/MTCD/publications/PDF/te_792_prn.pdf

considered adequate. Many of the participating countries recognized numerous good practices for AMPs, but the NARs also identified challenges and areas for improvement.

However, due to the different design features of the NPPs and their SSCs as well as differences in the regulatory framework, ageing management approaches are not identical across the countries. In particular, countries have different approaches to determine which SSCs are subject to ageing management.

With regard to research reactors, a number of regulators consider that the management of ageing by research reactor licensees needs to be more formalised: ageing management of the research reactors is often based mainly on the maintenance programmes and on periodic checks and tests.

This TPR has provided a useful forum for sharing experience in relation to OAMPs for both NPPs and research reactors. The peer review process offered a good opportunity for experts from participating countries to understand the differences in the regulation and implementation of OAMP and make use of lessons learned for identification of further improvements.

The TPR identified a good practice related to the peer reviews of licensees' AMPs, which is the use of external peer review services, both for NPPs as well as for research reactors, to obtain an independent assessment of whether the OAMPs are consistent with IAEA Safety Standards and generally accepted practices, and to identify areas for improvement.

The TPR highlighted in particular the following findings and defined them as the expected level of performance:

- International exchanges were recognized as a key element to improve the OAMP. In particular, countries were encouraged to share results of their R&D and to use existing R&D instruments available within the Euratom research programme.
- The scope of SSCs subject to ageing management. Countries will benefit from the ongoing work by IAEA to clarify guidance in this area and should review their approach with regard to the new standard;
- An effective OAMP to address ageing management issues, which could be induced by a prolonged construction period or shutdown,

The review also highlighted a European wide challenge where further development of improved performance indicators or other appropriate tools would enable more consistent evaluation of the effectiveness of the OAMPs among NPPs.

For the NPPs, the TPR concluded that the OAMPs are well-established in the participating countries.

Nevertheless, significant differences in the national approaches remain concerning research reactors. WENRA has already initiated activities to establish SRLs for research reactors, including their ageing management. The TPR supports the WENRA effort to define SRLs for research reactors. Moreover, the TPR defined an expected level of performance which requires that a systematic and comprehensive OAMP is implemented for research reactors, in accordance with the graded approach to risk, the applicable national requirements, international safety standards and best practices.

5. EUROPEAN PLANTS ASSESSMENT RELATIVE TO ELECTRICAL CABLES AGEING MANAGEMENT

5.1. Description of present situation of plants across Europe

5.1.1. Regulatory basis for safety assessment and regulatory oversight

There are no major differences in the regulatory basis of the ageing management activities for cables among the different reactor types across Europe (VVER, BWR, PWR, AGR, CANDU...). The AMPs are clearly driven by the types and characteristics of the cables installed and their utilisation, in compliance with the national regulatory requirements.

For most of the countries, there are no precise national requirements regarding ageing on electrical cables in the nuclear regulations, although sometimes specific national requirements on cables can be found in other regulations e.g. in the Construction Law. In at least one country, the frequency and the extent of the measurements of electrical cables' insulation in NPPs are defined in the legislation.

In order to assess the AMP, including different testing methods on electrical cables, regulators typically rely on the international standards and references (e.g. GALL and IGALL; EPRI and IEC).

5.1.2. Ageing assessment for electrical cables

Cables play an important role, as safety systems are dependent on power supply and control of the plant is dependent on signals from the instrumentation. In the context of this TPR, three categories of electrical cables are considered:

- High voltage (HV) cables (above 1 kV) subject to adverse environment;
- Medium voltage (MV) cables buried or in trenches (380 V to 1 kV);
- Neutron flux instrumentation cables.

Safety-significant cables are (or should be) qualified for the environment they are subject to. This is to ensure their operability for the duration of design life including postulated accident conditions. The qualification should be reviewed in case of extended life of operation. However, despite the qualification, the operability of the cables cannot be taken for granted, as the environmental stressors might change from those originally envisaged or effects may exist that weren't accounted for during qualification. Therefore the cables and their environment need to be monitored and the results of cable qualification verified throughout their lifetime.

The ageing assessment needs to consider not just the cable's conductor but rather all of its components. It is commonly found that the most vulnerable parts of electrical cables are the jacket, the insulation and the termination of the cables. In most cases the jacket and the insulation of the cables are made of polymeric materials such as polyvinyl chloride (PVC), ethylene propylene rubber (EPR), polyethylene (PE) or cross-linked polyethylene (XLPE). These materials can be damaged by environmental stressors e.g. temperature, radiation, chemical or mechanical impact, humidity and Joule effect, as well as induced electrical field (MV and HV cables). For all these stressors, degradation could affect the cable's functionality in particular when their level is beyond the manufacturers' specification or when one or another stressor has not been considered in the qualification programme.

The main mechanisms impacting the insulation and the jackets are:

- migration of additives,
- treeing phenomena[28]
- dehydrochlorination initiated by temperature, and

[28] an electrical pre-breakdown phenomenon where partial discharges progress through the stressed dielectric insulation in a path resembling the branches of a tree

- oxidation influenced by temperature and dose rate.

The main mechanisms impacting the terminations of a cable (mostly MV and HV cables) include mechanical damage thermal cycling, vibration and oxidation. Those could lead to local elevated temperature of the core cable and accelerate the degradation of the insulation.

5.1.3. Main approaches to ageing management applied to electrical cables

Nuclear power plants

As the reliance on international standards and guides is widespread, the AMPs on cables in many countries share similar features. The structure and elements of the AMPs as reviewed in the TPR follow some general principles/steps:

- All the cables installed in the NPP (HV, MV and I&C) are identified and recorded.
- Those in the scope of the AMP are selected. Reflecting the information in the NARs, many countries establish AMP activities only for the safety-related cables. Few have included cables which are important for the generation of electricity, and even fewer have included all the cables in their programmes. Including all cables in the AMP might be useful as many of the non-safety and the balance of plant (conventional plant) cables would have similar insulation material and might be subject to comparable stressors. Having all the cables included in the AMP allows the data collected to be extended and to follow up degradation, effectively broadening the population and in this way reducing uncertainties.
- The cables are categorised depending on the operational characteristic (e.g. voltage) and the specifics of a cable itself (e.g. insulation material), the manufacturer and other distinctive features, such as the nature of a cable’s core (e.g. single or multi core), to establish distinctive categories of cables (sometimes called “ cable commodity”).
- By means of periodically repeated inspections and walk-downs, but also using specific techniques and equipment, the stressors for the cables in their operating locations are established.
- If a cable is found to be subject to an operating environment harsher than the specification, special attention is given to the intensity of the stressor (e.g. temperature). Those cables or sections are (or could be) subject to increased monitoring or some other actions (e.g. removing a hot spot; replacing a cable with different type, etc.) to assure operability.
- For each group of cables having common features, a sample of cables is selected for testing, typically those that are subject to the highest stresses. These tests would range from visual inspections (e.g. to identify cracking or changing of colour of the jacket or embrittlement) over various electrical tests to tensile properties tests (namely elongation at break),
- The nature of tests is defined for specific cable groups. For HV and MV cables, the common tests are the measurements of the resistance of the insulation, the tangent delta and the partial discharge test.
- The results of the various cable tests can lead to an increase of the frequency of tests (regarding degradation kinetics), an increase of the number of cables to be tested, to rerouting or even replacing of cables.

In addition to those tests that are implemented as a part of surveillance of operating cables, some countries follow up the degradation of cables in locations exposed to increased stressors (e.g. in terms of temperature and dose rate), which results in accelerated ageing. For that purpose, cable segments are placed at locations of increased stressors (cable deposits). This allows the collection of information on changes in properties due to increased environmental stressors, which represent accelerated ageing conditions.

Other countries prefer to leave cables which are no more used (e.g. resulting from modifications) in place, which reflects the actual environment of such cables.

These cables (those either being accelerated aged or not) are then subject to other tests to verify the validity of their qualification: typical tests on such samples include measurement of the tensile strength and elongation at break, or measurement of concentration of degradation products (through the use of physic-chemical characterization methods such as Fourier transform infrared Spectroscopy (FTIR), etc.). Results of those tests are used to re-qualify cables for further use in NPPs including LTO.

Research reactors

The cables for research reactors might be subject to comparable localised environmental stressors as those of the NPPs. However, the scope of AMPs for the research reactors is often limited in comparison to NPPs. Significant differences in the national approaches exist. Nevertheless, for most of the research reactors, the AMP is less formalized. Some licensees operating complex research reactors are already committed to develop an AMP that might be comparable to NPPs. Others implement actions on case-by-case basis, which might be justified especially for some smaller and less complex research reactors.

5.1.4. Licensees' experience and regulators' assessment regarding ageing of electrical cables

Nuclear power plants

Operating experience

Although significant quantities of cables are installed in NPPs, relatively few cable failures have been recorded. The examples recorded include an operational failure of a cable located in a damp zone of a cable trench. Nevertheless, important operating experience has been collected, in particular in areas where high stressors are occurring, or cables are deployed in specific and challenging circumstances, including inaccessible locations where degradation cannot be observed or identified.

Several countries have reported cable replacements for various reasons. Visual inspections and mechanical and electrical tests within cable AMPs have revealed not only ageing degradation, but also design or installation defects, leading to preventive replacement before actual failures. Sometimes environmental monitoring has revealed hot spots (higher temperature or irradiation than postulated for the initial qualification programme), and actions have been taken not only by reducing the environmental stressors, but also rerouting and replacing exposed cables. Furthermore, some cables have been replaced due to obsolescence of certain cable types, or proactively with environmentally more resistant cable types. Early detection and replacement actions taken are indicators of efficient cable AMPs.

Several examples of such experience are described below:

- Systematic undertaking of visual and thermographic inspection to assess the environmental conditions in a plant revealed dozens of cables being in or close to a hotspot where the temperatures were higher than the manufacturer's specifications. While none of the cables had yet failed, preventive replacement of those, and others that might be under similar environmental stressors was initiated. Actions were also taken to limit the stress impacting new cables.
- Visual inspections and mechanical tests revealed that the outer sheath of a certain cable type was in a degraded condition. Due to early detection, action was taken before any failures occurred, and all cables of this specific type were replaced.
- Accelerated radiological and thermal ageing showed a reduction in insulation resistance under LOCA conditions, leading to replacement with cables of other insulating materials.
- Replacement of oil-filled cables with XLPE-insulated cables due to obsolete technology and spare part availability issues, replacement of existing cables by fire-retardant cables, replacement of in-

containment cables with those capable of withstanding the post LOCA-conditions for longer durations.

Additionally, useful operating experience is obtained from events at NPPs and from results obtained through surveillance programmes, including e.g. overheating and fire on PVC insulated cables leading to the generation of hydrochloric acid (or volatile chlorine compounds), or damage caused by water trees, etc. The review of plant documentation occasionally identifies cables not being qualified for the environment those are deployed in or for functions they are supposed to fulfil.

The operational experience collected and then shared within the industry is an important element of a proper implementation of AMP for cables. As documented in the NARs, practically all countries place high relevance on the use of their own and international operating experience.

Regulator's assessment

As documented in the NARs, most of national nuclear safety regulators consider the AMP programmes on cables both effective and compliant with the international guidance and standards. Nevertheless, in some cases improvements are sought e.g. one case where the AMP was still under development and an inspection by the regulator determined that there were neither acceptance criteria for cables nor consideration for hotspots.

During the last decade, some regulators have required improvements to cable AMPs. Several licensees have improved their AMP through a better characterization of the degradation of cables. Taking selected cables from the plant (that were subject to high levels of stress) allows laboratory characterization tests and the development of advanced ageing indicators, to better predict expected degradations. The most degraded ones are then submitted to qualification tests to test their ability to perform their function under accident conditions.

Some regulators also raised concerns on the AMPs or its elements. An example is whether the initial environmental qualification (EQ) justifies the exclusion of EQ-qualified cables from AMP. As international research programmes on cable ageing had identified uncertainties of the qualification processes, a regulator recommended verifying the validity of licensees' EQ processes.

Some regulators indicated limitations related to cable deposits and their use in assessing accelerated ageing. One regulator points out possible mismatch between the deposits and the actual cables used, i.e. the fact that for some safety-related cables there are no adequate deposits that would allow analysis of the impact of ageing. Another regulator is concerned about the future availability of the deposits, as these are kept in another plant that is planned to shut down.

Nuclear instrumentation (NIS) cables are often inaccessible, and some regulators expressed their concern about the effectiveness of the condition monitoring activities. In such cases, regulators recommend further investigations to improve or extend testing methodologies for better assessment of ageing degradation.

Research Reactors

The NARs highlighted that for research reactors, the AMP for cables is neither comprehensive nor formalized. However, safety-relevant cables are already subject to regular inspection and testing activities even when a formal AMP is not yet established. As mentioned above, some countries reported the on-going development of a more comprehensive approach to ageing management for their research reactors. As mentioned in chapter 4, the TPR considers that a systematic and comprehensive OAMP should be implemented for research reactors, in accordance with the graded approach to risk, applicable national requirements, international safety standards and best practices.

5.1.5. Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

NARs document a variety of measures that were identified or considered for implementation in the future. These fall into several categories, such as development of full AMP, interim assessments of results and updates of AMPs, modification of testing and inspection practices as well as utilisation of new or different methods for ageing management, as well as updates of the documentation of AMPs.

New AMPs on cables are planned where they do not yet exist, in particular for some of the research reactors. One example is from Poland where a new AMP for cables will be prepared for the research reactor. In Norway, current AMPs on cables of both research reactors will be extended into a comprehensive AMPs. In Romania, a global life-assessment study for electrical cables in NPP has been launched including the assessment of the effectiveness of AMP. In Sweden the regulator ordered a licensee to implement the AMP for cables before the end of January 2019. In the Czech Republic, safety cables of the research reactor will be included in the AMP.

Modification of testing procedures and inspections are planned or being implemented in research reactors in the Netherlands and Poland, and in NPPs in the UK. In Slovenia, a procedure for diagnostic testing of cables is being implemented. In Spain, the surveillance of cables located inside metallic ducts or cable trays and consequently not accessible for visual inspection should be improved.

The updates of documentation, including technical guidance in cable monitoring are progressing in the UK. In Romania the AMP manual for NPPs is to be updated.

The convergence of methods for the cables' condition monitoring is being required in the UK.

5.2. Assessment of electrical cables ageing management at the European level

5.2.1. Consistency of approaches used in Europe between countries and with international requirements

For NPPs, almost all countries have based or at least compared their AMP on cables to the international recommendations and standards, and therefore those AMPs are reasonably consistent. However, as some of those requirements are at a high level, there are differences in the details of application. Some of the international documents nevertheless provide more detailed recommendations, e.g. IAEA Technical Report NP-T-3.6 on cable deposits[29], IGALL or US NRC GALL, which is used in some EU countries.

When looking into more detail, there are variations in acceptance criteria, inspection / testing methods and intervals, sampling of cables for condition monitoring, etc. This is understandable given a large variety of cable material types, manufacturers' specifications, application (and associated stressors), design requirements, etc.

A detailed comparison of the various methods used for AMP has not been possible within the TPR due to the multitude of approaches, but also due to sometimes low level of detail provided in NARs. Some examples of differences that could be observed include:

- Treatment of environmentally qualified (EQ) cables within the AMP: one country appears to exclude EQ cables from the formal AMP. Nevertheless, those cables are subject to visual inspections, and the environmental conditions are followed. Some countries following US practices consider the EQ as an equivalent to time limited ageing analysis (TLAA), and do not

[29] https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1554_web.pdf

have sampling practices for laboratory tests of naturally aged cables. Some other countries, not following US practice, also do not practice such testing. One regulator has specifically recommended licensees to include EQ cables in the scope of AMP.

- Sampling from aged cables for ageing follow up (either special cable deposits or cables removed from operation): Many countries take samples from the plant at regular intervals to assess the cable condition and its residual lifetime through laboratory tests.

Research reactors

The scope of the AMP for cables for research reactors varies across the different countries, especially with regard to the inclusion of the power cables in maintenance and testing activities. For some research reactors power cables are not classified as safety-related due to the specificity of the design and are not included in the AMP. For some research reactors only the instrumentation and control cables for the nuclear instrumentation of the reactor are relevant for AMP.

The TPR considers that the ageing of safety-related cables should be monitored and managed. Design features, cable safety significance and some specific events, e.g., fire, should be adequately taken into account in identifying the cables that must be included in an AMP for research reactors. It should be considered however, that in research reactors, only a limited number of components are relevant for safety. A graded approach therefore needs to be considered.

Similarly to NPPs, the AMP for research reactors should rely on a comprehensive approach to determine the stressors and related degradation mechanisms. This must take into account observable indicators, environmental stressors, service conditions, and the potential consequences of taking no action. International practices and guides are available such as EPRI checklists or IAEA guides.

The inspection activities should have the objectives of detection, monitoring and trending ageing degradation. The inspection activities should take into account the nature of the cables, their location and stressors and their operating conditions, and should be described in terms of periodicity, size of samples and techniques.

5.2.2. Good practice

The peer review identified the following good practices.

Characterize the state of the degradation of cables aged at the plant

One method of monitoring the ageing of cables is to use samples taken from the plants. Some countries deposit pieces of cables in the areas of high stress, and others leave inactive cables in situ to be subject to ageing in their representative environment. Both approaches have advantages but also limitations that have to be considered.

Using cable deposits instead of operating cables from the plant does not disrupt operating cables, and permits their placing in the locations of the highest stressors. For formerly operating cables, it is important to test the most stressed part (heat, radiation, etc.) of the cable even when the whole length of a cable is removed. Techniques of assessing cables' characteristics such as elongation-at-break of insulation material, insulation resistance, FTIR and other cable testing techniques support estimating the residual lifetime and ability of cables to withstand the design basis accident environment. This ability is generally verified by performing additional ageing and accident tests on a limited set of aged cables coming from the plant.

Good practice: Cables are aged within the actual power plant environment and tested to assess cable condition and determine residual lifetime

5.2.3. TPR expected level of performance

The topics below were recognised as the expected level of performance during this TPR and therefore recognised as a good performance for those countries which already meet this expectation and as an area for improvement for the others.

Nuclear power plants

Documentation the cable ageing management program

Documentation of the cable AMP is done by the countries in different ways and many formats could fulfil the objectives:

- AMP of cables should be documented in a complete way (including identification number, manufacturer documentations, materials, characteristics, degradation mechanisms, diagnostic methods, remedial actions, new international experience for the material, measurement methods and complete / periodical review schedule) ;
- All investigations, calculations, type-tests and procedures must be traceable to the installed cables in the plant.

Expected level of performance: The AMP is sufficiently well-documented to support any internal or external reviews in a fully traceable manner.

Methods for monitoring and directing all AMP-activities

Due to the large number of cables in NPPs, having methods to record and monitor characteristics and eventual degradation of those cables and support the AMP should be considered. During the TPR, some countries reported on very sophisticated databases where all the plant cables are recorded and various AMP activities directed, depending on the cable conditions. In particular, for countries having limited experience, the importance of broadening the sources of information is highly relevant. One country reported on the plant vendor maintaining and populating the database with records of cables from multiple plants in other countries.

Expected level of performance: Methods to collect NPP cable ageing and performance data are established and used effectively to support the AMP for cables

Systematic identification of ageing degradation mechanisms considering cable characteristics and stressors

After more than 30 years of operating experience, many degradation mechanisms have been identified involving combination of stressors (temperature, radiation, water, electrical fields) and cable materials (insulation, jackets). There are international guides to help NPP licensees to determine and to address those mechanisms.

The TPR determined that countries are generally consistent in the identification and analysis of the various degradation mechanisms. However, some ageing mechanisms/stressors or their actual intensity and effects on cables may have been missed when establishing the initial qualification programme (for example water trees for cables qualified in the early 1980s). These need to be addressed in EQ verification and/or cable requalification.

For this purpose, other industries' operating experience and practices may be useful for the nuclear industry, as similar/comparable cables are used and those might be subject to comparable stressors. International exchanges to collect information are also available (OECD NEA failures database, experts groups from IGALL, etc.).

Expected level of performance: Degradation mechanisms and stressors are systematically identified and reviewed to ensure that any missed or newly occurring stressors are revealed before challenging the operability of cables.

Prevention and detection of water treeing

Water treeing is a process that causes degradation of insulation performance. Water trees are one of the major causes of premature ageing and failure of extruded high-voltage polymeric cables without water-impermeable barriers. A water tree is typically initiated in the insulation's micro-cavities (defect of insulation, fatigue cracking, localized heating due to impurities). Partial electrical discharges cause the propagation of water trees by degrading insulation and creating chemical conditions that could increase the size of cavities. When the length of a water tree increases, the electric field in front of the degraded area is amplified.

Preventing or minimising the growth of water trees can be achieved by minimizing stressors contributing to the growth of water trees. In some countries, this is achieved by ensuring that the cables are not subject to submerging or high humidity. It can also be achieved by use of methods available to detect this phenomenon, such as time-domain reflectometry, partial discharge, tangent delta, and polarization current measurement. One country uses a newly developed dielectric broadband spectroscopy.

<u>Expected level of performance</u>: Approaches are used to ensure that water treeing in cables with polymeric insulation is minimised, either by removing stressors contributing to its growth or by detecting degradation by applying appropriate methods and related criteria

Consideration of uncertainties in the initial EQ

EQ (environmental qualification) cables are likely to be originally qualified according to Environmental Qualification Standards (e. g.: IEEE-383-74). However, the qualification methods based on accelerated ageing and Design Basis Accident tests include uncertainties. Two international studies[30] [31] found that there are uncertainties in the qualified lifetime projected from the cables' environmental qualifications. Another report[32] points out that those uncertainties must be taken into account.

The uncertainties are mainly due to lack of accuracy in representing the accelerated ageing sequences applied (dose rate, choice of temperature for thermal ageing, etc.). Due to these uncertainties, the EQ process may be not representative of the actual conditions that cables will experience under normal and design basis accident (DBA) conditions at the plant. In some countries, the stress profile used during the qualification programme might not encopass the most limiting design basis accident sequences.

The AMP on cables creates conditions for assessing actual degradation and therefore evaluating the accuracy of the representation of the ageing sequence used in the initial qualification. The outcome from the AMP could therefore be used to improve the EQ process. For the requalification or for new accelerated-ageing tests, the practices that could limit the uncertainties include application of simultaneous thermal and radiation ageing, application of low thermal acceleration factors and dose rates, use of accurate activation energy values, and feeding oxygen into chamber during DBA test, etc.

<u>Expected level of performance</u>: The accuracy of the representation of the stressors used in the initial Environmental Qualification is assessed with regard to the expected stressors during normal operation and Design Basis Accidents.

[30] IAEA Nuclear Energy Series report NP-T-3.6 (2012)
[31] Sandia Report 2013-2388 (2013)
[32] IGALL TLAA-201, "Environmental Qualification of Electrical and I&C Equipment"

Determining cables' performance under highest stressors

The ageing of cables subject to highest stressors might result in cracks in the insulation, absorbance of humidity within insulation, etc. These degradations may affect redundant trains, e.g. exposing safety systems to common cause failures. As simultaneous failure of redundant cables and a consequent common cause failure of a safety systems is not postulated in the safety demonstration, determining the cable's performance under highest stressor environment (at short-, medium- and long-term) is of high importance, especially for cables that are necessary for accident mitigation. The TPR determined that:

- An adequate evaluation of the magnitude of the high stressors is essential to ascertain that the cables are able to perform their functions under Design Extension Conditions ;
- Such an evaluation needs to consider the cables that have been subject to stressors in their operating environment, and justifying through tests.

Such an approach would demonstrate that aged cables are still able to perform their functions under Design Extension Conditions.

<u>Expected level of performance</u>: Cables necessary for accident mitigation are tested to determine their capabilities to fulfil their functions under Design Extension Conditions and throughout their expected lifetime.

Techniques to detect the degradation of inaccessible cables

Multiple techniques are available and being used to detect the degradation of inaccessible cables. It should be noted, that the cable material also has a major influence on the choice of methods. The choice of popular methods includes:

- Insulation resistance measurement (for MV, LV, SIG[33]) ;
- Conductor resistance/impedance measurement (for MV, LV, SIG) ;
- Dielectric loss factor measurement (Tan δ, phase angle) (for MV) ;
- Signal transmission behaviour (time/frequency domain) (for SIG) ;
- Line Resonance Analysis (LIRA) (for MV, LV, SIG) ;
- Isothermal Relaxation Current Analysis (for MV) ;
- Partial discharge measurement (for MV).

Nevertheless there is room for European level research e.g. into determining effective surveillance testing for inaccessible cables (e.g. cables in conduits or buried).

<u>Expected level of performance</u>: Based on international experience, appropriate techniques are used to detect degradation of inaccessible cables.

5.3. Conclusion

The operability of cables should be guaranteed throughout the lifetime of NPPs, including LTO where applicable, for all operational and accident conditions, including severe accidents. Operability is ensured by the design concept i.e. selection of appropriate cables for specific applications, as well as by qualification of the cables for their environment in which they operate. Nevertheless, the cables need to be monitored to ensure that the design conditions remain as expected and that their qualification remains valid. This is normally ensured by the AMP for cables. This applies to all NPPs and to most research reactors (although, as seen in this TPR, some research reactors do not need power supplies to ensure safety and therefore do not use qualified cables).

[33] LV = low voltage cables, SIG = signal cables

Based on the NARs, the NPPs in all countries have extensive AMPs in place, while only a minority of research reactors have introduced a comprehensive AMP. While the AMPs are broadly comparable in their general objectives, the details vary significantly. This is the consequence of the multitudes of the types, manufacturers, characteristics etc. of cables installed in NPPs but also very different environments those cables might be subject to depending on the NPP design. Therefore, the direct comparison of different AMPs is not possible but also unnecessary: what is relevant is that the AMP results in ensuring the operability of cables in the circumstances it is exposed to.

The TPR concluded that the AMPs on NPP are generally satisfactory, though some specific improvements may be needed. In particular, the TPR recognized that operators are committed to continue the implementation of AMPs on cables and to make further improvements, in particular related to implementations of new methods or technological solutions. The regulatory oversight is robust, with some selected improvements advised or requested.

The TPR identified a good practice related to cable ageing with samples aged at the plant (cable deposits or cables taken out of operation). The TPR also defined expected levels of performance in several areas, as listed below:

- the documentation of the cable AMP,
- the methods for monitoring and directing all AMP-activities,
- the systematic identification of ageing degradation mechanisms,
- the prevention and detection of water treeing phenomenon,
- the consideration of uncertainties in the initial Environmental Qualification,
- the determination of cables’ performance under highest stressors,
- the techniques to detect the degradation of inaccessible cables.

The situation is however different for research reactors, where systematic AMPs for cables are generally not in place. Nevertheless, most of the research reactors have some elements in place for cable ageing oversight. The main objective for the future is to ensure that research reactors have a comprehensive AMP proportional to the risk significance. In this respect, research reactor licensees could learn from NPPs AMP, in particular on the methods and criteria that could be used at RRs.

At the European level the TPR identified that there is cooperation in terms of exchanging experience and improvement of common knowledge. Further cooperation and exchange of experience is encouraged, in particular related to methods and criteria but also operational records on specific cable types. Although technologies exist, there is also room for European level research e.g. into determining effective surveillance testing for inaccessible cables.

6. EUROPEAN PLANTS ASSESSMENT RELATIVE TO CONCEALED PIPEWORK AGEING MANAGEMENT

This chapter summarises the results of the ENSREG Topical Peer Review of ageing management practices for concealed pipework at NPPs and Research Reactors.

6.1. Description of present situation of plants across Europe

6.1.1. Regulatory basis for safety assessment and regulatory oversight

In considering the applicable standards for ageing management of concealed pipework (as defined within the scope of this TPR), there are no clear national or international standards available. The closest to a common standard is that described in the IAEA's International Generic Ageing Lessons Learned (IGALL) project, which provides detailed information on specific programmes to manage ageing and degradation. For concealed pipework, the most relevant is IGALL AMP125: Buried and Underground Piping and Tanks, although this only provides principles to be followed and good practices. As high-level guidance, it does not provide the detail to confirm the effectiveness of an AMP.

A number of national standards are quoted in NARs. However, these either relate to ageing management topics, of which concealed pipework is only a part (for example, the German KTA 1403 Ageing Management in Nuclear Power Plants), or they relate to inspection practices (such as a number of standards of Russian origin quoted in the Bulgarian NAR). Although no clear standards were evident for defining ageing management processes for concealed pipework in the nuclear industry, countries did not identify this as a problem and neither did the TPR review. There are many other sources of good practice, experience and general pipework standards that can be used to develop effective AMPs. These include those from other high hazard industries with safety-critical pipework, such as the chemical processing, oil and gas industries. Countries have also used advice from the US NRC Generic Ageing Lessons Learned (GALL) report and the Electric Power Research Institute (EPRI), whose BPWORKS™ software was quoted by many countries as a key tool in defining an effective AMP for concealed pipework. Whilst this tool is undoubtedly a valuable aid, and is reportedly used successfully in the USA, its use in Europe is relatively recent and so it cannot yet be regarded as proven to be effective for concealed pipework in the countries within this TPR, as is noted in a number of NARs.

6.1.2. Ageing assessment for concealed pipework

The TPR Terms of Reference define the scope of this section as concealed pipework important to safety for all pipework designs where the pipework is:

- Buried in soil,
- Encased in concrete, or
- In covered trenches.

The definition of concealed pipework in this section of the TPR was intended to limit the scope of the NARs and make their review manageable. Although this aim was achieved, as this grouping is not one used in day-to-day ageing management, it still led to some variability in the extent of pipework AMPs described in the NARs. This variability was evident even between countries with nominally identical reactor types, although there may well be differences in construction that would explain the apparent differences in approach between NARs.

Consequently, the NARs do not give a consistent approach to enable a ready comparison between countries. For example, Bulgaria and Czech Republic have VVER-1000 Model V320 nuclear power plants but the Bulgarian NAR considers only the Component Cooling Water System (Essential Cooling

Water System), whereas the Czech NAR considers a more extensive range of systems. This is simply a reflection of the report contents, rather than a real difference in the approaches to ageing management. Both approaches are acceptable, provided the overall scope of ageing management across the range of safety significant systems is appropriate. In this instance, both countries' regulatory bodies were satisfied with the approach taken and no concerns were raised in relation to these differences during the TPR.

Most countries NPPs and research reactors do not have a separate "AMP for concealed pipework" that can be referred to and described in NARs. Instead, there are a series of processes and procedures, which together manage ageing. This will include parts of the licensee organisation (for example, station chemists and civil engineers) which would not naturally regard their task as ageing management, but who have a vital part to play. This was considered to be an acceptable practice during the peer review process; the aim of the TPR is not to standardise practices but to build confidence in their adequacy, identify any areas where they can be improved and highlight good practices that others can learn from.

Another feature of NARs is that AMPs do not generally focus solely on the inaccessible parts of the system; rather the system is considered as a whole and the condition of inaccessible sections is predicted, based on the knowledge of accessible pipe sections, visual inspections, operating experience and the repair history. Again, this approach is entirely appropriate, but accounts for some of the differences between NARs.

All countries stated that the safety significance of the concealed pipework was a key consideration in development of suitable AMPs and that all safety-significant pipework was included. However, one clear area of difference between countries that emerged from the peer review of the NARs was that a number of countries explicitly stated that they go beyond this to include non-safety-related pipework whose failure may impact SSCs which deliver a safety function. This is reflected in the revision of IAEA Safety Standard NS-G-2.12 Ageing Management for Nuclear Power Plants[34].

In all cases, a knowledge of the potential or actual degradation mechanisms in a particular system is used to derive an appropriate AMP. Most pipework considered within the scope of the TPR was carbon steel or stainless steel. The principal degradation mechanisms for concealed pipework across European NPPs and research reactors, and which can ultimately lead to leakage or failure are:

- uniform corrosion, leading to wall-thinning, and
- pitting corrosion leading to localised loss of material.

Both mechanisms can occur from either the inside surface of the pipe due to the process fluid being carried, or from the outside, usually due to a breakdown in the barrier, such as a coating, intended to protect the pipework. These processes can be driven by other factors, such as microbiologically-induced corrosion, crevice corrosion or fouling, which alter the local environment and promote degradation. In addition, the Spanish NAR identifies stress corrosion cracking as a potential degradation mechanism for stainless steel piping carrying borated water. The Swedish NAR identifies the potential for stress corrosion cracking on the outside of pipework at Ringhals Reactors 2-4 due to exposure to chloride.

6.1.3. Main approaches to ageing management applied to this specific area

Common protective measures against corrosion damage are implemented at the design and installation stage, through selection of materials and the application of protective measures on external and/or internal surfaces. These often include painted, plastic or bitumen coatings, cement

[34] https://www-pub.iaea.org/MTCD/publications/PDF/Pub1373_web.pdf

mortar lining or cathodic protection. Good design and installation is fundamental to successful long-term operability.

The AMPs for all countries are based to some extent on inspection. The periodicity and number of locations inspected in a system depends on a range of factors, which include the safety function of the pipework, the degradation mechanism and expected rate of progression and operating experience. The most widely used techniques are successful at monitoring wall thinning from general corrosion. They include visual inspection of the external pipe surface during excavation works, visual inspection of the inner surface during maintenance, local ultrasonic thickness measurement, eddy current measurement and radiographic testing. The nature of these inspections is that they are often performed at accessible locations; hence, care needs to be taken with extrapolation of the results, as the local conditions at such locations may not be representative of the concealed parts of the system. Ageing management processes need to balance the need to gather sufficient data on the concealed parts of a system with the damage to the protective coating caused by such inspections. The German NAR states that, based on positive operating experience, they do not recommend uncovering buried pipework for inspection, due the risk of mechanical damage from the required earthworks. Hence, it is vital that opportunities for inspection are taken at other locations, whenever a concealed system is uncovered for another purpose. This point is discussed further in section 6.2.3.

Other successful inspection processes were reported. These included aerial thermography to identify areas of water leakage outside the plant (in the Czech Republic NAR) and measurement of direct current potential drop on water pipes to identify areas of damaged asphalt insulation (also Czech Republic). The integrity of concrete-covered carbon steel pipework is monitored through periodic measurement of settlement (for example, in the Netherlands NAR) or is monitored by georadar inspections (for example in the Slovak NAR). NPPs in a number of countries have corrosion loops, which allow periodic assessment of corrosion of representative materials in the service environment. Given the challenge of obtaining sufficient inspection results, it is important that all opportunities to gather and use supporting data are taken. This can include relevant data from inspection programmes, which are themselves not related to concealed pipework.

The NARs gave numerous examples where operating experience (OPEX) has been used to inform ageing management of concealed pipework. There is widespread use of local, national and international OPEX. There are many existing fora for sharing OPEX and the TPR workshop highlighted the work of bodies such as the VVER Owners Group and also a VVER Regulators' Forum. Further detail of the range of groups available for sharing OPEX is beyond the scope of this report.

In relation to research reactors, there is much greater variability in the approaches to ageing management of concealed pipework than was evident for NPPs. This was to be expected for a number of reasons, which were explored during the TPR:

- Many research reactors are different from each other and so there are fewer opportunities to share relevant experience and good practice.
- The consequences of failure of concealed pipework are usually lower than for NPP.

These factors are considered in more detail in Chapter 4 of this report in relation to the overall approaches to ageing management.

There was a very wide variation in the amount of relevant pipework reported in NARs. Italy reported no concealed pipework at their research reactors and so reported on their AMP for all pipework. In contrast, Poland reported around 80m of concealed pipework. Hence, the variability in approaches to ageing management of concealed pipework for research reactors was considered an inevitable feature of this diverse range of reactors and the different approaches are considered acceptable by each country's regulatory body.

6.1.4. Licensees' experience and regulators' assessments regarding ageing of concealed pipework

Knowledge of the general and local environments is an important part of ensuring the operating conditions remain as expected and that the ageing management processes remain appropriate. A number of countries reported using the monitoring of the process fluid as an indicator of the health of the pipework system, using parameters such as system pressure or chemical analysis. Whilst this is useful to identify leakage (either through a loss of quantity or quality of the fluid), it is unlikely to be useful as a leading indicator of progressive pipework degradation. A number of NARs reported that pipework flushing is carried out, or that a biocide is used, to ensure the operating environment remains as expected. Such processes can be a useful contributor to reducing the potential for the formation of aggressive local environments. Regular electrical measurements were also reported to be effective to demonstrate the performance of cathodic protection systems, where fitted.

Seasonal variations of the environment can be another factor leading to failure of concealed pipework. For example, the Hungarian NAR highlights significant corrosion of buried pipework at the Budapest Research Reactor, one of the causes cited being the de-icing of nearby roads using salt. Similarly, the Belgian NAR identifies road salting as a factor in an increased corrosion rate for buried pipework at the BR2 research reactor.

A common problem identified across AMPs in many countries was that of understanding the original build conditions. A number of unexpected failures of concealed pipework have occurred due to poor construction practices, coupled with shortfalls in quality control and quality assurance at the construction stage, resulting in a failure to achieve the original design intent of the corrosion protection system. Several countries reported issues caused by backfill materials containing building rubble, which, over time, have caused mechanical damage to the protective coating on the external surface of pipework and allowed local corrosion to initiate and propagate. Such degradation is hard to predict and to take into account in AMPs and is often only detected due to leakage from, or failure of, the pipe. This emphasises the importance of licensees and regulators paying close attention to the specification and installation of repaired or replaced pipework sections to ensure that the corrosion protection system is fully effective in service.

The challenge of identifying a representative sample of pipework for inspection is particularly important, when the likely failure mechanism is localised pitting corrosion or stress corrosion cracking, since the most onerous environmental conditions may be some distance from a normally accessible location. This challenge is discussed further in section 6.2.4. This is where software such as EPRI's BPWORKS™ is often used to assist identification of vulnerable locations, together with local, national or international operating experience. A number of countries reported that inspection results from other similar systems were used to drive inspection and replacement of concealed pipework systems.

There was less evidence of pro-active pipework replacement at research reactors than at NPPs. The age of such pipework also varies considerably. Belgium reported extensive pipework replacement at the BR2 research reactor, although some concealed city water pipework, with no safety significance, remains. There has been significant pipework replacement at the French CABRI reactor, although the safety significant pipework is not concealed. Poland still has the original concealed pipework at the MARIA reactor, as the consequences of failure are considered low. Leakage is often the main, though not exclusive, driver for replacement. The Hungarian NAR noted corrosion on an inspectable section of pipework at the Budapest Research Reactor, leading to further investigations, which uncovered extensive corrosion in secondary pipework, which then required replacing.

There was some evidence that AMPs for concealed pipework are now being set up at some research reactors and that the TPR has reinforced this. The Belgian NAR identifies that the BR2 research reactor now has an action plan agreed with its regulator to fill agreed gaps in relation to pipework ageing monitoring with additional testing sampling and inspection activities. A tritium leak from a buried cooling water transfer line at the High Flux Reactor at Petten in the Netherlands led to an improved AMP with pipe condition monitoring. Italy will introduce an AMP for its TRIGA RC1 reactor following upgrades being carried out during 2018. In contrast, Romania reported that ageing management of concealed pipework is not explicitly considered at their TRIGA14MW reactor where the AMP consists mainly of monitoring and inspection of the integrity of the primary heat transport system. Similarly, Poland reported that two buried systems at the MARIA research reactor are not included in ageing management as the consequences of failure are low. These positions are accepted by both countries regulatory body.

6.1.5. Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

All countries used the TPR process to review their approaches to ageing management of concealed pipework and the NARs give a summary of their conclusions. A significant number of countries did not self-identify any further improvements that were necessary in this thematic area. However, the process proved productive for many countries and meaningful improvements will be made as a result. For example, in Belgium AMPs for concealed pipework have been recently extended for all units in the framework of the TPR self-assessment. Bulgaria will revise the scope, method and frequency of in-service inspection of equipment and pipelines. UK will consolidate its existing buried pipework inspection strategy with its wider corrosion management programme. Delivery of all the self-identified areas for improvement will demonstrably improve ageing management processes for concealed pipework in a number of countries.

The TPR process has also ensured close regulatory oversight of such AMPs, which has also been a driver for improvement. For example, the Swiss Regulator ENSI notes that it will now extend the focus of its regulatory efforts regarding ageing management to ensure that all safety-relevant concealed piping systems are covered by suitable maintenance and inspection programmes.

6.2. Assessment of concealed pipework ageing management at the European level

6.2.1. Consistency of approaches used in Europe between countries and with international requirements (IAEA, WENRA)

Overall, there was a good level of consistency in approaches to the ageing management of concealed pipework for NPPs. This was despite there being no clear national or international standards that only cover concealed pipework, and the wide variability in the scope of ageing management in NARs. The reasons for this variability are explored in section 6.1.2 above, although the absence of specific standards was not identified by countries or by this TPR process as a problem. Other general pipework standards are available as noted in section 6.1.1.

For research reactors, there was a much wider variability in approaches to ageing management of concealed pipework. At one extreme, there has been widespread pipework replacement; at the other, original pipework continues in service and will be allowed to run to failure as the safety consequences are considered tolerable (such as, the loss of normal water supply to the site). These different approaches are considered acceptable by each country's regulatory body.

6.2.2. Good practices

The peer review identified the following good practices.

Use of results from regular monitoring of the condition of civil structures

Given the challenge of getting sufficient inspection results, it is important that all opportunities to gather and use supporting data are taken. This can include relevant data from inspection programmes, which are not themselves related to concealed pipework. Although not unique in doing this, one NAR gave an example which noted that data from a civil structures inspection programme for building settlement, to identify the occurrence of cracks in walls, was used to inform their concealed pipework inspections, as any such settlement may initiate pipework damage.

Good Practice: In addition to providing information on soil and building settlement, the results from regular monitoring of the condition of civil structures are used as input to the ageing management programme for concealed pipework.

Performance checks for new or novel materials

A number of countries reported that concealed pipework had been repaired or replaced due to deterioration or leakage in service. An option during replacement, which was evident from a number of NARs, is to use alternative materials, which offer the potential to improve the subsequent performance of the pipework system. Where there is little relevant previous experience of a particular material in nuclear power applications, it may be necessary to rely on evidence from elsewhere or to find another means of demonstrating that the material performs as expected in the service environment. This is essential when failure may, directly or indirectly, affect delivery of a safety function. Demonstrating the performance of a new or novel material may be achieved in a number of ways: one NAR identifies that the required material properties of plastic pipes in the emergency cooling water system at an NPP are checked annually using retained samples of pipework from the manufacturing batch stored in river water. Another NAR describes large-scale replacement of secondary cooling systems using High Density Polyethylene (HDPE) piping, the performance of which is checked by removing sections of pipework from service after 4 years, and will be checked again after 10 years of operation to ensure that the properties are as expected.

Good Practice: In order to establish the integrity of new or novel materials, sections of pipework are removed after a period of operation and inspected to confirm the properties are as expected.

6.2.3. TPR Expected level of performance

The topics below were recognised as the expected level of performance during this TPR and therefore recognised as a good performance for those countries which already meet this expectation and as an area for improvement for the others.

Inspection of safety-related pipework penetrations

A number of countries reported that pipework penetrations were specifically excluded from their ageing management programmes. Evidence supporting these exclusions was not always available in the NARs, although the TPR workshop explored this topic to ensure that the reasons for exclusion were understood, as there is operating experience that pipework at or near penetrations may be vulnerable.

Expected level of performance: Inspection of safety-related pipework penetrations through concrete structures are part of ageing management programmes, unless it can be demonstrated that there is no active degradation mechanism.

Scope of concealed pipework included in AMPs

As noted in section 6.1.2 above, one clear area of difference between countries that emerged from the peer review of the NARs was that a number of countries explicitly stated that they go beyond simply including safety-related concealed pipework to also include non-safety-related pipework whose failure may impact SSCs which deliver a safety function. This will soon be reflected in the revision of IAEA Safety Standard NS-G-2.12 Ageing Management for Nuclear Power.

<u>Expected level of performance</u>: **The scope of concealed pipework included in ageing management includes those performing safety functions, and also non-safety-related pipework whose failure may impact SSCs performing safety functions.**

Opportunistic inspections

It is vital that opportunities are taken to inspect concealed pipework whenever a system is uncovered for another purpose. Examples were given during the TPR workshop where removal of the covers from a trench for electrical work was also used to inspect pipework in the same trench; at another site, excavations for a new facility were used to enable buried pipework to be inspected.

<u>Expected level of performance</u>: **Opportunistic inspection of concealed pipework is undertaken whenever the pipework becomes accessible for other purposes.**

6.2.4. Challenges

Non-invasive inspection methods for long lengths or complex geometries

A number of novel inspection techniques were described in NARs. These included:

- contactless magnetometric diagnostics for detection of damaged external protective coating in sections of buried pipework. This technique is stated to allow 100% of pipework to be inspected,
- EDMET instrumentation, permanently fitted to certain buried pipes to determine the mean wall thickness,
- A long-range guided wave ultrasonic technique used to inspect the buried portions of concealed pipework,
- Robotic visual inspection for detection of local corrosion in long lengths of piping.

All these techniques were of interest during the TPR but not enough detailed information was available on their effectiveness and resolution, or their ability to detect localised corrosion, to identify any of them as good practices. They are, however, potentially useful methods of resolving one of the major difficulties facing all operators with concealed pipework, i.e. how to determine the integrity of long sections of inaccessible pipework without uncovering and potentially damaging it.

<u>Challenge</u>: **Non-invasive inspection methods for detection of local corrosion, suitable for use on long lengths or complex geometries of concealed piping, are not well established. Research and development of such methods would enhance the tools available for demonstrating the integrity of concealed pipework and increase the overall safety of nuclear installations.**

6.3. Conclusion

The principal degradation mechanism experienced by concealed pipework and which can ultimately lead to leakage or failure is corrosion (uniform corrosion leading to wall thinning and pitting corrosion leading to localised loss of material). Common protective measures against corrosion damage are implemented at the design and installation stage, through selection of materials and the application of protective measures on external and/or internal surfaces. The ageing management programmes for all countries are based to some extent on inspection.

Based on the NARs, there is evidence of improvements being made, as a result of the TPR, in ageing management of concealed pipework; a significant number of countries have self-identified several areas for improvement, and delivery of these will demonstrably improve ageing management of concealed pipework across those participating countries.

The TPR recognized that the AMPs on concealed pipework have not yet proven to be effective, as they have only recently been introduced; hence there will be an ongoing need for regulatory attention to this important topic area. This TPR has provided a useful forum for sharing experience and good practice in relation to concealed pipework at NPPs and research reactors. In particular, the TPR identified good practices for the following areas:

- use of civil structures monitoring as an input for concealed pipework AMP,
- removal of sections of new materials after a period of operation to confirm their properties.

The TPR also defined expected levels of performance for the following areas:

- inspection of safety-related pipework penetrations through concrete structures,
- the scope of concealed pipework included in AMP,
- opportunistic inspection of concealed pipework whenever it becomes accessible for other purposes.

The review also highlighted an industry-wide challenge where further work at a European level to evaluate the capability of a number of promising inspection technologies could enable the integrity of long lengths or complex geometries of concealed pipework to be demonstrated, without the need to gain access, with the potential for damage to corrosion protection systems that this may entail.

In relation to research reactors, there is much greater variability in the approaches to ageing management of concealed pipework than for NPPs. There was some evidence that AMPs for concealed pipework are now being set up at some research reactors and that the TPR has reinforced this. As mentioned in chapter 4, there is a need to have a systematic and comprehensive OAMP implemented for the research reactors, in accordance with the applicable national requirements, international safety standards and best practices.

At the European level, the TPR workshop highlighted the existing fora for sharing local, national and international operating experience (OPEX), used to inform ageing management of concealed pipework.

7. EUROPEAN PLANTS ASSESSMENT RELATIVE TO REACTOR PRESSURE VESSELS OR CALANDRIA/ PRESSURE TUBES AGEING MANAGEMENT

This chapter summarises the results of the ENSREG Topical Peer Review of AMPs for reactor pressure vessels (RPV) and Calandria/pressure tubes at NPPs and research reactors in Europe.

7.1. Description of present situation of plants across Europe

The RPV is the pressurized component that contains the core of the nuclear reactor, for PWR and BWR. The RPV therefore ensures the confinement of the radioactive materials, playing the role of the second barrier, and hence one of the main safety functions. Among all safety significant SSCs, the RPV is of prime significance, as its failure is unacceptable and its replacement unfeasible. Therefore, the ageing management of the RPV is of primary importance for ensuring the safety of NPP throughout its lifetime.

The design of the RPV has to take into account all functional requirements to provide hot water (in PWRs) or steam (in BWRs) and all possible deviations from normal operating conditions, as well as external loads such as seismic events. Prevention of failure of the RPV requires that the amount of material degradation, and stresses that occur over its lifetime, for both normal and transient operations, are predicted prior to construction, and followed throughout the operational lifetime. With regard to neutron irradiation, design considerations are usually limited to the core beltline region of the RPV, which is typically defined as the region where the material accumulates a fluence of more than 10^{17} n/cm^2 (E > 1 MeV). The level of quality of a RPV is a very important factor, affecting the integrity of the RPV throughout its service life. This quality level is directly related to the selection and manufacturing of the materials and fabrication practices used in the manufacture of the RPV.

Due to the various types of NPPs, different RPVs are installed in the 19 countries participating in the TPR. Forged RPVs are the most common, but RPVs made from welded plates are also represented.

Romania is the only country in Europe operating CANDU type reactors. CANDU reactors do not have a RPV as in the case of PWR and BWR, but rather they have a Calandria or vessel, containing pressure tubes of zirconium alloy, in which the fuel is located.

Only a few countries indicated that their research reactors are pressurized, thus having a RPV. In this context, the assessment for research reactor is limited to the few reactors that meet the pressure-temperature characteristics of pressurized equipment as mentioned in the pressure equipment directive 2014/68 (> 0.5 bars and significant temperature).

7.1.1. Regulatory basis for safety assessment and regulatory oversight

The regulatory basis for safety assessment and regulatory oversight of the RPVs differs between different types of reactor. The regulatory basis for safety assessment is typically based on codes and standards, national or international, used for design and manufacturing: for instance ASME code and all American standards associated like ANSI/ASME and IEEE, ASTM A508 and A533, Russian codes, KTA for German safety standards or RCC-M for French standard.

<u>Countries applying American standards (and sometimes NRC regulations)</u>

The load restrictions on as-fabricated RPVs in various national standards and codes are generally based on Section III of the ASME Boiler and Pressure Vessel Code. RPVs in Europe that followed the American standards are inspected in accordance with Section XI of the ASME Code.

German standards

The German reactor vessel designs follow the German KTA standards for light water reactors (LWRs). The KTA requirements are very similar to those in the ASME code regarding the definition of stress intensities and allowable stresses. The in-service inspection and non-destructive examination are in the German KTA 3201.4 Code.

French standards

France developed a regulation to manage the design, the manufacturing and the in-service inspection of nuclear equipment. The codes and standards developed in France are the RCC-M for design and manufacturing and RSE-M for in service inspection.

VVER standards

The RPVs and primary system piping for all VVERs are safety-related components and are primarily based on the former Soviet Codes and Rules. Special analysis requirements are also provided for radiation embrittlement. A mandatory part of this Code, contained in appendices, is also a list of the materials (and their guaranteed properties) to be used for manufacturing the components of the NPPs, including the RPVs.

CANDU standards

CANDU inspections and assessments are performed in accordance with the standard CSA N285.4-94 and the Fitness-for-Service Guidelines (FFSG). Industry is currently migrating to CSA N285.4-09 and CSA N285.8-10.Acceptance criteria are derived from the IAEA-TECDOC-1037 - Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety[35].

As described above, countries have established regulatory frameworks where the codes and standards applied in the design and manufacturing are also applied for the monitoring during operation. Several years ago, a code comparison was performed within the Multinational Design Evaluation Programme (MDEP). This comparison focused on the main codes used for design and manufacturing of Class I pressure equipment. The general conclusion was that although differences exist between the applied codes they generally ensure a harmonised level of safety. However, currently there is no comparison performed on how different codes are applied in the monitoring of the RPVs during operation.

Due to the differences in the regulatory frameworks, there is no common regulatory approach in Europe for the safety assessment of the RPVs. Some countries, such as France, have developed national regulations for the primary components including the ageing management of the RPV. Some countries, such as Czech Republic, have established technical specifications with specific requirements concerning RPV ageing management linked to the legislation. Some countries, like Belgium, Slovenia and Spain, apply international standards, like ASME XI.

For RPVs and pressure tubes, the ageing management relies on (non-exhaustive list):

- National regulatory safety requirements or guides dealing with in-service inspection, monitoring, sampling, testing, needs of margins in design, effects of environmental conditions, embrittlement (material surveillance programme), thermal ageing and material fatigue, load monitoring, obsolescence
- IAEA standards – TECDOC - 1037 for Calandria and pressure tubes of CANDUs reactor
- IAEA standards – TECDOC - 1470 for BWR RPVs
- IAEA standards – TECDOC - 1556 for PWR RPVs

[35] https://www-pub.iaea.org/MTCD/publications/PDF/te_1037_prn.pdf

- Preventive maintenance database from EPRI and other guidelines from EPRI (such as water chemistry guidelines report 1014986)
- USNRC rules and associated documentation specific to RPV ageing assessment
- VERLIFE : guidelines for integrity and life time assessment of components and piping in VVER NPPs during operation
- IAEA-EBRVVER - 11 Methodology for Qualification of ISI Systems for VVER Nuclear Power Plants. 1998, European network for inspection and qualification ENIQ (EUR 17299 EN. European Methodology for Qualification of Non-Destructive Testing, (Third Issue) 2007, ...

There are no specific international guides for research reactor RPVs. Research reactors with highly pressurized RPV generally apply the same guides as NPPs.

Several past and ongoing, national and international, research programmes are also a source for ageing management of RPVs and pressure tubes.

7.1.2. Ageing assessment for reactor pressure vessels or Calandria/pressure tubes

Scope

The scope of this chapter is the reactor pressure vessels (RPV body and its closure head, comprising studs, seals and nozzles safe-ends) of all types of reactors (PWR, BWR, Research Reactors) and the Calandria pressure tubes.

The Reactor Pressure Vessel (RPV) is one of the most important components in nuclear power plants. It is considered irreplaceable, which means that it can be the life-limiting component of the nuclear power plant, if its mechanical properties are degraded to such an extent that its integrity cannot be proven for all operational and accident situations of the plant. Moreover, in the frame of the defence-in-depth approach, the failure of the RPV is not assumed. This means that there are no measures which could ensure accident mitigation in case of sudden RPV failure. As a result, many studies have been carried out, since the early days of the nuclear programme, to understand ageing mechanisms affecting RPVs and to define the monitoring of these ageing mechanisms. These have been and remain the subject of significant R & D programmes.

The research reactor RPVs considered in the framework of this chapter are those of pressurized research reactors (> 0.5 bars and significant temperature) identified in the NARs.

The Calandria pressure tubes are obviously also one of the most important components for CANDU reactors.

The AMPs related to the RPV are generally based on the standard approach recommended by international standards (scoping, screening, monitoring, etc). As a consequence, the RPV AMPs are very similar from one country to another.

Screening

The main ageing mechanisms affecting RPVs have been studied for many years and the related knowledge (understanding of the phenomenon, operating experience, R&D results etc.) is internationally shared.

The main ageing mechanisms identified for the NPP RPVs are:

- irradiation embrittlement
- thermal ageing of low alloy steel (LAS)
- fatigue under cyclic loading
- corrosion (e.g. boric corrosion)
- stress corrosion cracking (SCC)
- atmospheric corrosion of dissimilar metal welds
- mechanical damage / wear
- loss of pre-load of bolt connections

For research reactors, one degradation mechanism, corrosion, is always considered. The screening becomes more extended as the thermal power of the research reactors increases, and for RPVs of the RB2 and HBWR research reactors the same degradation mechanisms are identified as for NPP RPVs.

For Calandria pressure tubes in Romania, the degradation mechanisms screened in their specific AMP cover the international recommendations.

The ageing phenomena for RPV are briefly described below.

Irradiation embrittlement

The phenomenon of irradiation embrittlement of ferritic low-alloy steels is characterized by an increasing brittle / ductile transition temperature and is generally accompanied by a decrease of the resilience in the ductile domain.

The main parameters that influence this embrittlement are:

- the neutron fluence
- the irradiation temperature
- the chemical composition of the material

The estimation of the embrittlement can be made by means of calculation formulas (generic embrittlement trend curves) or by testing of surveillance specimens irradiated in the reactor.

Thermal ageing of Low Alloy Steel

This ageing phenomenon is due to the segregation of impurities (Phosphorus and Sulphur) at the grain boundaries of metallic materials. This phenomenon results in an increase in the brittle / ductile transition temperature. It depends on the amount of impurities in the material, the operating temperature and time.

Fatigue under cyclic loading

This ageing phenomenon may lead to cracks in the component. It depends on the geometrical design of the component and on the characteristics of the cyclic loading (in particular on the magnitude of the mechanical or thermal stresses).

The TPR experts discussed this type of ageing mechanism during the workshop, even if it appears that the RPV is not very sensitive to this ageing degradation, given the large safety margins to fatigue failure, introduced from the RPV design. Nevertheless, taking into account environmental effects on fatigue calculations is one of the findings identified by the TPR experts, which is discussed in section 7.2.

Corrosion (especially boric acid corrosion)

This ageing mechanism occurs in the case of leakage of borated water onto some part of the RPV. In such a case, the concentration of boric acid or the development of damp boric acid deposits can lead to a significant loss of material from the external surface of the RPV (such as in the Davis-Besse event in USA).

Stress corrosion cracking

This mode of ageing mechanism can affect parts made of stainless steel or nickel alloy (base and weld material).

It requires the simultaneous presence of a particular environment (primary coolant), significant tensile stresses and a sensitive material.

Atmospheric corrosion of dissimilar metal welds

The presence of a humid atmosphere that may be corrosive, or weakly corrosive, may cause localized aqueous corrosion of dissimilar metal welds. Austenitic stainless steels with a high carbon content and sensitized to intercrystalline corrosion can be affected by this type of ageing mechanism, which results in the presence of intergranular decohesions. For the RPV, these defects are located in the first layer of austenitic buttering metal and can be located on the outer wall of certain dissimilar welds.

Provisions are made in terms of monitoring and periodic inspections to detect this ageing mechanism.

Mechanical damage / wear

This degradation mechanism is not directly ageing-related, and was not covered during the TPR assessment. This type of damage can be induced by loose metal parts in the primary circuit.

Loss of pre-load of bolt connections

The loss of pre-load is a result of relaxation of tension from increased temperature or due to vibrations, which results in loosening of bolt connections.

For countries that identified this ageing mechanism, the criteria for assessing the admissibility of loss of pre-load are set in the relevant instructions for the in-service inspections and are monitored each time the bolt connections are dismantled. All countries participating in the TPR identified within their NARs (or confirmed taking them into account during the TPR workshop) all the above-mentioned ageing mechanisms for NPP RPVs.

Concerning Calandria and pressure tubes, the main degradation mechanisms that affect the operational behaviour of the zirconium alloy pressure tubes are the following:

- DHC (Delayed Hydride Cracking)
- Irradiation enhanced deformation
- Changes in pressure tube material properties

The determination of the ageing mechanism and the degradation in the pressure tubes and Calandria tubes complies with the IAEA Standards – TECDOC-1037.

For the in-service-inspection, the licensee uses the Canadian standards for the in-service programme.

The ageing surveillance programme implemented in the reactors is also in compliance with Canadian Standards.

7.1.3. Main approaches to ageing management applied to this specific area

All countries specify in the NARs that they have developed adequate monitoring for the degradation mechanisms considered in their AMPs. The TPR experts note some differences between countries concerning the monitoring of the degradation mechanisms (scope, extent, frequency, etc.), again resulting from the application of the different codes as well as from differences in design and materials.

In-service inspection programme (ISI)

All countries with NPPs have an ISI programme in order to ensure the absence or detection of any degradation driven by the mechanisms listed above. These ISI are carried out on all welds of the RPVs. For base metal, the scope of these inspections depends of the design and/or the national requirements. ISI can be performed by visual, dye penetrant, manual or automated ultrasonic and eddy current examinations Some countries also indicate that ISI is carried out by radiographic examination on dissimilar welds.

This point is discussed in section 7.2 as a finding.

The ISI programmes in research reactors are not as well described as for power reactors. Some countries have developed an ISI programme for research reactors while most of them do not mention it in their NARs.

Material surveillance programme

All the countries have developed a material surveillance programme of the shells in the beltline area by placing surveillance specimens between the core and the inner surface of the RPV wall, and by removing them periodically in order to perform mechanical tests and to ensure that the effect of the irradiation embrittlement is covered by the considered trend curve.

This point is discussed in section 7.2 as a finding.

Fatigue and corrosion

All countries usually monitor the attributes that have an impact on fatigue and corrosion degradation mechanisms by:

- Compiling an inventory of the transients undergone by the RPV,
- Defining and applying criteria in guidelines related to water chemistry.

In addition to common monitoring measures for corrosion and fatigue, some countries reported performing other measures such as early leakage detection or vibration monitoring.

This point is discussed in section 7.2 as a finding.

7.1.4. Licensees' experience and regulators' assessments regarding ageing of RPVs or Calandria/pressure tubes

All licensees consider that the RPV AMP allows them to identify the potential degradation mechanisms and to monitor the evolution of the material properties in order to adequately manage the RPV ageing.

In this framework, all licensees implement preventive and/or remedial actions following national and international operating experience feedback. In consequence some improvements have been made during the operation of the plants:

- The surveillance programme allows the confirmation of embrittlement of the material. Operational Experience feedback shows the necessity to re-evaluate periodically the quality of the prediction of irradiation embrittlement.
- New samples have been introduced close to the core to cover a longer operating life, or low leakage core loading patterns allowed reducing the neutron flux on the RPV wall.
- During the in-service inspection of the RPVs, licensees have discovered some degradation, like cracks. Two types of defects were highlighted during periodic inspections :
    - Cracks initiated during operation, such as the defects due to PWSCC, for example those that have been highlighted on adapters or Bottom Mounted Instrumentation (BMI) penetrations. For adapters, most licensees of reactors susceptible to this degradation mechanism have replaced the top head of the RPVs (e.g. Davis-Besse NPP). For BMI, proactive specific non-destructive examinations are performed in most countries to detect this type of indication.
    - The second type of defects highlighted are those originating during manufacturing such as under-clad defects or hydrogen flakes. These are not specifically problems related to the ageing of the RPVs, but which, nevertheless may have consequences for the justification of the structural integrity of the RPVs, and were therefore also discussed during the TPR.

Furthermore, most countries have documented improvements related to RPV resulting from national and/or international operational experience feedback:

- The inspection of the inlet and outlet nozzles inside radius

- Determination of the fluence received by the RPV wall using validated neutron physics calculations and measurements
- The use of the transition temperature shift determined by the surveillance programme, in order to confirm the conservatism of the embrittlement trend curves
- The replacement of closure heads equipped with alloy-600 parts which are subjected to stress corrosion cracking
- Identification of degradation mechanisms
- Irradiation embrittlement assessment and a surveillance programme
- Boric-acid corrosion programme and a water chemistry programme. For PWR, timely detection of leakage prevents the boric acid corrosion
- Surveillance of areas sensitive to stress corrosion cracking
- Periodic in-service inspection using appropriate techniques
- The design calculation of usage factors - low cycle fatigue
- Fatigue transient monitoring programme

Regulator assessment

The RPV is one of the most important components in a NPP, moreover it is a non-replaceable component and its failure is not considered in the safety demonstrations. As a result, this equipment has been the subject of research and development by national and international research organizations and extensive monitoring by licensees. The characteristics and conditions of RPV monitoring are also well documented in the codes and standards, both at the international and national levels.

As a result, the regulators confirmed in the various NARs that the ageing management programmes for RPVs are considered adequate.

7.1.5. Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

In the framework of the TPR self-assessment carried out by the European countries, no additional measure has been identified by any country for strengthening the RPV AMPs of their NPPs.

7.2. Assessment of reactor pressure vessels or Calandria/pressure tubes ageing management at the European level

During the national self-assessments and the peer review, the AMPs of the RPVs in participating countries have been reviewed. The RPV is the most significant and therefore most studied component of a NPP and the experience sharing on RPVs is well globally developed. National self-assessments did not identify improvements to their existing RPV AMPs. This is also supported by the peer review concluding that the AMPs in participating countries rely on the globally applied codes and standards, research and development on the RPVs as well as on the experience sharing of the RPV AMPs. Therefore, only a few findings are highlighted, related to some specific ageing degradation mechanisms, and not applicable to all RPV types. The findings identified by the TPR and described below concern the monitoring programmes and the determination and application of preventive and/or remedial actions. The assessment highlights that all the findings are dependent on the particular design of the reactor and the RPV, their operational life and the national requirements and hence do not apply to all RPV types.

7.2.1. Consistency of approaches used in Europe between countries and with international requirements (IAEA, WENRA)

The RPV AMPs are generally very similar from one country to another. However when investigating in detail the content of each step of the programme, the TPR experts identify some differences in terms of monitoring or definition of acceptance criteria. Differences originate from national regulations and international or national codes and standards applied and implemented in each country: the codes and standards applied in the design and manufacturing are also applied for the monitoring during operation.

The country acceptance criteria are also derived from different codes and standards and therefore differ between countries: for example for irradiation embrittlement, it can be the transition temperature or the definition of mechanical margins.

The AMPs developed for RPVs in the participating countries are consistent with international requirements (IAEA, WENRA). In particular, the reports IAEA-TECDOC-1556 June 2007, IAEA-TECDOC-1470 October 2005, and WENRA Safety Reference Level for Existing Reactors, September 2014 provide guidance for the ageing management of reactor pressure vessels.

Six RPV ageing degradation mechanisms are addressed in the IAEA standards. The associated IAEA guidance, provided in the IAEA-TECDOC, is summarized in table 1, which also shows the consistency of the approaches between countries although also some differences exist:

Table 1: IAEA guidance for the different degradation mechanisms vs country approaches

Ageing degradation mechanisms	Guidance	Consistency of approaches between countries
Radiation embrittlement	Utilization of the irradiation embrittlement databases/trend curves, to predict the degree of irradiation embrittlement for a given RPV	All the countries utilize the irradiation embrittlement databases/trend curves
	Implementation of a material surveillance programme	Except for most research reactors, countries have developed surveillance programmes based on the regular testing of surveillance specimens
	Low leakage Core fuel management programme to economize the neutron and a secondary benefit is reducing the neutron flux in the RPV wall.	Most countries mentioned the use of Low Leakage Core (LLC) fuel management programme
	Additional RPV wall shielding to reduce the rate of irradiation embrittlement	Some countries mentioned the use of such shielding (a real shield or with dummy assemblies).
	Application of thermal annealing	Two countries operating VVERs mentioned the heat treatment of the core weld seam and one of them the thermal annealing of the RPV.
SCC of alloy-600 components	ISI programme for the alloy-600 penetrations to ensure timely detection of any cracking (UT, ET or PT on RPV heads that are susceptible to PWSCC and BMV of 100% of the head surface)	Most of the countries discussed this ageing degradation mechanism. Some of the concerned countries did not explain which RPV components are affected by this mechanism. Moreover, not all of the countries mentioned ISI on the alloy-600 penetrations.

Ageing degradation mechanisms	Guidance	Consistency of approaches between countries
Thermal ageing	Periodic ISI of the regions outside the RPV beltline welds to ensure timely detection of any flaw	All countries address this guidance.
	Evaluation of flaws, if detected	When flaws are detected, an evaluation is performed.
Fatigue	Analytical method to assess the possibility of fatigue crack initiation. Check that the cumulative usage factor is below 1.0	Most of the countries use an analytical method and check the value of the cumulative usage factor. The criteria are not usually mentioned.
	Monitoring the number of cycles and evaluating cyclic stresses. Transient monitoring.	All the countries perform at least the inventory of the transient conditions. One of the countries mentioned the implementation of a fatigue monitoring system.
	Evaluation of ISI Results and fatigue analysis in case of a flaw	This is commonly performed according to the surveillance codes and standards.
	Microstructural analysis of a flaw by taking boat sample	This guidance is not documented in the NARs.
Wear	Inspections of studs, the surface of flanges and the O-ring	The affected RPV components were not in the scope of the TPR. In consequence, wear is not mentioned very often in the NARs. However some countries mentioned performing these inspections.
Boric acid corrosion	Visual inspections of RPV flanges, top closure heads and studs during every refuelling outage	This ageing degradation mechanism is one of the most documented in the NARs. Affected countries are in compliance with this guidance.

While reading the table above, one must keep in mind firstly that for technical reasons not all guidance and every recommended action are feasible for all types of RPV/NPP, and secondly that the guidance provided in the IAEA-TECDOC is not mandatory. It is therefore not expected that all countries apply all the guidance to their RPV AMP. In that framework, this table mostly highlights that the countries are following as appropriate the IAEA guidance relevant to their RPV types and implement adequate actions for the monitoring of the identified ageing degradations.

The only specific finding identified for research reactors is the development of a specific comprehensive RPV AMP. This finding is incorporated in the generic findings for research reactors.

7.2.2. Good practices

The peer review identified the following good practices. When a measure is performed proactively in order to augment the ageing management programme, it is considered as a good practice. However, when the same measure is required to fill in a gap in the ageing management programme, it is only considered as an adequate remedial action.

Hydrogen water chemistry

Some austenitic alloys can be sensitive to Intergranular Stress Corrosion Cracking (IGSCC).

The presence of oxygen and hydrogen peroxide increases the risk for IGSCC. A means of reducing the concentration of these chemical species is to inject hydrogen into the primary coolant which lowers of the levels of oxygen and hydrogen peroxide and thereby establishes mitigating environmental conditions in order to prevent intergranular stress corrosion cracking (IGSCC).

The implementation of a hydrogen water chemistry (HWC) programme for BWRs is a preventive action against IGSCC.

<u>Good Practice</u>**: Hydrogen Water Chemistry (HWC) is used in BWRs which may be sensitive to Intergranular Stress Corrosion Cracking**

Implementation of a shield

There are different ways to reduce the neutron fluence of a PWR RPV wall (e.g shield, heavy reflector, water gap). The aim of introducing a shield is to preventively reduce the neutron flux received by the RPV wall. It consists of implementing shielding in front of the area where the flux is significant (shielding walls, shielding rods and fuel assemblies). Such action is only applicable to PWR type reactors with relatively high fluence.

<u>Good Practice</u>**: Shielding in the core of PWRs with relatively high fluence is implemented to preventively reduce neutron flux on the RPV wall.**

7.2.3. TPR expected level of performance

The topics below were recognised as the expected level of performance during this TPR and therefore recognised as a good performance for those countries which already meet this expectation and as an area for improvement for the others.

Volumetric inspection for nickel base alloy penetration

In some PWRs, parts are made of nickel alloy sensitive to primary water stress corrosion cracking. Operational Experience feedback for head and Bottom Mounted Instrumentation penetrations has highlighted leakage and failure of components. To have this type of degradation it is necessary to have:

- High tensile stresses,
- Corrosive environment,
- Susceptible material.

For these PWRs, it is necessary to implement volumetric in-service inspection to detect the occurrence of a crack as early as possible.

<u>Expected level of Performance</u>**: Periodic volumetric inspection is performed for nickel base alloy penetrations which are susceptible to Primary Water Stress Corrosion Cracking for PWRs to detect cracking at as early a stage as possible.**

Non-destructive examination in the base material of beltline region

Recent operating experience feedback has highlighted that some manufacturing defects were not detected in the base material during fabrication or previous inspections. For example, under-clad defects in France in the late 1990s, hydrogen flakes in Belgium in 2012 and non-metallic inclusions in Switzerland in 2015 were highlighted during in-service inspection. These are not ageing related degradation, but the presence of defects has to be taken into account in mechanical analyses and the ageing phenomena of RPV. These defects have been highlighted with the implementation of NDE using the most recent techniques.

In early 2014, WENRA recommended a comprehensive review of the manufacturing and inspection records of the forgings of the RPV and an examination of the base material of the vessels if considered necessary. In the summary note on this recommendation, WENRA highlights that most countries considered at that time that comprehensive NDE in the base material of the beltline region is not necessary, based on the manufacturing and inspection records of the forgings of the RPV.

However, taking into account the experience from the Swiss case in Beznau where another type of defect was discovered, it is considered during the TPR as an insufficient standard to not perform a comprehensive NDE in the base material of the beltline region at least once in order to detect any defects. It is also highlighted that standard qualified techniques for craking type defect detection in the welded zones are not necessarily suitable for defect detection in the belt-line regions. The use of qualified techniques and adequate recording limits for NDE are necessary for comprehensive NDE of the base material of the beltline region in order to detect defects.

<u>Expected level of Performance</u>: Comprehensive NDE is performed in the base material of the beltline region in order to detect defects

Environmental effect of the coolant

The fatigue mechanism is affected by an aggressive environment; some experimental programmes have shown that the fatigue life of steel components was reduced in the light water reactor coolant environment.

During the design and construction of early reactors, the importance of this effect was not fully appreciated. Indeed such environmentally assisted fatigue analyses have already been performed for many years by some countries; several mention having recently performed or planning to perform those analyses, in their self-assessment, mostly in the framework of LTO assessment. Finally, in some countries, environmentally assisted fatigue is covered through a screening criterion, such as usage a factor which is not to be exceeded, in their national standards.

As this phenomenon is well known, it is considered that fatigue analyses have to account for new information on environmental fatigue.

<u>Expected level of Performance</u>: Fatigue analyses have to take into account the environmental effect of the coolant.

Suitable and sufficient irradiation specimens

For some operating RPVs, it is sometimes necessary to have reconstructed specimens, or to have a comparison between reactors to evaluate the irradiation embrittlement.

Hence, for new reactors, it was recognised as the expected level of performance for this TPR to have sufficient surveillance specimens to robustly support unforeseeable future events, specimen loss and code changes and to cover the whole period of operation.

<u>Expected level of Performance</u>: For new reactors, suitable and sufficient irradiation specimens and archive materials are provided to support the reactor through its full operational life.

7.2.4. Challenges

State of the art and qualified techniques for NDE

NDE techniques and performance evolves all the time and the detection capabilities are continually improving. This is highlighted by the recent cases of defect detection in the core beltlines of Doel 3 and Tihange 2 RPVs in Belgium, or Beznau 1 in Switzerland. For these RPVs, the specific qualification and upgrade of the NDE technology for the defect characterization leads to a significant increase of the detection capability of the NDE technique. These cases highlight that, while the usual NDE technique was fully qualified for the standard NDE inspections, significant upgrades were achievable for a better characterization of the RPVs. Using qualified state of the art techniques consequently improves the confidence in the capability of defect detection. In this context, while many countries are already using the state of the art NDE technology, it remains a challenge for each country to continuously maintain periodic non-destructive ISI techniques at the qualified state of the art level and was recognised as such during the peer review.

<u>Challenge</u>: NDE techniques are continuously developing and improving and it is a challenge for licensees to know the current state of the art in qualified RPV inspection techniques. The RPV inspections could be improved by establishing and maintaining an up to date European catalogue of state of the art new techniques and technologies for NDE.

7.3. Conclusion

The RPV is one of the most important components in a NPP. As a result, this equipment has been the subject of research and development by national and international research organizations and extensive monitoring by licensees. The characteristics and conditions of RPV monitoring are also well documented in codes and standards, both at the national and international levels.

Based on the NARs, regulations and practices are to some extent different from one country to another, mainly for practical reasons resulting from different designs of the RPVs and codes and standards applied in the design, manufacturing and during operation. It is worth noting that AMPs for NPPs in every country take into account ageing under irradiation which is the main phenomenon affecting the mechanical properties of the RPV. Every country has also implemented monitoring programmes for their RPVs.

National self-assessments did not identify improvements to their existing RPV AMPs. This is also supported by the peer review conclusion that the AMPs in participating countries rely on the globally applied codes and standards, research and development on RPVs, as well as on the sharing of experience of the RPV AMPs.

The TPR has been an opportunity to compare European practices in the field of AMPs of RPV. Some findings were identified related to certain specific ageing degradation mechanisms, though not necessarily applicable to all RPV types:

- the monitoring programmes (volumetric inspection for nickel alloy penetration, non-destructive examination in the base material of the beltline region)
- the determination and application of preventive actions (hydrogen water chemistry injection against IGSCC, neutron dosimetry, reconstructed specimen of irradiated materials, implementation of a shield)
- environmentally assisted fatigue (effect of the coolant).

The review also highlighted an industry-wide challenge where further work at a European level is needed to continuously maintain periodic non-destructive in-service inspection techniques at the qualified state of the art level.

Concerning research reactors, very few are considered to have an RPV. One degradation mechanism, corrosion, is considered in every AMP. As mentioned in chapter 4, there is a need to have a systematic and comprehensive OAMP implemented for the research reactors, in accordance with the applicable national requirements, international safety standards and best practices.

Concerning CANDU reactors, the TPR concluded that the ageing management of Calandria and the pressure tubes at Romanian CANDU reactors is in compliance with the international standards.

8. EUROPEAN PLANTS ASSESSMENT RELATIVE TO CONCRETE CONTAINMENT STRUCTURES OR PRE-STRESSED CONCRETE PRESSURE VESSELS AGEING MANAGEMENT

This chapter summarises the results of the Topical Peer Review (TPR) related to the ageing management of concrete containment structures and pre-stressed concrete pressure vessels (PCPVs) of NPPs and research reactors in Europe.

8.1. Description of present situation of NPPs/ research reactors across Europe

NPPs in the participating countries have different designs of concrete containments and civil structures:

- Pressurized water reactors (PWR) (including VVER) – Concrete containments of most PWRs installed in the subject countries are fabricated from reinforced concrete, pre-stressed concrete or a combination of both. Single or double wall construction may be used and the inside surface may be lined to provide a leak-tight barrier. In some designs, the containment function is provided by a freestanding steel containment 'vessel'. A concrete shield building provides shielding and protection from external hazards. In this case only the concrete part is included in the scope of the TPR.
- Boiling Water Reactors (BWR) – Although the majority of BWR use a steel containment vessel, some units use either pre-stressed or reinforced concrete containment, where leak-tightness is provided by a steel liner either attached to the concrete surface or embedded in it.
- Advanced Gas Cooled Reactors (AGR) – The main civil engineering structure in an AGR is the Pre-stressed Concrete Pressure Vessel (PCPV). The PCPVs are cylindrical concrete structures with pre-stressed ungrouted tendons to withstand the high pressures within the reactor. The leak tightness is provided by a steel liner anchored to the internal face of the PCPV and the PCPV is cooled by numerous cooling pipes embedded in the concrete.
- CANDU – The CANDU containment is fabricated from reinforced pre-stressed concrete with epoxy liner attached to the concrete surface.

8.1.1. Regulatory basis for safety assessment and regulatory oversight

Based on the national self-assessments and the peer review, there are no major differences in the regulatory basis for safety assessment, and regulatory oversight of concrete containment structures among the different reactor types used across Europe. All countries have established a national legal basis stipulating the requirements for AMPs covering concrete structures in the scope for both NPPs and research reactors.

Regarding research reactors, the national regulatory requirements for AMPs of concrete structures vary in the participating countries. In some countries, in addition to the regulatory safety guide for NPPs, there is also a special guide for research reactors that specifies the application of the requirements set in national legislation. In other countries, the regulator issued specific prescriptions for certain structures with particular ageing management implications.

8.1.2. Ageing assessment for concrete containment structures or pre-stressed concrete pressure vessels

Regarding NPPs, National programmes use the international recommendations (such as WENRA SRLs, IAEA Safety Standards and guidance, such as US NRC relevant documents) and the best international practice described in the IAEA's International IGALL project, which provides detailed information on specific programmes to manage ageing and degradation of concrete structures. For concrete structures, the most relevant are IAEA IGALL AMP301 – AMP313. IAEA Safety Report Series No.82 (Ref 54) and NP-T-3.5 (Ref 55) which describe practices and techniques for the inspection, mitigation of ageing degradation, corrective action including repair methods, and operating experience for concrete containments. It also provides general guidance for developing an effective ageing management process for concrete structures.

The specific AMPs are generally well established, and result in implementation of periodic monitoring, inspections, testing, surveillance, preventive and corrective maintenance activities of concrete structures, which are generally considered effective.

Ageing degradation mechanisms for concrete structures are well known and are covered by extensive comprehensive documents such as IAEA-TECDOC-1025 and its updated version NP-T-3.5, IAEA-SRS No.82 – IGALL, NS-G-2.12, NUREG-1801 – GALL, etc.

The concrete civil structures within the TPR scope are essential in ageing management because they are irreplaceable, belonging to the critical life-limiting SSCs of the installation. Construction elements have been also covered in the TPR, such as water-stops, seals, gaskets and protective coatings.

The degradation mechanisms and ageing effects for concrete structures have been known for many years and are widely shared in the international community. They are identified usually on the basis of the generalized worldwide experience (compiled e.g., in US NRC GALL, IGALL Safety Report, EPRI, IAEA, ACI), from the NPP's own operating history, knowledge of the containments and PCPV, experience feedback from the inspections and tests performed, on the basis of relevant research and development programmes or lessons learnt from the conventional civil structure industry. The main ageing degradation mechanisms identified for concrete structures and mentioned in the NARs are:

- Concrete degradation due to physical and chemical attacks (cracking, creep, shrinkage, carbonation and internal swelling pathologies),
- Corrosion of steel reinforcement,
- Corrosion of metallic liners,
- Corrosion and stress relaxation in post-tensioning systems,
- Degradation of coatings accelerated by high temperature, high humidity, abrasion or localized effects.

Concrete structures can be damaged by environmental stressors, e.g. high humidity, water ingress, chemical or mechanical impact, high temperature and radiation. For all these stressors, when their level is beyond the designer's or manufacturer's specification, they can accelerate degradation of concrete structures which could impact on their integrity and functionality. Assessment of concrete structures uses a variety of methods as listed in section 8.1.3.

In general, the countries consider that concrete degradation is managed within the existing AMPs. However, a few countries reported some problems in the ageing of concrete structures and elastomeric components, which may be considered to be NPP- or site-specific (e.g., plant type, location, compound and reinforcement of concrete constructions, climate and external or internal impacts). These problems are being resolved in co-operation with specialized institutions.

8.1.3. Main approaches to ageing management applied to this specific area

Nuclear power plants

The AMPs of concrete containment structures and PCPVs are in line with national and international standards and guides providing recommendations for effective ageing management (e.g., IAEA-TECDOC-1025, IAEA Nuclear Energy Series No. NP-T-3.5, IAEA-SRS No.82 – IGALL, NS-G-2.12, NUREG-1801 – GALL), and on operational experience.

The ageing of concrete structures is managed through several specific AMPs, periodic in-service inspections, monitoring, testing (integral leak tests, pressure tests), surveillance, preventive and corrective maintenance activities, etc.

Within the assessment of concrete containment structures or PCPVs the essential element is the systematic and rigorous assessment of concrete structure conditions. The AMPs include monitoring the ageing effects on the physical conditions of the structures, revealing the adverse effects of degradation mechanisms, and if trending analysis is performed, the structural behaviour and conditions of the structures can be predicted to a good extent.

The monitoring of concrete structures is helped bytracking the environmental conditions to which the structures are exposed, to track the changes in characteristics of the structures, to better understand the mechanical behaviour of structures, verify the analytical models developed, and to ensure a proactive ageing management. Different technologies are implemented in the countries to monitor and evaluate the ageing of structures. The scope and range of monitoring varies between the countries depending on the design and the safety significance of the structures.

In all countries the ageing management of concrete structures is kept under continuous review and improvements are made if some new knowledge is available from operational experience, from results of international practice or from results of international or national research projects. Even if the research projects are primarily focused on NPPs, the outcomes are also largely applicable to research reactors.

AMPs for concrete structures use both reactive and proactive ageing management. The reactive ageing management relies on visual inspections considered as a first method of the graded approach in the applicable standards. However, visual inspections do not reveal internal degradation if there are no visible surface degradation symptoms and their use is limited to accessible structures only. Alternative methods to the visual inspections are applied to ensure proactive ageing management. The countries consider the inspections of concrete structures well established except for inspection of inaccessible structures and/or areas with limited access. This is discussed in 8.2.2.

The monitoring system for the state of pre-stressing in the pre-stressed concrete structure provides an indication of the state of tendon relaxation, to avoid structural degradation before it becomes critical. The scope of monitoring of forces in the pre-stressing systems (tendons) varies between countries. On-line active monitoring is established only in some countries, as confirmed during the peer review. This is discussed in section 8.2.3.

In the AMPs, acceptance criteria for the degradation mechanism are applied to confirm the functionality of the concrete structures. Depending on the kind of concrete structure assessed or the regulation that is applied, these acceptance criteria may be either qualitative or quantitative. Usually, the acceptance criteria are based on technical standards and consider design recommendations and the ageing history of the structures. Specification of common acceptance criteria applicable to all concrete structures is considered to be difficult, due to differences in construction materials, functional requirements, behaviour characteristics, exposure conditions, and other conditions. Several countries reported that they have started to develop objective acceptance criteria, evaluated their implementation and conducted trending analyses. However, some countries reported that development of acceptance criteria and their implementation has been neither systematic nor comprehensive. This topic was discussed during the workshop and is reflected in section 8.2.4.

Research reactors

The ageing management of concrete structures for research reactors is based principally on scheduled periodic monitoring (visual inspections, testing). The nature of the steps taken during these inspections consists of monitoring of cracks, penetration tightness and checking of containment leak rates. The compliance of the containment with requirements is verified during the periodic safety reviews (PSR).

8.1.4. Licensees' experience and regulators' assessments regarding ageing of concrete containment structures or pre-stressed concrete pressure vessels

In general, several elements of ageing management had been established in the form of various operating programmes even before the term “ageing management” was introduced (e.g., maintenance, in-service inspections and surveillance, tests, monitoring, etc.). Implementation of these activities was based on national and international requirements for safe operation of nuclear power plants. However, since harmonised requirements to address ageing of concrete structures, had not been established, the assessment approaches of concrete structures varied considerably.

From the licensee’s point of view, the ageing management process is in practice accomplished via coordination of existing AMPs that are well established at most NPPs. The programmes include maintenance, in-service inspections and surveillance, technical support activities (including analysis of any ageing mechanisms), and are often supported by external research and development programmes. The licensees consider ageing management programmes for NPP concrete containment structures and PCPVs as comprehensive and adequate. AMPs meet the current requirements of national regulations and international standards.

In relation to concrete structures, the ageing management programmes focus on the most safety relevant concrete structures; concrete containment structures and PCPVs. The state of the concrete structures is, in most cases, checked by visual inspections. Since not all concrete structures can be inspected visually, other methods (e.g., instrumentation, pressure tests) are also used.

Countries provided several examples in their NARs regarding degradation in concrete structures. These examples show both where the AMP failed to deal with the degradation and events that were successfully managed. As an example of the first case, there is an event reported by Belgium regarding degradation of concrete structures not part of the containment, which required several repairs and underlined the inadequacy of the preventive and remedial actions. In the Spanish NAR one example is given where the perimeter joint of the containment building was found to be degraded, allowing water to enter to the lower elevations of the liner, to an inaccessible area. In the latter case, the existing AMP was demonstrated to be effective in the detection and correction of the degradation.

From the regulator’s point of view, the licensees have implemented national requirements for ageing management of concrete structures. The NARs confirmed that the existing approaches to ageing management (usually called Overall Ageing Management Programmes) are largely based on practice and experience from operation of NPPs around the world and results of international research projects on ageing, documented in international references issued by IAEA, WENRA, etc. However, some regulators stated that the AMPs for some NPPs are not fully and systematically implemented, and that further effort is needed.

For research reactors the situation is less satisfactory. Many of them lack developed systematic and comprehensive AMPs, and national regulators are identifying more areas for improvement at research reactors than at NPPs. In some countries, the AMPs for research reactors have been mostly implemented only in recent years and thus the programmes are often under development or being updated. The review of NARs has found that some of these programmes need further development.

In all countries, the AMPs consider long-term effects of environmental conditions and different modes of operations of SSCs. In most of the countries, AMPs are linked with other relevant programmes (Periodic Safety Review, relicensing, LTO). The results of R&D programmes are used in support of AMPs.

8.1.5. Measures (including further studies) already decided or implemented by operators and/ or required for follow-up by regulators

All countries gave a summary of their conclusions on concrete containment structures and PCPV in their NARs. Most of them did not identify any relevant further improvement since they consider their AMPs for those structures are satisfactory in general terms. However, some other countries reported that, as a result of the TPR, some improvements will be made. Those measures could be triggered by a regular AMP update in accordance with the international recommendations. Others could be the result of PSR, findings from international mission, or findings of the national regulator. Some of these measures are described in the following paragraphs.

The Swiss regulator concludes that the existing AMPs allow detection of ageing effects in a timely manner. ENSI highlights its efforts in the monitoring of inaccessible or difficult to access structural components, for example the outer surfaces of earth-covered components, groundwater seals or concrete-encased tendons. However, to date such methods have rarely been used. ENSI has pointed out this monitoring gap to the licensees on a number of occasions, and in its future inspections, ENSI will demand the corresponding tests.

The most frequent reason for taking measures is probably the insufficiency or incompleteness of some specific AMPs. Examples of such measures could be the requirements for completion of the civil structure documentation, extension of concrete structures monitoring, recording of defects/ faults of the civil structures, etc., as in the NAR of Czech Republic (one of the findings from the IAEA SALTO Mission on Dukovany NPP).

The Swedish regulator states that degradation mechanisms differ partially from one licensee to another and the acceptance criteria need to be more developed in order to be able to make an accurate ageing assessment. In the UK NAR; ONR states that the licensee should review its company guidance relating to ageing mechanisms and acceptance criteria for concrete structures by the end of 2018 to ensure that it is comprehensive and based on relevant good practices.

One of the important measures is also the management of data for the AMPs. In Spain, a database is being implemented for collection and storage of data, as a basis for data processing and evaluation, as well as for the determination of trends in monitored characteristics. Based on this, the appropriate measures can be proposed to prevent the effects of ageing. Fostering trending analysis on a regular basis in order to prevent structure degradation is also carried out in Sweden.

8.2. Assessment of concrete containment structures or pre-stressed concrete pressure vessels ageing management at the European level

8.2.1. Consistency of approaches used in Europe between countries and with international requirements (IAEA, WENRA)

Overall, there was a good level of consistency in approaches to the ageing management of concrete containment structures for NPPs.

In terms of assessment of concrete structures, the examination methods used are generally comparable, and are based mainly on combination of records from in-service inspections, monitoring of structures, leakage tests and checks. As degradations are identified usually through visible indications on exposed concrete surfaces, the general condition of concrete is mostly assessed by visual inspections. Structures that are inaccessible or to which access is limited are inspected by measurements or through indirect monitoring. The inspections, measurements and monitoring provide the data that are further used for assessment of trends in behaviour of the concrete structure.

Ageing management of research reactors is usually tailored to each individual facility as each research reactor is unique and has specific risks and operating conditions. Their ageing management is currently based on the maintenance programmes and on periodic checks and tests. The compliance of research reactor containments against requirements is verified also during the PSR, performed at least every ten years. For some research reactor types, programmes for monitoring of containment cracks are also applied. The scope of AMPs for the research reactors is therefore limited in comparison to NPPs.

8.2.2. Good practices

The peer review identified the following good practices.

Monitoring of concrete structures

The concrete containments are required to withstand the pressure and temperature associated with a significant leakage of coolant from the reactor cooling system. The safety significance of these civil structures is high, since they are generally the last barrier between the reactor contents and the environment and are one of the few irreplaceable structures in NPPs. The outcomes of the discussions during the workshop can also be applied to PCPVs.

The demonstration that the containment fulfils its safety function is based on periodic leak tests, structural monitoring carried out during and between the tests, and visual inspections.

Some sensors (typically strain gauges) embedded in concrete provide additional information on the deformation state of the containment wall, This information is important to predict the mechanical behaviour of the concrete containment structures and also verify any the analytical models developed. However, some sensors fail in operation and information may be lost. The installation of additional instrumentation may compensate for the loss of the sensors and still enable prediction of the containment mechanical behaviour throughout the lifetime of the plant, which is recognized as a good practice. The additional instrumentation (surface strain meters for example) may measure the same physical parameters as the embedded sensors, concrete deformation in the case of strain meters.

Good practice: Complementary instrumentation is used to better predict the mechanical behaviour of the containment and to compensate for loss of sensors throughout the life of the plant.

Assessment of inaccessible and/or limited access structures

Ageing management of concrete structures is mainly based on visual inspections and on testing of material samples. Such inspections are difficult or even impossible in structures which are inaccessible or with limited access.

This topic is an important safety subject of AMP since ageing of inaccessible structures could potentially lead to severe latent degradation in concrete structures. This should be considered from the design and construction of the nuclear installation. Structural modifications during the life of an NPP may provide opportunities to access formerly inaccessible parts of the structure. Licensees should consider the effect of these modifications on the structures and maintenance regime, but also the opportunities that some of these modifications provide opportunities to inspect inaccessible areas.

In quite a few inaccessible structures, if no proper monitoring system (i.e. fixed NDE devices) is embedded in the structure during its construction, it will not be possible to inspect those parts of the structure during the life of the plant. In some countries regulators, have established or amended regulatory guides to address inspections and monitoring of inaccessible and limited access structures. A licensee has invested heavily in the development of NDE for the inspection of structures with limited access.

<u>Good Practice</u>: A proactive and comprehensive methodology is implemented to inspect, monitor and assess inaccessible structures or structures with limited access.

8.2.3. TPR expected level of performance

The topic below was recognised as the expected level of performance during this TPR and therefore recognised as a good performance for those countries which already meet this expectation and as an area for improvement for the others.

Monitoring of pre-stressing forces

Where pre-stressing systems are used, the tendon tension has to be carefully monitored due to its significance for the containment function. A key point concerning the assessment of the durability and safety of pre-stressed concrete containments is the technology chosen for tendon protection; bonded with cement grout or unbonded and protected by grease or other soft products.

Whatever the technology, pre-stressing forces should be monitored on a periodic basis to ensure the containment fulfils its safety function: this is recognized as the expected level of performance. For those with unbonded tendons, lift-off tests in line with codified sampling requirements may be undertaken at periodic intervals. As an alternative to lift-off tests, the use of active strain gauges on strands and periodic logging provides an indication of the state of relaxation of the tendons. A strong correlation was observed in benchmarking against lift-off tests.

<u>Expected level of performance</u>: Pre-stressing forces are monitored on a periodic basis to ensure the containment fulfils its safety function.

8.2.4. Challenges

Acceptance criteria for the degradation mechanisms

The ageing of concrete structures of NPPs necessitates systematic inspections, condition assessments and repairs to maintain the prescribed functionalities of the structural elements. Setting adequate acceptance criteria for some of the degradation mechanisms and ensuring that they are achieved is one way of achieving this goal. Both quantitative and qualitative criteria exist. Some countries reported difficulties in defining objective and comprehensive acceptance criteria for ageing management of concrete structures. It was concluded during the peer review workshop that acceptance criteria for degradation mechanisms should be based not only on technical standards but should also consider the ageing history of the structures, the designer recommendations and the trending analysis. The definition of objective and comprehensive quantitative acceptance criteria for ageing management of concrete structures is a challenge for the industry as a whole and was recognized as such during the peer review.

<u>Challenge</u>: It is difficult to define objective and comprehensive acceptance criteria for ageing management of concrete structures. The development of such criteria for a number of degradation mechanisms would improve the effectiveness of the AMPs.

8.3. Conclusion

The properties of the concrete structures can be degraded by operational and environmental conditions. Implementation of AMPs should ensure that concrete containment structures will retain their integrity and functionality and will not jeopardize the safety of the NPP or research reactor.

Based on the NARs, national AMPs are generally in line with international guides that have been issued by IAEA, etc., and which provide guidance on how to manage ageing of concrete structures, especially those in NPPs. In general, these international guides are based on worldwide experience and knowledge, thus summarising the best approaches.

The TPR concluded that the examination methods are generally comparable, and mainly based on combination of records from in-service inspections, monitoring of structures, leakage tests and checks. However, the extent of monitoring and assessment of the condition of concrete structures varies; starting from visual inspections, measurements and tests performed at regular intervals and ending with use of advanced technologies and continuous advanced measurements.

The TPR recognised the importance of the research programmes and the inspection programmes to improve the knowledge of material properties of concrete structures subject to ageing.

In particular, the TPR identified good practices for the following areas:

- the use of complementary instrumentation, to be able to predict the containment mechanical behaviour through the entire life of the plant,
- the assessment of inaccessible structures and/or structures with limited access, with proactive and comprehensive methodology.

The TPR also defined an expected level of performance for the monitoring of the pre-stressing forces.

The review also highlighted an industry-wide challenge where further work at a European level to develop objective and comprehensive acceptance criteria for a number of degradation mechanisms would help to improve the effectiveness of the AMP.

Concerning PCPVs, the TPR concluded that the findings mentioned above are also applicable to PCPVs and made no specific findings for PCPVs.

Concerning research reactors, the review of NARs has found that some AMPs need further development. As mentioned in chapter 4, there is a need to have a systematic and comprehensive OAMP implemented for the research reactors, in accordance with the applicable national requirements, international safety standards and best practices.

9. Conclusions and recommendations

The first Topical Peer Review as set out in Article 8e of Directive 2014/87/EURATOM has been carried out. All participating countries made a self-assessment and reported results in their National Assessment Reports. Most countries identified a number of areas for improvement, good practices and challenges. In the course of the Topical Peer Review, national results have been evaluated through the peer review process, complementing the national assessments.

Self-assessment results constitute the basis for countries to enhance their Ageing Management Programmes. In addition the review identified generic findings, namely good practices and expectations to enhance ageing management, which were allocated to participating countries (the country specific findings). The review also identified challenges common to many or all countries. All generic and country-specific findings are documented in the Topical Peer Review documentation and published on the European Nuclear Safety Regulators website.

There is evidence based on the National Assessment Reports and their peer review that improvements have already been made or are on-going as a result of the Topical Peer Review. Countries will establish National Action Plans to address findings resulting from their self-assessment and the peer review. The delivery of National Action Plans will further improve the ageing management of both Nuclear Power Plants and Research Reactors.

The peer review met its generic goals and objectives set out in the Directive and in the European Nuclear Safety Regulator Terms of Reference. The peer review enabled countries to review their Ageing Management Programmes, share information and experience, and provided an open and transparent framework for participating countries to develop appropriate follow-up measures.

Lastly, performing a Topical Peer Review has been a challenge and has required significant resources from the participating countries and the European Commission. Since Topical Peer Reviews will be conducted every six years, it is of the utmost importance to learn from the experience to ensure efficiency and effectiveness in the future peer reviews.

9.1. Summary of review process compliance with Topical Peer review Terms of Reference and Technical Specifications

The ENSREG Terms of Reference describe the process to be followed in this Topical Peer Review on ageing management. This process was generally followed in the preparation of National Assessment Reports, their peer review and the development of this report. The structure and content of the National Assessment Reports is defined in the Technical Specification prepared by the Western European National Regulators Association. Although there were differences in the level of detail and presentation, all National Assessment Reports addressed the topics reasonably well, providing a sufficient overview of the Ageing Management Programmes. In conclusion, National Assessment Reports, the answers provided to the questions from the public consultation phase, the presentations and discussions at workshop in May 2018, enabled peers to conduct a desktop review.

The Topical Peer Review on ageing management focused on the Overall Ageing Management Programmes and four thematic areas: electrical cables, concealed pipework, reactor pressure vessels and Calandria, and concrete containment structures and Pre-stressed Concrete Pressure Vessels. The scope of the first Topical Peer Review covered Nuclear Power Plants in operation and under construction, and Research Reactors with thermal power of 1 MW or above. In general, the information provided in National Assessment Reports was comprehensive for Nuclear Power Plants in all areas and less comprehensive for Research Reactors.

9.2. Summary of the results regarding Ageing Management Programmes for Nuclear Power Plants

Based on the Topical Peer Review results, national requirements for the Overall Ageing Management Programmes are in all countries in line with the International Atomic Energy Agency Safety Standards and WENRA Safety Reference Levels on ageing management. There is variation on the level of implementation, due to, for instance, different Nuclear Power Plant designs and regulatory frameworks. Although Ageing Management Programmes are not regulated and implemented in a fully consistent manner, compliance with the international requirements can be considered adequate in all countries.

The review identified that all participating countries have Overall Ageing Management Programmes in place for nuclear power plants. There are differences in the scope and implementation of these programmes for practical reasons such as different Nuclear Power Plant designs, differences in Systems, Structures and Components, and their age. Despite the differences, the results of the peer review demonstrated that the Overall Ageing Management Programmes cover safety significant Systems, Structures and Components and therefore support safe operation of the Nuclear Power Plants. Consistent scopes for Ageing Management Programmes will be ensured in the near future with the expectation to all countries to review and implement the International Atomic Energy Agency's new safety guide on ageing management.

In all countries, Ageing Management Programmes for Nuclear Power Plants are reviewed and updated by the licensees. Implementation of the programmes and compliance with the requirements are verified by the regulators within inspection programmes, periodic safety reviews and license renewals, as appropriate. In addition, the Topical Peer Review demonstrated that experience and information on the review and update of Ageing Management Programmes, their implementation and regulation is widely shared within the international nuclear community. There are, for instance, the IAEA International Generic Ageing Lessons Learned (IGALL) project and Electric Power Research Institute (EPRI) database to obtain practical component level information on ageing. Furthermore, countries use external peer review services such as the IAEA Safety Aspects of Long Term Operation (SALTO) or Operational Safety Review Team (OSART)-Long Term Operation missions to ensure compliance with best international practices. This was considered as a good practice and the Topical Peer Review Board encourages countries to invite such peer review missions and utilize their results to further improve ageing management.

The review highlighted an industry-wide challenge at the European level to develop the means to evaluate the effectiveness of the Ageing Management Programmes, for instance, through performance indicators or other appropriate tools. Resolving this challenge would ensure more consistent evaluation of the effectiveness of the Ageing Management Programmes across countries.

9.3. Summary of results regarding Electrical Cables at nuclear power plants

Based on the Topical Peer Review results, the Ageing Management Programmes for electrical cables are generally considered adequate. An observation was that, while the general objectives of Ageing Management Programmes for electrical cables are broadly comparable, the details vary significantly. These differences in detail are due to a number of reasons, such as variety of cable materials and manufacturers, cable characteristics and the different environments cables are exposed to at Nuclear Power Plants.

The review identified one good practice in following the ageing of cables with samples aged at the Nuclear Power Plants in real conditions. This can be achieved with specific cable deposits or with cables taken out of operation, but left in place to support ageing management.

The review identified several areas where actions taken by the countries would enhance ageing management of cables. These include proper documentation of the cable Ageing Management

Programme, methods for monitoring and directing all ageing management programme activities, systematic identification of ageing degradation mechanisms, consideration of uncertainties in the initial Environmental Qualification, determination of cables’ performance under highest stressors, techniques used to detect the degradation of inaccessible cables, and prevention and detection of water-treeing. These findings were not allocated to the countries due to the large variation of cables and their use at Nuclear Power Plants.

9.4. Summary of results regarding concealed pipework at nuclear power plants

Based on the Topical Peer Review results, the Ageing Management Programmes for concealed pipework are considered adequate. There is a good level of consistency in Ageing Management approaches across countries. Whilst the review did not identify any clear deficiencies, a number of countries indicated that they have recently introduced Ageing Management Programmes for concealed pipework. Therefore, there is an ongoing need for licensee and regulatory attention in this area.

The review identified two good practices, in the ageing management of concealed pipework:

- utilizing the results from regular monitoring of the condition of civil structures as inputs to the Ageing Management Programme for concealed pipework,
- verifying the integrity of new or novel materials by removing and inspecting sections of the pipework after a period of operation.

The review identified areas where actions taken by the countries would enhance ageing management of concealed pipework. These concern ensuring that the scope of pipework in the Ageing Management Programme includes both safety related pipework penetrations through concrete structures and non-safety related pipework whose failure may impact safety significant Systems, Structures and Components. In addition, the ageing management of concealed pipes would benefit from opportunistic inspections, whenever the pipework becomes accessible for other purposes.

The review also highlighted an industry-wide challenge on the use of novel inspection techniques. Further work at the European level to evaluate the capability of a number of promising inspection technologies could enable the integrity of long lengths or complex geometries of concealed pipework to be demonstrated, without the need to gain access, with the potential for damage to corrosion protection systems that this may entail.

9.5. Summary of results regarding reactor pressure vessel and calandria at nuclear power plants

Based on the Topical Peer Review results, the Ageing Management Programmes for Reactor Pressure Vessels can be considered both adequate and consistent with international requirements. This is expected since the Reactor Pressure Vessel is the most significant component at the Nuclear Power Plant, and therefore also the most studied and followed both nationally and internationally. The review identified differences in the approaches and deviations from the international guidelines that are due to different Nuclear Power Plant designs, different operating parameters, and use of different codes and standards for engineering and manufacturing of the Reactor Pressure Vessels.

The main ageing phenomenon affecting material properties of the Reactor Pressure Vessel is irradiation embrittlement. The review showed that this phenomenon is addressed by Ageing Management Programmes in all countries. The review identified one good practice to proactively enhance protection against irradiation embrittlement by the installation of shielding in the core to reduce neutron flux on the vessel wall.

The review identified areas where actions taken by the countries would enhance ageing management of Reactor Pressure Vessels. One of them sets an expectation to all countries to perform comprehensive Non Destructive Examination in the base material of the beltline region in order to detect defects. This expectation comes from recent operating experience at European Nuclear Power Plants, namely hydrogen flakes detected in Belgium and non-metallic inclusions detected in Switzerland. Although these were not ageing-related degradations, the presence of defects has to be taken into account in mechanical analyses and the ageing phenomena of reactor pressure vessel can impact these analyses. Another expectation is to take into account the environmental effect of coolant in the fatigue analyses.

The review also highlighted an industry-wide challenge where further work at the European level is warranted. This challenge also originates from the above-mentioned events in Belgium and Switzerland, in which the use of qualified state of the art Non Destructive Examination techniques improved the capability to detect defects. The Reactor Pressure Vessel inspections could be improved by establishing and maintaining an up to date European catalogue of state of the art new techniques and technologies which are qualified for Non Destructive Examination.

Concerning CANDU reactors, the Topical Peer Review concluded that the ageing management of Calandria and the pressure tubes at Romanian CANDU reactors is in compliance with the international standards.

9.6. Summary of results regarding concrete containment structures and pre-stressed concrete pressure vessels at nuclear power plants

Based on the Topical Peer Review results, the Ageing Management Programmes for concrete containment structures and Pre-stressed Concrete Pressure Vessels at Nuclear Power Plants can be considered adequate. No significant deficiencies or concerns were identified. In addition, a good level of consistency in the ageing management approaches for concrete containment structures was identified, despite the different Nuclear Power Plant designs.

The review identified two good practices in the ageing management of concrete containment structures and Pre-stressed Concrete Pressure Vessels. One is to implement complementary instrumentation in containment concrete structures to follow and predict the behaviour of concrete over time. The other good practice is to implement a proactive and comprehensive methodology to monitor, inspect and assess inaccessible structures and structures with limited access.

The review identified an area where actions taken by the countries would enhance ageing management of concrete structures. The expectation is to monitor pre-stressing forces periodically to ensure that the containment fulfils its safety function.

The review highlighted an industry-wide challenge where further work at the European level is warranted. This challenge is the difficulty to establish objective and comprehensive acceptance criteria for some concrete degradation mechanisms. Addressing this challenge would improve the effectiveness of concrete structures’ ageing management.

9.7. Main results regarding Research Reactors

Based on the Topical Peer Review results, the ageing management programmes for Research Reactors are not regulated or implemented as systematically and comprehensively as for Nuclear Power Plants. Activities can be generally described as more limited and reactive, rather than programmatic and proactive. This may be justifiable due to the variety of Research Reactor designs and their potentially lower risk significance compared to NPPs. However, the general conclusion of the review is that more systematic and comprehensive Overall Ageing Management Programmes should be implemented for the Research Reactors, in accordance with a graded approach and with the applicable national requirements, international safety standards and best practices.

WENRA has decided to establish Safety Reference Levels for Research Reactors. The Topical Peer Review Board supports this activity and encourages WENRA to address relevant requirements for ageing management to support development of Ageing Management Programmes for Research Reactors.

9.8. Recommendations to the European Nuclear Safety Regulators Group and Countries for future positions and actions

- The scope of this peer review was Nuclear Power Plants in operation and under construction, and Research Reactors with thermal power of 1 MW or above. The generic outcome of the peer review was that the regulation and implementation of the Ageing Management Programmes is more systematic and comprehensive for Nuclear Power Plants compared to Research Reactors. There are also other nuclear installations in operation in the EU which were not covered by the peer review. The Board recommends that countries explore the regulation and implementation of Ageing Management Programmes of other risk significant nuclear installations while developing and implementing National Action Plans to ensure they exist and are effective.
- According to the Directive "*Member States should establish national action plans for addressing any relevant findings and their own national assessment*". The countries' National Action Plans should address the results of the self-assessment and respond to the country specific findings allocated to them for reaching the Topical Peer Review expected level of performance. Furthermore, the Board encourages countries to explore all generic findings of this peer review and to study their applicability to improve the regulation and implementation of Ageing Management Programmes at each Nuclear Power Plant and Research Reactor.
- The challenges identified by the peer review are Europe-wide and difficult to resolve for individual countries. The Board recommends the European Nuclear Safety Regulators Group (ENSREG) to ask the Western European National Regulators Association (WENRA) to address identified challenges in collaboration with European Technical Safety Organisation Network (ETSON) when applicable.
- The Board recommends the European Nuclear Safety Regulators Group to ask the International Atomic Energy Agency and Western European National Regulators Association to consider addressing Topical Peer Review findings in their safety standards or Safety Reference Level documents. This could ensure more consistent implementation and application of Ageing Management Programmes and further improvement of nuclear safety globally.
- As per the Directive these Topical Peer Reviews will be conducted every six years. Conducting the first peer review has been a challenge and has required significant resources from the participating countries and the European Commission. The Board recommends the European Nuclear Safety Regulators Group to ask its Working Group 1 to collect feedback from the countries and from the Board to draw lessons learned from this peer review to ensure efficiency and effectiveness in the future peer reviews

Annex I: Glossary

ACI: American Concrete Institute
AGR: Advanced Gas Cooled Reactors
AMPs: Ageing Management Programmes
ASME: American Society of Mechanical Engineers
BMI: Bottom Mounted Instrumentation
BWR: Boiling Water Reactor
CANDU: CANada Deuterium Uranium
CFR: Code of Federal Regulation (US NRC)
CSA: Canadian Standards Association
DEC: Design Extension Conditions
DHC: Delayed Hydride Cracking
EC: European Commission
EU: European Union
ENSREG: European Nuclear Safety Regulators Group
EPR: ethylene propylene rubber
EPRI: Electric Power Research Institute (US)
EQ: Environmental Qualification
ETSON: European Technical Safety Organisation Network
FFSG: Fitness-for-Service Guidelines
FTIR (cables) testing
GALL: Generic Ageing Lessons Learned (US NRC)
HDPE: High Density Polyethylene
HV cables: High Voltage cables
HWC: Hydrogen Water Chemistry
IAEA: International Atomic Energy Agency
I&C: Instrumentation and Control
IEC: International Electrotechnical Commission
IEEE: Institute of Electrical and Electronics Engineers
IGALL: International Generic Ageing Lessons Learned (IAEA)
IGSCC: Intergranular Stress Corrosion Cracking
INSARR: Integrated Safety Assessment of Research Reactors (IAEA)
ISI: In-Service Inspection
KTA: German standards
LLC: Low Leakage Core
LOCA: Loss Of Coolant Accident
LTO: long-term operation
LWR: Light Water Reactors
MDEP: Multinational Design Evaluation Programme (OECD-NEA)
MV cables: Medium Voltage cables
NAR: National Assessment Report
NDE: Non Destructive Examination
NIS: Nuclear Instrumentation
NPPs: Nuclear Power Plants
OECD NEA: Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD),
OPEX: Operating Experience
OSART: Operational Safety Review Team (IAEA)
PCPVs: Pre-stressed Concrete Pressure Vessels
PSR: PSR periodic safety reviews

PVC: polyvinyl chloride
PWR: Pressurised Water Reactor
PWSCC: Primary Water Stress Corrosion Cracking
RCC-M: French manufacturing and design rules for mechanical components
RPV: Reactor Pressure Vessel
RRs: Research Reactors
SBO: Station Blackout
SCC: Stress Corrosion Cracking
SSCs: Systems, Structures and Components
SRLs: WENRA Safety Reference Levels for Existing Reactors
SALTO: Safety Aspects of Long Term Operation (IAEA)
TLAA: Time Limited Ageing Analysis
ToR: Terms of Reference
TPR: Topical Peer Review
TS: Technical Specification
TSO: Technical Support Organisation
VVER: Water Energy Reactor
WANO: World Association of Nuclear Operators
WENRA: Western European National Regulators Association
XLPE: cross-linked polyethylene

Annex II: Compilation of Good Practices; TPR expected level of performance and challenges

Definitions

Good Practice

A good practice is an aspect of ageing management which is considered to go beyond what is required in meeting the appropriate international standard.

TPR expected level of performance

A "TPR expected level of performance" for ageing management is the level of performance that should be reached to ensure consistent and acceptable management of ageing throughout Europe.

Challenge

Challenges are common to many or all countries and are areas where action at a European level could help to increase available knowledge or drive consistency or produce beneficial new techniques or technology to assist in specific aspects of ageing management.

Overall Ageing Management Programmes (OAMPs)

Good practice:

External peer review services: External peer review services (e.g. SALTO, OSART-LTO, INSARR-Ageing) are used to provide independent advice and assessment of licensees' ageing management programmes.

TPR expected level of performance:

Data collection, record keeping and international cooperation: Participation in international R&D projects, experience exchange within groups of common reactor design and the use of existing international databases are used to improve the effectiveness of the NPPs OAMP.

***Methodology for scoping the SSCs subject to ageing management*:** The scope of the OAMP for NPPs is reviewed and, if necessary, updated, in line with the new IAEA Safety Standard after its publication.

***Delayed NPP projects and extended shutdown*:** During long construction periods or extended shutdown of NPPs, relevant ageing mechanisms are identified and appropriate measures are implemented to control any incipient ageing or other effects.

Overall Ageing Management Programmes of research reactors: A systematic and comprehensive OAMP is implemented for research reactors, in accordance with the graded approach to risk, the applicable national requirements, international safety standards and best practices.

Challenges:

***Effectiveness of the OAMP and use of performance indicators*:** Indicators are considered important for the evaluation of the effectiveness of the OAMPs but no unified approach is available. Further development of improved performance indicators or other appropriate tools would enable consistent evaluation of the effectiveness of the OAMPs among NPPs.

Electrical cables:

Good practice:

***Characterize the state of the degradation of cables aged at the plant*:** Cables are aged within the actual power plant environment and tested to assess cable condition and determine residual lifetime

TPR expected level of performance:

***Documentation the cable ageing management program*:** *T*he AMP is sufficiently well-documented to support any internal or external reviews in a fully traceable manner.

***Methods for monitoring and directing all AMP-activities*:** Methods to collect NPP cable ageing and performance data are established and used effectively to support the AMP for cables

***Systematic identification of ageing degradation mechanisms considering cable characteristics and stressors*:** Degradation mechanisms and stressors are systematically identified and reviewed to ensure that any missed or newly occurring stressors are revealed before challenging the operability of cables.

***Prevention and detection of water treeing*:** Approaches are used to ensure that water treeing in cables with polymeric insulation is minimised, either by removing stressors contributing to its growth or by detecting degradation by applying appropriate methods and related criteria

***Consideration of uncertainties in the initial EQ*:** The accuracy of the representation of the stressors used in the initial Environmental Qualification is assessed with regard to the expected stressors during normal operation and Design Basis Accidents

***Determining cables' performance under highest stressors*:** Cables necessary for accident mitigation are tested to determine their capabilities to fulfil their functions under Design Extension Conditions and throughout their expected lifetime.

***Techniques to detect the degradation of inaccessible cables*:** Based on international experience, appropriate techniques are used to detect degradation of inaccessible cables.

Concealed pipework:

Good practice:

***Use of results from regular monitoring of the condition of civil structures*:** In addition to providing information on soil and building settlement, the results from regular monitoring of the condition of civil structures are used as input to the ageing management programme for concealed pipework.

***Performance checks for new or novel materials*:** In order to establish the integrity of new or novel materials, sections of pipework are removed after a period of operation and inspected to confirm the properties are as expected.

TPR expected level of performance:

***Inspection of safety-related pipework penetrations*:** Inspection of safety-related pipework penetrations through concrete structures are part of ageing management programmes, unless it can be demonstrated that there is no active degradation mechanism.

Scope of concealed pipework included in AMPs: The scope of concealed pipework included in ageing management includes those performing safety functions, and also non-safety-related pipework whose failure may impact SSCs performing safety functions.

Opportunistic inspections: Opportunistic inspection of concealed pipework is undertaken whenever the pipework becomes accessible for other purposes.

Challenges:

Non-invasive inspection methods for long lengths or complex geometries: Non-invasive inspection methods for detection of local corrosion, suitable for use on long lengths or complex geometries of concealed piping, are not well established. Research and development of such methods would enhance the tools available for demonstrating the integrity of concealed pipework and increase the overall safety of nuclear installations.

Reactor Pressure Vessel or calandria pressure tubes

Good practice:

Hydrogen water chemistry: Hydrogen Water Chemistry (HWC) is used in BWRs which may be sensitive to Intergranular Stress Corrosion Cracking

Implementation of a shield: Shielding in the core of PWRs with relatively high fluence is implemented to preventively reduce neutron flux on the RPV wall.

TPR expected level of performance:

Volumetric inspection for nickel base alloy penetration: Periodic volumetric inspection is performed for nickel base alloy penetrations which are susceptible to Primary Water Stress Corrosion Cracking for PWRs to detect cracking at as early a stage as possible.

Non-destructive examination in the base material of beltline region: Comprehensive NDE is performed in the base material of the beltline region in order to detect defects

Environmental effect of the coolant: Fatigue analyses have to take into account the environmental effect of the coolant.

Suitable and sufficient irradiation specimens: For new reactors, suitable and sufficient irradiation specimens and archive materials are provided to support the reactor through its full operational life.

Challenges:

State of the art and qualified techniques for NDE: NDE techniques are continuously developing and improving and it is a challenge for licensees to know the current state of the art in qualified RPV inspection techniques. The RPV inspections could be improved by establishing and maintaining an up to date European catalogue of state of the art new techniques and technologies for NDE.

Concrete containment structure and pre-stressed concrete pressure vessel

Good practice:

***Monitoring of concrete structures*:** Complementary instrumentation is used to better predict the mechanical behaviour of the containment and to compensate for loss of sensors throughout the life of the plant.

***Assessment of inaccessible and/or limited access structures*:** A proactive and comprehensive methodology is implemented to inspect, monitor and assess inaccessible structures or structures with limited access

TPR expected level of performance:

***Monitoring of pre-stressing forces*:** Pre-stressing forces are monitored on a periodic basis to ensure the containment fulfils its safety function.

Challenges:

***Acceptance criteria for the degradation mechanisms*:** It is difficult to define objective and comprehensive acceptance criteria for ageing management of concrete structures. The development of such criteria for a number of degradation mechanisms would improve the effectiveness of the AMPs.

Annex III: Statistics

NAR	No of questions per country
Belgium	177
Bulgaria	122
Czech Republic	147
Finland	123
France	233
Germany	184
Hungary	94
Italy	76
Netherlands	127
Poland	53
Romania	86
Slovak Republic	115
Slovenia	84
Spain	134
Sweden	118
United Kingdom	137
Norway	36
Switzerland	108
Ukraine	175
Total	**2329**

Chapter / topic title	No of questions per topic
01. General information	76
02. Overall Ageing Management Programme requirements and implementation	628
03. Electrical cables	493
04. Concealed pipework	280
05. Reactor Pressure Vessels	328
06. Calandria/pressure tubes (CANDU)	0
07. Concrete containment structures	495
08. Pre-stressed concrete pressure vessels (AGR)	16
09. Overall assessment and general conclusions	11
10. References	2
Total	**2329**