Nuclear Safety
NEA/CSNI/R(2015)13
July 2015
www.oecd-nea.org

Questionnaire on Long-Term Operation of Commercial Nuclear Power Plants

Unclassified **NEA/CSNI/R(2015)13**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **22-Dec-2015**

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

NEA/CSNI/R(2015)13
Unclassified

Results of Questionnaire on Long-Term Operation of Commercial Nuclear Power Plants

JT03388590

English text only

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;

– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

THE COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers with broad responsibilities for safety technology and research programmes, as well as representatives from regulatory authorities. It was created in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety among NEA member countries. The main tasks of the CSNI are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and reach consensus on technical issues; and to promote the co-ordination of work that serves to maintain competence in nuclear safety matters, including the establishment of joint undertakings.

The priority of the committee is on the safety of nuclear installations and the design and construction of new reactors and installations. For advanced reactor designs, the committee provides a forum for improving safety-related knowledge and a vehicle for joint research.

In implementing its programme, the CSNI establishes co-operative mechanisms with the NEA Committee on Nuclear Regulatory Activities (CNRA), which is responsible for issues concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with other NEA Standing Technical Committees, as well as with key international organisations such as the International Atomic Energy Agency (IAEA), on matters of common interest.

FOREWORD

This report has been written by members of the Working Group on Integrity and Ageing of Components and Structures (WGIAGE) of the NEA, and the members of the metal subgroup have been responsible for developing the responses in this report. The activity is fully consistent with NEA strategies for WGIAGE.

This activity was initiated by a CSNI activity proposal sheet (CAPS) on long-term operation (LTO) research that was approved in December 2009. The CAPS was proposed and led by the United States Nuclear Regulatory Commission (NRC), the CSNI representative from the United States.

The stated purpose of the CAPS is to identify technical areas of mutual interest related to age-related degradation of materials during long-term operation (LTO) of nuclear power plants (NPPs). The work of the CAPS was largely carried out by the metal subgroup members of WGIAGE. As a result, the responses focus on age-related degradation of materials of the long-lived metal components. However, there is also information associated with age-related degradation of concrete along with electrical and instrumentation and control (I&C) cables.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report summarises the responses provided by the member organisations of the Working Group on Integrity and Ageing of Components and Structures (WGIAGE) of the Committee on the Safety of Nuclear Installations (CSNI) to a questionnaire on long-term operation (LTO) of commercial nuclear power plants. The questionnaire asks each country to identify if they are supporting LTO, technical and regulatory issues associated with LTO, component and material inspection challenges, areas of related research, and identification of possible areas for collaborative research sponsored by CSNI. The original intent of the CAPS was to examine issues related to age-related degradation beyond 60 years. However, during the work it was recognized that there is little international operating experience for NPPs beyond 40 years of life. Also, most age-related degradation mechanisms occur slowly and there is not typically a significant difference between the mechanisms present after 40 years compared to those present after 60 years. Based on these reasons, the member organisations decided to define LTO to be applicable to more than 40 years of NPP operation for the purposes of this report.

Responses were provided from representatives from 13 countries as well as the Joint Research Centre (JRC) of the European Commission (EC). Responses indicated many similar technical issues among the countries, several common research areas, and some common inspection challenges. There were also issues identified that are also unique to particular reactor types and the regulatory framework used within each country. There were also several technical areas that multiple countries expressed interest in considering for additional CSNI-sponsored research projects. The most common areas identified relate to ageing of reactor pressure vessel internals, embrittlement of the reactor pressure vessel, ageing of I&C and electrical components, environmental effects on metal fatigue, and ageing degradation of concrete and, more specifically, containment structures. These high-interest topics are currently being addressed in several NEA-sponsored projects, including the following:

- The concrete subgroup of WGIAGE is sponsoring a project on ageing of concrete, entitled "Assessment of Structures subject to Concrete Pathologies (ASCET)". This project was initiated in 2013. A prior project in this area has recently resulted in the report NEA/CSNI/R(2015)5, entitled "Bonded or Unbonded Technologies for Nuclear Reactor Prestressed Concrete Containments."

- The metals subgroup of WGIAGE is sponsoring a project on the effects of ageing and embrittlement on the structural integrity of the reactor pressure vessel (RPV) in the project entitled, "Probabilistic Structural Integrity of a PWR Reactor Pressure Vessel (PROSIR)."

- The metals subgroup is also conducting an NEA workshop on metal fatigue in Sevilla, Spain, starting on 27 September 2015. Metal fatigue is an ageing mechanism that affects structural reactor vessel internal and piping components. Fatigue is exacerbated by the high temperatures and water environments present in commercial nuclear reactors. The NEA is also developing databases that track age-related failures of important nuclear power plant components. The Cable Ageing Data and Knowledge (CADAK) Project is establishing a database of age-related degradation in electrical and instrumentation and control (I&C) components. The Component Operational Experience, Degradation

and Ageing Program (CODAP) is collecting information on passive metallic component degradation and failures of the primary system, reactor pressure vessel internals, main process and standby safety systems, as well as non-safety-related components with significant operational impact.

Future projects in these areas will continue to be pursued within the WGIAGE and specifically within the metal and concrete subgroups. For example, during the 2015 WGIAGE meetings, a new activity on in-service inspection requirements for reactor vessel internals and bottom-mounted instrumentation nozzles was identified and an international database on metal fatigue tests that is being developed by the US was discussed and interested participants were solicited. Projects related to reactor pressure vessel structural integrity that are being conducted in several countries were also discussed. Additional projects related to concrete and electrical and I&C cable ageing could also be proposed during the next WGIAGE meetings.

ABBREVIATIONS AND ACRONYMS

BTP	Buried tank and piping
CAPS	CSNI activity proposal sheet
CSNI	Committee on the Safety of Nuclear Installations
I&C	Instrumentation and control
LTO	Long-term operation
LRA	License renewal application
NDE	Non-destructive evaluation
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission (USA)
PSR	Periodic safety review
RPV	Reactor pressure vessel
SCC	Stress corrosion cracking
SSC	Systems, structures and components
WGIAGE	Working Group on Integrity and Ageing of Components and Structures

INTRODUCTION

This activity was initiated by a CSNI activity proposal sheet (CAPS) on Long-term operation (LTO) research that was approved in December 2009. The CAPS was proposed and led by the Nuclear Regulatory Commission (NRC), which is the representative from the United States (US) to CSNI. The stated purpose of the CAPS is to identify technical areas of mutual interest related to age-related degradation of materials during long-term operation (LTO) of nuclear power plants (NPPs). The original CAPS defines LTO as operation of greater than 60 years. This initial definition was made because, at the time of the proposal, the United States already had a regulatory framework and sufficient generic technical bases for approving license renewal of NPPs from 40 to 60 years of operation. At the time, the US had also granted renewed licenses for approximately 60% of the operating fleet. The US was also just starting to consider the possibility of operation of NPPs beyond 60 years, which is called the subsequent license renewal (SLR) period in the US. Therefore, the original intent of the CAPS was to examine issues related to age-related degradation beyond 60 years.

However, while the US had granted licenses for operation up to 60 years, it was recognised that there was actually little international operating experience for NPPs beyond 40 years of life. Most other countries also have a different regulatory structure than the US, which provides an initial 40-year operating licence. Most countries grant continued operation in 10-year increments upon approval of the licensee’s periodic safety report (PSR). Finally, most age-related degradation mechanisms also occur slowly and, if unmitigated, and do have the potential to gradually worsen over time. However, there is not typically a distinction between the mechanisms present at 40 years compared to those present at 60 years. For all these reasons, the member organisations decided to refine the CAPS definition of LTO as NPP operation greater than 40 years.

The original CAPS is comprised of a Phase I and a Phase II component. Phase I has two activities. The first activity is related to age-related degradation during LTO which is the focus of the questionnaire and responses that are summarised in this report. The second activity was related to the evaluation of buried tank and piping (BTP) issues and the proposed development of a database of international operating experience. This activity was seen as a trial for coordination among the member organisations on LTO issues that could be used to inform collaboration on LTO topics arising from the questionnaire responses. This results of the BTP activity in Phase I is summarised in a separate report.

Phase II is intended to be a follow-on activity (or activities) that would be identified by the Phase I questionnaire responses where sufficient mutual interest exists for collaborative research on specific LTO topics. The Phase II output would be a cooperative research plan for each proposed topic. Each research plan would also be used as the basis for a new CAPS proposal to be recommended for approval by CSNI. Recommendations for proceeding to Phase II are provided in this report. Phase II of the BTP activity is intended to extend and expand any BTP database on operating experience developed during Phase I. Recommendations for Phase II of the BTP activity are also provided in a separate report.

The remainder of this report summarises the objective and scope of the LTO questionnaire, the questions addressed to each country, the responses from the organisations, conclusions and recommendations for proceeding to Phase II of this effort as described in the CAPS. A reference list related to LTO topics is also provided by each country. Each organisation’s responses to the questionnaire are contained in the appendix.

OBJECTIVE

The principal objective of the LTO questionnaire is to identify technical areas of mutual interest related to age-related degradation of materials in safety-related systems, structures and components (safety-related SSCs) during LTO (i.e. greater than 40 years) of NPPs. Research plans will be developed to propose collaborative research that would address current understanding and gaps in each technical area that has sufficient overlapping interest from the member countries. In order to support the principal objective, material and SSC inspection challenges, areas of related LTO research are assessed, and the ability and interest of member organizations to share information and possibly participate in collaborative research on topics of mutual agreement are discussed.

SCOPE

As indicated previously, the questionnaire asks each respondent to identify technical and/or regulatory issues related to age-related degradation in passive SSCs during LTO. A passive SSC is generally defined as one which does not require movement to perform its intended function during normal operation or in response to a transient or accident condition. Examples include heat exchangers, cables, the reactor pressure vessel, reactor pressure vessel internals, valve and pump bodies, piping, and concrete structures. Of particular interest are age-related degradation modes (i.e. locations, materials, and degradation mechanisms) that are difficult to mitigate (or are presently unmitigated), and that are expected to increasingly challenge continued safe operation during extended plant operation periods. These degradation modes may not lead to safety concerns until after 40 or 60 years of plant operation.

QUESTIONNAIRE

The questionnaire is comprised of seven questions. In this section each question will be presented and the intent of the question will be summarised along with any examples or other information provided to the respondents to clarify the question.

1. **Is your country currently supporting allowing commercial reactors to operate longer than the original length of the licensing or approved design (i.e. > 40 years)?**

This question is intended to identify those countries that are currently considering licensing the operation of commercial NPPs beyond 40 years of life.

2. **What technical issues or concerns does your agency have related to material or component ageing during long term operation (i.e. not regulatory concerns but scientific concerns resulting from material degradation in passive system components)? For each issue or concern, please provide the following information:**

    a. **your country's rationale or reasons for the issue or concern,**

    b. **a contact person for the issue or concern, and**

    c. **a qualitative ranking (i.e. high, medium, or low) for each issue or concern.**

This question is intended to identify technical issues within each participating organisation. Of particular interest is the supporting rationale for the issue and a qualitative ranking of high, medium, or low for the issue. A contact person within the organisation was also requested for the purpose of pursuing additional information or collaborative opportunities as appropriate. The following examples of relevant technical issues were also provided with this question: reactor pressure vessel embrittlement, and ageing of large concrete structures and basemats.

3. **What regulatory issues or concerns does your agency have related to material or component ageing during long term operation (i.e. not scientific concerns but concerns related to the regulatory requirements, framework, or structure applicable to long term operation)? For each issue or concern, please provide the following information:**

    d. **your country's rationale or reasons for the issue or concern,**

    e. **a contact person for the issue or concern, and**

    f. **a qualitative ranking (i.e. high, medium, or low) for each issue or concern.**

This question is intended to identify issues related to the regulatory requirements, framework, or structure applicable to LTO. Of particular interest is the supporting rationale for the issue and a qualitative ranking of high, medium, or low for the issue. A contact person within the organisation was also requested for the purpose of pursuing additional information on the issue if appropriate. The following examples of relevant regulatory issues were also provided with this question: a lack of regulatory infrastructure to address issues related to LTO, and the effectiveness and implementation of ageing management programs.

4. **Please identify any components or systems that are expected to be difficult to inspect and may potentially experience degradation that could challenge the required functionality (i.e. the ability of the components to perform their intended function) of such components or systems under long-term operation. Some examples of relevant components that may be challenging to inspect include cast austenitic stainless steel components (CASS), dissimilar metal welds, certain reactor internals components, electrical cables, thick-section concrete, or buried tanks and piping.**

This question is intended to identify materials and SSCs that are difficult to inspect. Understanding inspection challenges is of interest because inspection is a common strategy for characterizing the extent of age-related degradation and determining what, if any, remediation is required to mitigate any found degradation. Examples of some well-known inspection challenges are provided including CASS, dissimilar metal welds, some reactor internals components, electrical cables, concrete, and buried tanks and piping.

5. **Please identify areas of related research that your organisation is currently sponsoring or has sponsored in the past?**

This question is intended to summarise research activities related to passive SSC performance during LTO. The purpose is to give other countries knowledge of what related research has been, or is being, conducted. This research can provide a basis for additional, non-duplicative work in other organisations to address remaining gaps and serve as a basis for possible collaboration among interested CSNI organisations.

6. **Are you able to share research results for related research projects that are either ongoing or completed? If not, please discuss limitations, challenges or constraints that must be resolved in order to share research results.**

This question is intended to determine which research activities are publicly available or at least can be shared among the member CSNI organisations. Additionally, this questions asks to identify activities that are either proprietary or subject to other constraints such that information cannot be shared unless additional measures are taken to make the information available

7. **What future areas of research (or technical issue) are of most interest to your country in conducting a research activity sponsored by CSNI? Please list the research areas in decreasing order of priority. Additionally, for each area of research, please provide the following information:**

   g. **your country's rationale or reasons for the research area,**

   h. **a contact person for the research area, and**

   i. **a qualitative ranking (i.e. high, medium, or low) associated with the research area.**

This question is intended to identify research topics related to LTO that each country would be interested in participating in through a CSNI-sponsored collaborative research program. Of particular interest is the supporting rationale for the research topic and a qualitative ranking of high, medium, or low for the top. A contact person within the organisation was also requested for the purpose of pursuing additional information and collaboration on the topic if appropriate. A note was included with this question to stress that the intent of this question is to identify possible future CSNI-sponsored activities and not reaffirm interest in current CSNI-sponsored projects (e.g., those presently underway in WGIAGE).

SUMMARY OF RESPONSES

Organisations representing twelve countries and the JRC responded to the initial questionnaire in 2012. The organisations included Bel V, **Belgium**; the Canadian Nuclear Safety Commission (CNSC), **Canada**; the Nuclear Research Institute (UJV Rez), **Czech Republic**; Radiation and Nuclear Safety Authority (STUK), **Finland**; Materiaprüfungsanstalt (MPA), **Germany**; Nuclear Regulatory Authority (NRA, formerly Japan Nuclear Energy Safety Organisation), **Japan**; Ministry of Environment and Transport, Department of Nuclear Safety, Security & Safeguards (KFD), **Netherlands**; Nuclear Power Plant Research Institute (VUJE), **Slovak Republic**; Slovenian Nuclear Safety Administration, **Slovenia**; Swedish Radiation Safety Authority (SSM), **Sweden**; Swiss Federal Nuclear Safety Inspectorate (ENSI), **Switzerland**; US Nuclear Regulatory Commission (NRC) , **United States**; and as mentioned, the **JRC**.

The questionnaire was revised in 2013 to clarify some of the initial questions, with the final questions as shown in the previous Questionnaire section. The Institut de Radioprotection et de Sûreté (IRSN), **France** provided responses to the revised questionnaire. Updated responses to the revised questionnaire were provided by the Czech Republic, Finland, Germany, Slovakia, and Sweden in 2013, and Japan in 2015. All other countries retained their original responses. The responses are summarised in the rest of this section. The more detailed, individual responses to the questionnaire are provided in the appendix.

The first question seeks to determine which countries are supporting LTO of commercial nuclear power plants beyond 40 years. Most countries (11) are supporting LTO. Germany is not currently supporting LTO and their last remaining NPPs are planned to cease operation in 2022. While the Belgium nuclear regulations put no limit on the length of operation, a law enacted in 2003 limits the life of NPPs to 40 years. This law was adapted in December 2013 allowing for Tihange 1 NPP to operate for 50 years. Currently, discussions are on-going to consider long term operation for Doel 1&2 also. Japan is also currently supporting LTO after amending related laws and regulations in 2013.

The second question asks each participating organisation to identify technical issues related to LTO. There is a good deal of agreement within several broad areas. Nine countries identify ageing of containment, or more generally concrete, as an issue. The ageing, or embrittlement, of the reactor pressure vessel (RPV) is also listed as an issue by eight countries. The degradation mechanism of metal fatigue is also listed by eight countries. Metal fatigue is most often an issue for RPV internals components and piping within the primary coolant circuit. This issue is exacerbated by environmental effects which was specifically mentioned by several countries and, for the RPV internals, may also be affected by radiation. Degradation of electrical and instrumentation and control (I&C) components is identified by eight countries. This topic includes ageing of cables and well as obsolesce and modification of electrical and I&C systems. Five countries indicated that the ageing, or embrittlement, of cast austenitic stainless steels (CASS) is an issue. CASS can embrittle due to both thermal ageing and radiation. Finally, five countries also identify the ageing of RPV internals as an issue.

There are also issues that are unique to individual countries. Their uniqueness may be due to the particular reactor design or operating conditions. For example, the unique characteristics of the Canada Deuterium Uranium (CANDU) reactors results in Canada’s interest in ageing of specific reactor components such as the pressure tube and the outlet feeders in the primary coolant circuit.

Unique responses may results because the issue is considered to be of higher importance in one country than in the others. For example, the Canadian response indicates that ageing in valves, pumps, and other components is an issue. The passive system features of these components typically have significant margin. Further, operating and laboratory experience has not identified any active ageing mechanisms within these components. This is likely why more countries do not identify this issue. Additionally, while the active portions of these components are certainly subject to age-related degradation, most countries have separate requirements to mitigate the effects of ageing in the active portions of these components.

Another example of a unique issue raised by Finland is pitting and crevice corrosion near deposits and metallic contact points, especially under stagnant conditions. These corrosion mechanisms are an issue in Finland due to the difficulty in predicting their severity and because they can initiate other mechanism such as SCC. The VVER steam generator dissimilar weld cracking in Dukovany is cited as an example where pitting and crevice corrosion may have served as a precursor to SCC.

The third question asks each participating organisation to identify regulatory issues related to LTO within each participating organisation. There is much more diversity of opinion on the responses to this question due to the somewhat unique regulatory structure that is in place within the countries. The US is unique in that it originally licenses the plants to operate for 40 years and then renews their licenses in 20-year increments upon approval of each licensee's renewal application (LRA). Most other countries provide approval to operate every 10 years upon approval of the licensee's periodic safety report (PSR). While there are some differences in specific requirements, both the LRA and the PSR are required to have ageing management programs (AMPs) for important, passive SSCs.

Most countries seem comfortable with this regulatory framework. A few indicate that the development of an ageing management system (or process) is an existing issue (France), particularly for concrete structures (Finland). Canada stresses the need for an integrated ageing management approach. The most common issue identified (5 countries) is the adequate implementation and overall effectiveness of AMPs, especially newer ones that have not had time to be validated through operating experience. The US raises a similar concern about the ability of existing AMPs to manage degradation that is not currently anticipated but becomes more likely with longer plant operation. Many countries, through PSRs, stress tests, and adoption of safety improvements require an increased safety level, greater than the plant's original design basis, as a precondition for LTO. For example, Switzerland aims to review the original safety concept of the plant and to implement adequate back fittings for safety improvement. France actually expresses expectations for its reactors to reach an improved safety level during LTO that is ideally similar to new Generation III NPPs.

The fourth question is intended to identify materials and SSCs that are difficult to inspect. The containment structure is most commonly cited (5 countries). Specific emphasis is placed on the metal liner and grouted tendons and cables for those designs. The difficulties of inspecting CASS, a long-standing issue, are identified by several countries. Other generic inspection challenges that are identified include cables in conduits with fire-proofing, buried piping, some RPV internal components, certain dissimilar welds, and spent fuel pool concrete structures.

Several countries also identify challenges associated with components that appear to be unique to a particular plant-type or a specific plant configuration. One example of a challenge unique to a particular plant-type, the CANDU plants (Canada), is the Calandria assembly. Examples of inspection challenges that may be unique to the specific plant configuration include crevices at thermal shields (Finland), RPV safety injection nozzles (Slovenia), and the welded frame supporting the RPV (Netherlands).

The fifth question asks the country to identify research related to ageing in passive SSC materials that is applicable to LTO. The extensive list is contained in the appendix. Two examples for each country are subsequently provided. These examples are not meant to illustrate the major thrust of research in a given country or the most common research activities among the countries. Rather, they have been chosen to identify some of the more unique research activities related to LTO. There is little mention, for instance, of research related to stress corrosion cracking (SCC) of stainless steels and nickel-base alloys, although several countries are conducting research on this topic.

Belgium is conducting research on the development of advanced methods for RPV embrittlement and irradiation swelling of stainless steel PWR reactor internals as part of the joint project on Swelling of Austenitic Stainless Steels Under PWR Irradiation Conditions (GONDOLE Project). Canada is developing a roadmap of ageing mechanisms and effects based on research and operational experience and inspection and testing techniques to provide assurance of the bonded pre-stress systems in concrete containment. The Czech Republic is studying primary coolant circuit environmental effects on degradation in VVER nuclear power plants and ageing of reactor internals

Finland has a comprehensive research program related to nuclear plant safety (currently SAFIR2018). There are specific activities related to evaluating age-related degradation in SSCs such as a project on the environmental influence on cracking susceptibility and ageing of nuclear materials and the evaluation of failure modes for pre-stressed tendons, steel liners and fastening bolts in concrete. France is studying concrete pathologies such as the alkali-aggregate reaction and internal sulfate attack, which are two common degradation mechanism of concern. They are also examining aspects of I&C systems including electrical cables, seals, elastomer bearing pads and epoxy coating systems. Germany is conducting metallic fatigue testing under air and environmental conditions and also studying changes in material properties due to neutron irradiation

Japan has been very active in conducting research associated with all aspects of material degradation during LTO in metal components, electric and I&C equipment, and concrete structures. The JRC also sponsors a wide array of related activities including evaluating irradiation of RPV materials due to late-blooming phases and studying creep and thermal fatigue in metals. The Slovak Republic currently has programs investigating thermal ageing in NPP materials and embrittlement of RPV materials to consider the effects of new fuels, power uprates, and LTO. Slovenia is performing several activities in order to effectively manage ageing processes in the Krško NPP and is also sponsoring an evaluation of fatigue due to stratified flow in the pressuriser surge line.

Sweden is sponsoring research in metals, concrete, and electrical/I&C including work on ageing of non-metallic materials, and studying waterline corrosion on the concrete carbon steel liner cast at the condensation pool. Switzerland also has a robust research program. For example, they are developing nondestructive evaluation (NDE) techniques to detect corrosion damage in steel containments and evaluating noble metal deposition behavior in BWRs. The US also has a robust research program related to LTO. For example, the US is participating in the Zorita Internals Research Project (ZIRP) to evaluate ageing degradation in the Zorita reactor vessel internals and continues to participate in research to study ageing in RPV internals. There is also an effort underway to understand the combined effects of thermal ageing and radiation on the embrittlement of CASS. Recent years has also shown an increased emphasis on evaluating ageing effects in electrical/I&C cables and other components, as well as ageing of concrete.

The sixth question asks about the ability of countries to share information on their research activities either publicly or at least among the member CSNI organisations. Most countries (11) are generally able to share results for research activities, which have been sponsored by government and have been marked as publicly available. Information that has not been classified as being publicly available may require special permission or be releasable for use by the CSNI member countries on a case-by-case basis. Most countries cannot share proprietary research activities or security-related information. Belgium can only share publicly available publications developed as part of their program on “Development of Advanced Methods for RPV Embrittlement". The JRC can only share results from their programs on a case-by-case basis. Most JRC-sponsored projects are performed in collaboration with partner organisations and require agreement of all participants in order to share the results.

The seventh question asks each country to identify LTO-related research topics that they would be interested in participating in through a CSNI-sponsored collaborative research project. The topic areas most commonly mentioned are on environmental fatigue effects and lifetime prediction (7 countries), ageing of concrete and, more specifically, containment structures (5 countries), RPV embrittlement (4 countries), and cable ageing (4 countries). There are also some unique topics and activities identified by the countries. Canada is interested in developing guidelines on ageing management of passive SSCs. Germany proposes collaboration on on-line monitoring and evaluation of age-related degradation, particularly fatigue. Similarly, Switzerland is interested in collaboration on developing advanced NDE techniques. Sweden is interested in collaborating on research related to the safety and security of programmable digital control systems. These high-interest topics are currently being addressed in several NEA-sponsored projects, including the following:

- The concrete subgroup of WGIAGE is sponsoring a project on ageing of concrete, entitled "Assessment of Structures subject to Concrete Pathologies (ASCET)". This project was initiated in 2013. A prior project in in this area has recently resulted in the report NEA/CSNI/R(2015)5, entitled "Bonded or Unbonded Technologies for Nuclear Reactor Prestressed Concrete Containments."

- The metals subgroup of WGIAGE is sponsoring a project on the effects of ageing and embrittlement on the structural integrity of the reactor pressure vessel (RPV) in the project entitled, "Probabilistic Structural Integrity of a PWR Reactor Pressure Vessel (PROSIR)."

- The metals subgroup is also conducting an NEA workshop on metal fatigue in Sevilla, Spain, starting on September 27 2015. Metal fatigue is an ageing mechanism that affects structural reactor vessel internal and piping components. Fatigue is exacerbated by the high temperatures and water environments present in commercial nuclear reactors.

- The NEA is also developing databases that track age-related failures of important nuclear power plant components. The Cable Ageing Data and Knowledge (CADAK) Project is establishing a database of age-related degradation in electrical and instrumentation and control (I&C) components. The Component Operational Experience, Degradation and Ageing Program (CODAP) is collecting information on passive metallic component degradation and failures of the primary system, reactor pressure vessel internals, main process and standby safety systems, as well as non-safety-related components with significant operational impact.

Future projects in these areas will continue to be pursued within the WGIAGE and specifically within the metal and concrete subgroups. For example, during the 2015 WGIAGE meetings, a new activity on in-service inspection requirements for reactor vessel internals and bottom-mounted instrumentation nozzles was identified and an international database on metal fatigue tests that is being developed by the US was discussed and interested participants were solicited. Projects related to reactor pressure vessel structural integrity that are being conducted in several countries were also discussed. Additional projects related to concrete and electrical and I&C cable ageing could also be proposed during the next WGIAGE meetings.

CONCLUSIONS AND RECOMMENDATIONS

The questionnaire and the subsequent responses provides a summary of challenges related to continuing to ensure safe and secure operation of nuclear power plants as they continue to age beyond 40 years of life. Most countries are either currently or planning to support continued plant operation beyond 40 years. While several countries identify several unique technical challenges, there is a good deal of consensus States on the following broad topics of interest:

- ageing of containment, or more generally concrete,
- ageing, or embrittlement, of the reactor pressure vessel (RPV),
- metal fatigue, both with and without environmental effects,
- degradation of electrical and instrumentation and control (I&C) components,
- ageing, or embrittlement, of cast austenitic stainless steels (CASS), and
- ageing of RPV internals.

There is much more diversity of opinion on the regulatory challenges being faced by each country, but this is not surprising given the unique regulatory structure in each country. Most countries believe their existing regulatory framework is sufficient to support long-term operations, while a few indicate that the development of an ageing management system (or process) is still an existing issue within their country. The most common challenge identified is ensuring the adequate implementation and overall effectiveness of ageing management programs as reactors continue to age.

Inspection is the most common strategy used to mitigate the effects of age-related degradation, but there are locations, materials, and systems, structures and components that are difficult to inspect. The containment structure is most commonly cited example. Responses also identify the challenges of inspecting CASS, cables in conduits with fire-proofing, buried piping, some RPV internal components, certain dissimilar welds, and spent fuel pool concrete structures. Particular plant types or specific plant configurations also pose unique inspection challenges within several countries.

International research activities related to long-term operation appear to be broad and diverse. Historically, most research in this area has focused on aged-related degradation in metals. Research in fatigue and embrittlement of RPVs are examples of topics that have remained active for 40 years or more. More recently, however, research in concrete pathologies and the inspection and evaluation of concrete degradation has been initiated in several countries. Research related to ageing of electrical and instrumentation and control (I&C) cables continues to be maturing focus area. Similarly, research to ensure the safety and security of digital I&C systems that are replacing obsolete analog systems is an evolving area that has become more important over the last decade or so.

While there are barriers to sharing propriety research results and results developed through group-sponsored projects, much of the research sponsored by the government of each country appear to be available for sharing. It is recommended that, as a next step, each country provide a list of publications developed over the last several years that is applicable to issues related to long-term operation that can be shared among the CSNI member countries.

Finally, there are many collaborative research opportunities that have been identified from the responses to the questionnaire. Some of these topics, including environmental fatigue effects and lifetime prediction, ageing of concrete structures, RPV embrittlement, and cable ageing appear to have relatively widespread support (i.e. of interest to 4 or more countries). Therefore, these topic areas are all candidates for moving to Phase II of the CAPS on LTO. It is recommended that more specific projects be developed in these areas and proposed using the CSNI Activity Proposal Sheet (CAPS). The specific projects and CAPS should be identified and developed by the members of the Working Group on Integrity and Ageing of Components and Structures.

For example, it may be of interest to develop a benchmark problem on environmental fatigue that could be evaluated using the procedures required in each country. It may also be useful to develop an international database related to fatigue testing results. Developing a database related to RPV embrittlement results may also be of interest. A state of the art report (SOAR) on ageing in concrete structure may be useful to summarise existing knowledge on concrete pathology, inspection techniques, and lifetime evaluation methods, as well as identify existing knowledge gaps in these areas. A SOAR on inspection, lifetime evaluation, and replacement of cables may also be on interest. It is recommended that activities related to cable ageing be pursued as part of the Cable Ageing Data and Knowledgebase Project (CADAK).

There are many other unique and interesting topics on ageing degradation related to long-term operations that individual countries have identified. CAPS associated with any of these topics can be developed if there is sufficient interest among countries to pursue CSNI-sponsored research. It is recommended that the country that identifies this topic take the lead on developing the CAPS. Using this approach, other activities of interest can move into Phase II of the CAPS on LTO. If there is insufficient broad interest or agreement within the CSNI member countries on pursuing collaborative research on any of these topics, individual countries can always share information and develop joint research activities independently of CSNI.

REFERENCE LIST

The following is a list of references with regulations and or technical information related to long-term operation as supplied by several countries.

Belgium

[1] Strategy Note "Long Term Operation of Belgian Nuclear Power Plants Doel 1&2 and Tihange 1", FANC (Federal Agency for Nuclear Control) report 008-194 revision 2, September 2009 (public – available in Dutch and French).

[2] Long Term Operation: Technische Rapport Doel 1 en Doel 2 – Versie 2.0 – 30 June 2012 (public – available in Dutch).

[3] Long Term Operation: Rapport Technique Tihange 1 – Version 2.0 – 30 June 2012 (public – available in French).

Canada

[4] REGDOC-2.3.3 "Integrated Safety Reviews", August 2014 (Consultation version) (http://www.nuclearsafety.gc.ca/eng/acts-and-regulations/regulatorydocuments/comment/index.cfm).

Czech Republic

[5] Safety guide JB-2.1 "Ageing management of NPP equipment" (2010), State Office for Nuclear Safety (in Czech)

[6] Safety guide JB-1.2 "Periodic Safety Review" (2012), State Office for Nuclear Safety (in Czech)

[7] Safety guide JB-1.9 "Maintenance, Surveillance and In-service Inspections" (2010), State Office for Nuclear Safety (in Czech)

Finland

[8] Guide YVL A.8, Ageing Management of a Nuclear Facility, Radiation and Nuclear Safety Authority, Helsinki, 20 May 2014, 20 p.

[9] Hämäläinen, Jari, Suolanen, Vesa. 2015. SAFIR2014 - The Finnish research programme on nuclear power plant safety 2011-2014. Final report. VTT Technology: 213, Espoo, VTT, 722 p. ISBN 978-951-38-8226-6 (Soft back ed.), 978-951-38-8227-3 http://www.vtt.fi/inf/pdf/technology/2015/T213.pdf

[10] Simola, Kaisa (ed.). 2013. SAFIR2014. The Finnish Research Programme on Nuclear Power Plant Safety 2011-2014. Interim Report. VTT Technology: 80, Espoo, VTT, 447 p. ISBN 978-951-38-7918-1 (Soft back ed.), 978-951-38-7919-8 http://www.vtt.fi/inf/pdf/technology/2013/T80.pdf

[11] SAFIR2010, The Finnish Research Programme on Nuclear Power Plant Safety 2007–2010, Final Report, E.K. Puska, V. Suolanen (eds.), VTT Technical Research Centre of Finland, URL: http://www.vtt.fi/publications/index.jsp, 578 p.

Japan

[12] The Law on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (Reactor Regulation Act) (Law No. 166, June 10, 1957, revised on 26 June 2013, latest revision on13 June 2014)

[13] Safety research in NRA, Nuclear Regulation Nuclear Regulation Authority (NRA), 25 September 2013

[14] Safety research in NRA for 2015 JFY, Nuclear Regulation Authority (NRA), 22 April 2015

[15] Operation Guide for Application for Approval of Extended Operation Period of Commercial Power Reactors, Nuclear Regulation Authority (NRA), 19 June 2013, revised on 6 December 2013 (in Japanese)

[16] Guide for Implementing Measures for Ageing Management in Commercial Power Reactor Facilities, Nuclear Regulation Authority (NRA), 19 June 2013, revised on 6 December 2013 (in Japanese)

[17] Operation Period Extension Review Criteria for Commercial Power Reactor, Nuclear Regulation Authority (NRA), November 2013 (in Japanese)

[18] Establishment of Operation Guide for Safety Improvement Evaluation for Commercial Power Reactors, Nuclear Regulation Authority (NRA), 27 November 2013 (in Japanese)

Switzerland

[19] ENSI Guideline “Periodic safety review ENSI-A03/d (in German), „Periodische Sicherheitsüberprüfung von Kernkraftwerken, Ausgabe Oktober 2014; the guideline is also addressing specific LTO requirements

United States

[20] 10 CFR Part 54, “Requirements for Renewal of Operating Licenses for Nuclear Power Plants,” U.S. Nuclear Regulatory Commission, Washington, DC.

[21] EPRI 1007933, Ageing Assessment Field Guide, Electric Power Research Institute, Palo Alto, CA, December 2003.

[22] EPRI 1009743, Ageing Identification and Assessment Checklist, Electric Power Research Institute, Palo Alto, CA, August 27, 2004.

[23] IAEA-TECDOC-1557, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: PWR Vessel Internals, 2007 Update, International Atomic Energy Agency, Vienna, June, 2007,

[24] NEI 03-08, Guideline for the Management of Materials Issues, Nuclear Energy Institute, May 2003.

[25] NRC Inspection Procedure IP-71003, Post-Approval Site Inspection for License Renewal, U.S. Nuclear Regulatory Commission, Washington, DC, February 25, 2013.

[26] NRC Technical Letter Report, Summary of Ageing Management Program Effectiveness Audits to Inform Subsequent License Renewal: R.E. Ginna Nuclear Power Plant and Nine Mile Point

Nuclear Station, Unit 1, ML13122A009, U.S. Nuclear Regulatory Commission, Washington, DC, May 2013.

[27] NUREG-1611, Ageing Management of Nuclear Power Plant Containments for License Renewal, U.S. Nuclear Regulatory Commission, Washington, DC, September 1997.

[28] NUREG-1800, “Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants,” Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC, December 2010

[29] NUREG-1801, “Generic Ageing Lessons Learned (GALL) Report,” Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, December 2010

[30] NUREG-1950, Disposition of Public Comments and Technical Bases for Changes in the License Renewal Guidance Documents NUREG-1801 and NUREG-1800, U.S. Nuclear Regulatory Commission, Washington, DC, April, 2011.

[31] NUREG-1412, "Foundation for the Adequacy of the Licensing Basis: A Supplement to the Statement of Considerations for the Rule on Nuclear Power Plant License Renewal (10 CFR Part 54)," U.S. Nuclear Regulatory Commission, Washington, DC, December 1992

[32] NUREG-1568 "License Renewal Demonstration Program: NRC Observations and Lessons Learned," U.S. Nuclear Regulatory Commission, Washington, DC, December 1996

[33] NUREG-1611, “Ageing Management of Nuclear Power Plant Containments for License Renewal,” U.S. Nuclear Regulatory Commission, Washington, DC, September 1997

[34] NUREG/CR-6679, “Assessment of Age-Related Degradation of Structures and Passive Components for U.S. Nuclear Power Plants,” U.S. Nuclear Regulatory Commission, Washington, DC, August 2000

[35] NUREG/CR-6923, Expert Panel Report on Proactive Materials Degradation Assessment, U.S. Nuclear Regulatory Commission, Washington, DC, February, 2007.

[36] NUREG/CR-7153, “Expanded Materials Degradation Assessment (EMDA): Executive Summary of EMDA Process and Results,” Volume 1, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, October 2014

[37] NUREG/CR-7153, “Expanded Materials Degradation Assessment (EMDA): Ageing of Core Internals and Piping Systems,” Volume 2, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, October 2014

[38] NUREG/CR-7153, “Expanded Materials Degradation Assessment (EMDA): Ageing of Reactor Pressure Vessels,” Volume 3, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, October 2014

[39] NUREG/CR-7153, “Expanded Materials Degradation Assessment (EMDA): Ageing of Concrete and Civil Structures,” Volume 4, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, October 2014

[40] NUREG/CR-7153, “Expanded Materials Degradation Assessment (EMDA): Ageing of Cables and Cable Systems,” Volume 5, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, October 2014

[41] Regulatory Guide 1.188, “Standard Format and Content for Applications to Renew Nuclear Power Plant Operating Licenses,” Rev. 1, U.S. Nuclear Regulatory Commission, Washington, DC, September 2005

APPENDIX: RESPONSES TO SURVEY ON LONG-TERM OPERATION SUMMARISED BY QUESTION

1. Is your country currently supporting allowing commercial reactors to operate longer than the original length of the licensing or approved design (i.e. > 40 years)?

Japan

- Yes
- The Amended Reactor Regulation Act, effective as of 8 July in 2013, prescribes an operating life of 40 years. However, it is possible to extend the operating life once, for a period of no more than 20 years, if approval is obtained from the NRA.
- In determining whether or not to extend the operation period of a facility, it is necessary to determine the current status of the plant in detail. Therefore, applicants for life extension must conduct a special inspection (or special safety check) to assess such factors as degradation.
- Licensees must carry out a technical evaluation of any known degradation, document their maintenance and management policy during the extension period, and provide these details as part of their extension application.
- The special safety check requires the licensee to conduct detailed evaluations of equipment, components, and structures at locations that have not been previously evaluated that may be susceptible to ageing phenomena . These evaluations include inspection of the base metal and weld for 100% of the rector pressure vessel core region using ultrasonic testing (UT) and confirmation of the strength of a concrete core sample obtained from concrete structures.
- Ageing management technical evaluation emphasises ageing phenomena including stress corrosion cracking, corrosion, embitterment, fatigue, decrease in concrete strength, degradation of cable insulation etc.
- Before the extension period, licensees must submit a maintenance and management plan covering all relevant and additional maintenance measures identified as a result of the technical evaluation of degradation.
- Licensees operating reactors 40 years or older are required to conduct ageing management technical evaluations for components and structures every ten years and to incorporate their maintenance and management plan in their operational safety programs to ensure compliance.
- The maintenance and management plan details the required inspections and maintenance of individual equipment during each operating cycle. The maintenance plan takes into account past inspection performances and the status of any existing degradation. These details of the maintenance and management plan are reviewed by the NRA.
- NRA operational safety inspectors also perform Operational Safety Inspections to verify that the maintenance plan is being appropriately implemented.

Netherlands

- Yes, this is currently under investigation for the nuclear power plant located in Borssele, the Netherlands: the original license for 40 years of operation expired at end of 2013, and a license was granted at the end of 2013 to extend the operation of the plant to a total length of 60 years (2033) according to the covenant between the Kingdom of the Netherlands and the owner of the NPP-Borssele.

Slovakia

- Yes, LTO project is under way with the aim to operate the NPP for 60 years.

Canada

- Yes. The CNSC has issued REGDOC-2.3.3 “Integrated Safety Reviews”, which requires a licensee to conduct an Integrated Safety Review (ISR) to assess the safety of their operations, facilities and equipment, prior to either a reactor refurbishment or the granting of a life extension to an existing plant. REGDOC-2.3.3 sets out the CNSC requirements regarding activities a licensee must undertake in support of long-term operation

Finland

- Yes. The lifetime of Loviisa NPP (VVER 440) was extended to 50 years. An extension up to 60 years is expected for Olkiluoto 1&2. PSRs are done during these extensions as they are for 20 extra years.
- The relicensing procedure covers e.g. conformance to current safety requirements, fatigue and PTS analysis renewals, evaluation of foreseeable ageing mechanisms and efficiency of the AMP programme.

Belgium

- In principle, there is no limit in time in the license of Belgian NPP.
- Periodic Safety Reviews every 10 years are conducted for each NPP.
- However in 2003, the government enacted a law that limits the life of NPPs to 40 years. This law however foresees that in some situations (in particular in case of power shortage risks), this limit could be postponed.
- For Doel 1&2 and Tihange 1 NPP, Long Term Operation files were prepared in view of a possible modification of the nuclear phase-out law. These files were finalised in June 2012.
- In December 2013, the Belgian government allowed Tihange 1 NPP to operate up to 50 years, and decided to shutdown Doel 1&2 NPP after 40 years of operation.
- In 2014, the Belgian government decided to consider possible long term operation of Doel 1&2 NPP also. A decision is expected in the course of 2015.

Switzerland

- Yes, NPPs are allowed to operate as long as they are safe and fulfill required regulations.
- So far no immediate objection against an operation period up to 50 years for NPP Beznau,
- On 8 November 2013 the licensee of the NPP Mühleberg officially notified to ENSI that it has decided to permanently cease operation in 2019. ENSI requested to provide evidence of the planning work undertaken by the licensee toward the cessation of operation of the NPP Mühleberg in 2019 and its decommissioning.

Sweden

- Yes, there is no time limitation for Nuclear Power Reactors for operation.
- A PSR is conducted every 10 years.

Slovenia

- Possible extension of operation for NPP Krško to 60 years.
- Possible extension of operation depends on the owners of the plant and on successfully passed periodic safety reviews in the year 2013 and 2023.

Germany

- Following the Fukushima Accidents, the German government decided for an accelerated step-by-step phase-out from nuclear power until 2022. Therefore, LTO is not an issue anymore in Germany.

Czech Republic

- There is no limit for the operational life time from a legislative point of view. Czech NPPs usually get permission to operate for 10 year intervals and they must apply each 10 years for permission to operate over the next 10 years. Permission is granted upon fulfillment of requirements defined by Government.
- The original projected lifetime of the Czech NPPs is 30 years with exception of reactor pressure vessels (40 years).
- In 2004, the Czech NPPs operator initiated activities necessary for LTO up to 60 years of operation.
- Czech regulatory body defined criteria for granting operational extensions in accordance with IAEA recommendations.

United States

- Yes, the NRC has approved many applications for license renewal, or operating a NPP beyond the initial 40-year license. As of 2013, several plants have entered into their license renewal period and have operated for more than 40 years.

France

- No regulatory time limit for operating a reactor when the once the license is obtained. Therefore, a nuclear power plant (NPP) could operate theoretically as long as the safety requirements are met.
- At the design stage, systems, structures and components (SSCs) were designed under the cumulative loading and environmental conditions for an assumed 40 years of operation.
- For the operation of NPP beyond 30 years, the Safety Authority requires the operator to plan and implement an ageing management program in addition to the existing requirements for the operation of the NPP.
- A periodic safety review (PSR) of each reactor is required every 10 years in order to maintain high safety level of not only the ageing management program, but also for every activity in the operational safety program.
- EDF has recently expressed the wish to operate its reactors significantly beyond their design life of operation. Therefore, long term operation (LTO) is currently under investigation for the French nuclear power plants beyond 40 years.
  - In the context of the fourth PSR of 900 MWe NPPs, the French safety authority will have to make its decision on the LTO by the end of this decade.
  - The first of the fourth ten-year outages are planned in 2019 and the decision for extending operation of each existing reactor will be made on a case by case basis.

2. What technical issues or concerns does your agency have related to material or component ageing during long term operation (i.e. not regulatory concerns but scientific concerns resulting from material degradation in passive system components)? For each issue or concern, please provide the following information:

a. your country's rationale or reasons for the issue or concern,
b. a contact person for the issue or concern, and

c. a qualitative ranking (i.e. high, medium, or low) for each issue or concern.

Some examples of relevant technical issues/concerns include reactor pressure vessel embrittlement or ageing of large concrete structures and basemats.

Japan

- The following ageing mechanisms are considered to be important to LTO;
  - Low cycle fatigue – Medium
  - Neutron irradiation embrittlement of reactor pressure vessel (RPV) and core internals - High
  - Irradiation assisted stress corrosion cracking (IASCC) – Medium
  - Thermal ageing for cast stainless steel – Medium
  - Decrease in insulation for electric and I&C equipment – High
  - Concrete strength decrease and concrete shielding performance decrease – High
  - Stress corrosion cracking (except IASCC) – High
  - Pipe wall thinning – Medium
  - Others
- As a result of the operational period extension approval system (OPEAS) and revision of ageing management system (AMS) effective as of July 2013, the Nuclear Regulation Authority, Japan (NRA) issued a document entitled "Safety research in NRA", in September, 2013.. A revised document entitled "Safety research in NRA for 2015 JFY" was made public by NRA on 22 April 2015.
- In this document, the research being performed to develop technical knowledge on OPEAS and AMS is summarised.
- The following knowledge are necessary to address the issues;
  - Prediction of irradiation embrittlement for the reactor pressure vessel
  - Integrity of aged electric cable and I&C facilities under severe accident conditions
  - Strength degradation and shielding performance degradation for concrete structures
- Contact for all issues – Masakuni Koyama, masakuni_koyama@nsr.go.jp

Netherlands

- Material fatigue
  a. Temperature stratification in pipelines, possibly leading to material fatigue. Fatigue is normally tested under different (environmental) conditions as the ones that apply during normal operation (air under testing conditions vs water under operating conditions) Some plant locations exhibit high fatigue load factors at the end of the 60 year period. The licensee must provide more accurate fatigue calculations based on a local fatigue monitoring system (FAMOS).
  c. Medium

Slovakia

- "Evaluation of equipment (structures and component)" is currently under development within the LTO project. So far, the issue on the buried emergency service water piping has been identified.

Canada

- CANDU Pressure Tube - High
- CANDU Outlet Feeders in the Primary Coolant Circuit - High
- SG Tubes and External Surfaces - High
- Containment/Civil Structures - High
- Secondary Coolant Circuit - High
- Cables - High
- Electrical components and I&C - High
- CANDU Calandria and its internals - Medium
- Valves, pumps and other components - Medium
- Bolting - Low

Finland

- Radiation embrittlement, particularly in combination with hydrogen flaking and high nickel content
- Thermal ageing and SCC in RPV safe ends and other dissimilar welds
- Fatigue in thermal stratification and mixing areas
- Pitting and crevice corrosion near deposits, metallic contact points and stagnant conditions
- Boric acid corrosion in bolted closures of the primary circuit pressure boundary
- SCC and IASCC in RPV internals
- For concrete structures,
  - Condition of prestressing tendons
  - Condition of steel liners
  - Condition of cooling water channels

Belgium

- Justifying the environmental effects on fatigue is one of the major challenges for metal components
- Managing degradation mechanisms affecting concrete structures
- Electrical and I&C equipment ageing issues

Switzerland

- RPV embrittlement - High
  - Contact: D. Kalkhof (ENSI)
- Ageing management of class 1 structures made of concrete with limited accessibility for inspection - Medium
  - Contact: U. Bumann (ENSI)
- Corrosion of primary containment (freestanding pressure vessel made of steel) - Medium
  - Contact: K. Germerdonk (ENSI)

Sweden

- Thermal ageing embrittlement of cast austenitic stainless steels, stainless steel weld materials, and martensitic stainless steels - Medium
  - Contact: Peter Ekström, peter.ekstrom@ssm.se
- Radiation embrittlement of the reactor pressure vessel (RPV) - High
  - Contact: Peter Ekström, peter.ekstrom@ssm.se
- Stress corrosion cracking (SCC) including IASCC, IGSCC, TGSCC and PWSCC - Low
  - Contact: Jan Linder, jan.linder@ssm.se
- Environmental Fatigue - High
  - Contact: Björn Brickstad, bjorn.brickstad@ssm.se
- Electrical and I&C equipment issues
  - Ageing management program effectiveness
  - Replacement of ageing components.
  - Ageing of electrical connections in safety critical equipment.
  - Contact: Mathias Franzon, mathias.franzon@ssm.se
- Concrete structures – corrosion damage of embedded components due to structural deviations from the design drawings and/or codes and standards
  - Contact: Kostas Xanthopoulos, Kostas.Xanthopoulos@ssm.se
- Degradation of grouted tendons and loss of tendon force
  - Contact: Kostas Xanthopoulos, Kostas.Xanthopoulos@ssm.se

Joint Research Centre

- Stress corrosion cracking (SCC) of Alloy 690 and 800s;

- Development of monitoring systems for SCC and small fault detection (i.e. acoustic emission);
- Side effects of mitigation methods (i.e. annealing) to restore fracture toughness of reactor pressure vessels (RPVs) from irradiation embrittlement;
- Embrittlement behaviour of RPVs irradiated with higher neutron fluxes and different neutron spectra compared to what is common now;
- Ageing of RPV cladding and how can its toughness be controlled and assessed during service;
- Concrete – steel interaction, buried piping;
- Compositions of concrete used for containment structures of NPPs around the world and their ageing behaviour;
- LBB in conjunction with active degradation mechanisms like PWSCC;
- Interaction between known degradation mechanisms (fatigue & SCC);
- RI-ISI approaches;
- Ageing PSA;
- Ageing of I&C;
- Interfaces between mechanical and electronic components and their reliability with increasing age.

Slovenia

- There are no major open technical issues or concerns related to ageing in NPP Krško

Czech Republic CEZ, the owner and operator of Czech NPPs is collaborating with technical support organisations that are responsible for ageing management of the most important structures and components. The initial point of contact for all these issues is J. Zdarek, Jiri.Zdarek@ujv.cz.

- Ageing of safety important cables (especially ageing of cables covered by fire protection coating) − High
- Ageing of concrete structures that serve as the boundary for radioactive material (especially concrete structures in spent fuel pools) − High
- Ageing of reactor pressure vessels and reactor internals − High
- Environmentally assisted fatigue of primary circuit metals − Medium
- Motor and air operated valve ageing and diagnostics − Medium
- Flow accelerated corrosion of high energy pipelines − High

United States The NRC, jointly with the US Department of Energy, has been conducting an extended materials degradation assessment (EMDA) using expert opinion to identify specific areas of concern related to materials degradation during long-term operation. Four different panels have been formed to address materials ageing in the RPV, reactor internals and piping, cables and instrumentation & control (I&C), and concrete. Results from this activity will be finalised by the end of 2013. However, the expectation is that the following general topics will be of interest. The initial point of contact for all these issues is R. Tregoning, Robert.tregoning@nrc.gov

- Ageing of concrete structures with an emphasis on containment − High
- Ageing of reactor vessel internals − High
- Cable ageing − High
- Obsolesce and modification of I&C systems − High
- Thermal and neutron embrittlement of cast austenitic stainless steels (CASS) − Medium
- Metal fatigue of components considering environmental effects − Medium
- RPV embrittlement − Medium

France Evaluation of systems, structures and components (SSCs) is currently under development within the LTO project. A better knowledge of the following ageing mechanisms considered of high importance is needed:

- Metallic components
  - Irradiation embrittlement of reactor pressure vessel (RPV),
  - Irradiation embrittlement of reactor vessel internals,
  - stress corrosion cracking of nickel alloys,
  - Thermal ageing
  - Fatigue considering the environmental effects,
  - Non destructive examination (NDE) techniques
- Concrete structures
  - Assessment of long-term behaviour of concrete buildings including creep and shrinkage
  - The concrete pathologies such as :
    - Alkali-aggregate reaction
    - Internal sulfate attack
- Polymeric materials
  - Electrical cables, seals, elastomer, bearing pads and epoxy coating systems
- Obsolescence and modification of I&C systems
- Buried piping

3. What regulatory issues or concerns does your agency have related to material or component ageing during long term operation (i.e. not scientific concerns but concerns related to the regulatory requirements, framework, or structure applicable to long term operation)? For each issue or concern, please provide the following information:

a. your country's rationale or reasons for the issue or concern,
b. a contact person for the issue or concern, and

c. a qualitative ranking (i.e. high, medium, or low) for each issue or concern.

Some examples of relevant regulatory issues or concerns could include a lack of regulatory infrastructure to address issues related to long-term operation or the effectiveness and implementation of ageing management programs.

Japan

- Regarding documents for operation period extension and ageing management, we have documents for review criteria [17], operation guide [15] and implementation guide [16]. Further, there is a document for safety improvement evaluation that addresses a survey and analysis for maintenance activities on ageing phenomena including neutron irradiation embrittlement, IASCC and low cycle fatigue, and an evaluation for their effectiveness.
- Structures and components subjected to technical evaluation of degradation status [16]are as follows;
  - Low cycle fatigue – Medium
  - Neutron irradiation embrittlement − High
  - Irradiation assisted stress corrosion cracking (IASCC) − Medium
  - Thermal ageing for cast stainless steel − Medium
  - Insulation decrease for electric and I&C facility − High
  - Concrete structures
    - Concrete strength decrease due to irradiation effects - High
    - Concrete strength decrease due to temperature, carbonation, salt penetration, alkali silica reaction, mechanical vibration and freezing & thawing - Medium
  - Concrete shielding performance decrease due to temperature - Medium
  - Steel frame strength decrease due to both corrosion and wind fatigue - Medium

  - Other mechanisms - Medium
  - Stress corrosion cracking, pipe wall thinning etc.
- Contact for all issues – Masakuni Koyama, masakuni_koyama@nsr.go.jp

Netherlands

- Differences of opinion between the plant operators and the regulatory body.
  a. Discussion between the operator and the regulatory body with respect to the interpretation of IAEA safety report series no. 57: Safe Long term operation of Nuclear Power Plants. Eventually, a SALTO mission advised to also incorporate active components into the scope of the LTO-investigations. This recommendation was adopted such that active components are now incorporated in the LTO investigations and program.
  c. Low, as the plant operator agrees with the SALTO advice to include active components in the investigations.
- Assessment of physical status (see page 17 of IAEA Safety Report Series no. 57)
  a. While the plant operator performed the prescribed assessment, he does not provide a conclusion based on the assessment.
  c. Medium, as the discussion between operator and regulatory body had been resolved

Slovakia

- On 1 March 2012, Regulation No. 33/2012 on regular, comprehensive, and systematic review of plant nuclear safety as issued by the national regulatory (licensing) authority became a law. This regulation defines intervals and scope of performance of the regular, comprehensive, and systematic review of plant nuclear safety (i.e. "periodic safety review” or PSR). In accordance with Section 18 of this regulation, "Plant operation beyond the original design life”, the objective of the PSR is to make sure that a comprehensive long term operation program has successfully been implemented at the plant.

Canada

- Impact of aged components on Safety Analysis - High
- Effective ageing management throughout the lifetime of the NPP - High
- LBB applications on components with active degradation mechanism - High
- An integrated ageing management approach - High
- Choice between relying on ageing management and/or on necessary design upgrades/replacement – **Medium**

Finland

- Ageing in stand-by systems whose safety functions would be needed for extended periods of time.
- Corrosion and other ageing phenomena whose presence and progress with time may not be reliably predicted
- Adopting, within each technical discipline, a proactive approach where monitoring and mitigation with regard to anticipated ageing mechanisms is in place before degradation occurs
- Maintenance of the knowledge, competence and motivation needed for successful ageing management in the long term

Belgium

- In general, there are no major regulatory issues related to material or component ageing during LTO

Switzerland

- Ageing management process: Process to ensure the actuality of ageing management process implemented at each NPP - Medium
    - Contact person: K. Germerdonk (ENSI - mechanical components), U. Bumann (ENSI - civil structures) and F. Altkind (ENSI - electrical components)
- LTO implementation: Ensure that adequate back fittings are adopted and implemented.

Sweden

- Uncertainty about the effectiveness of the applied inspection and testing methods for verifying the condition of the reactor containments
    - Contact: Giselle Garcia Roldan, Giselle.GarciaRoldan@ssm.se
- Considering more frequently and detailed reporting requirements (i.e. every 5 years instead of 10 years) about status for cables and other safety important equipment for NPP´s running over 35-40 years of life time
    - Contact: Mathias Franzon, mathias.franzon@ssm.se

Slovenia

- In general, no major regulatory issues related to material or component ageing during LTO
- Some issues associated with reviewing the NPP Krško submission in that certain aspects of the Ageing management program for systems and components were incomplete, missing, dated, or did not comply with program in GALL.

Czech Republic

- No specific regulatory issues related to material or component ageing during LTO
- Czech regulatory body requires effective ageing management program for all safety related systems, structures and components. – e.g. implementation of integrated AMP (PLIM)
- Specific Czech regulatory body requirements for LTO are based on IAEA’s recommendations for safety aspects of long-term operation
- Standard operational permission for each 10 years is based on Periodic Safety Review and Final Safety Analysis Report

United States Contact for all issues - Robert Tregoning, robert.tregoning@nrc.gov

- Effectiveness of ageing management programs (AMPs) in identifying expected degradation due to issues with accessibility and inspection technique resolution
    - Rationale: Increased degradation, such as cracking and reductions in fracture toughness, with increased operating time will challenge inspection techniques to identify ever smaller critical flaws
    - Ranking: Medium
- Ability of existing AMPs to manage degradation that is not anticipated but may occur with longer plant operation (e.g., looking for corrosion when cracking is actually occurring)
    - Rationale: With the potential for new unanticipated degradation mechanisms to occur, an evaluation of the capability of existing inspections to detect these new mechanisms, or the need to enhance existing inspections, is needed
    - Ranking: Medium
- Adequacy of knowledge on long-term exposure (e.g., > 60 years) effects to RPV neutron embrittlement trends, concrete exposed to elevated temperatures and radiation, and other degradation mechanisms

  - Rationale: Current methods to extrapolate degradation trends, such as reactor pressure vessel neutron embrittlement, and knowledge of materials behavior response to aggressive environmental stressors for greater plant operating times may not be adequate
  - Ranking: Medium
- Environmental qualification of electrical cables for > 60 years operation
  - Rationale: Expanded plant operating times will challenge the ability to demonstrate environmental qualification of electrical cables using current methods
  - Ranking: Medium
- Effectively incorporating operating experience in an on-going basis by enhancing existing AMPs or developing new AMPs
  - Rationale: Need to assess whether licensees are able to update their ageing management activities in a sufficiently nimble manner in response to operating experience
  - Ranking: Low
- Ability to effectively track and regulate plants when the licensing bases vary plant-to-plant
  - Rationale: Implementing effective regulatory improvements to ageing management is challenged because licensing bases variances plant-to-plant can be broad
  - Ranking: Low
- Development of nondestructive examination techniques for concrete (e.g., inaccessible areas)
  - Rationale: Understanding ageing of concrete with longer operating periods will necessitate nondestructive techniques to assess the condition of structural concrete
  - Ranking: Medium
- Long-term effect of creep in concrete on strength of prestressed containments
  - Rationale: Effects of concrete creep can degrade the strength of prestressed containments
  - Ranking: Currently Low, but there is much unknown about this mechanism
- Ageing management needs for safety-related structures, including adequacy of visual inspections for timely identification of degradation and the need for updated baseline inspections
  - Rationale: Visual examinations of safety-related structures may not be sufficient to allow timely identification of degradation
  - Ranking: Medium
- The integrity of spent fuel pools
  - Rationale: Concerned about possible degradation within the linear, especially at weld locations and degradation of the supporting concrete.
  - Ranking: Low

France

- There is no specific regulatory concern related to ageing facilities
- However, for pressurised equipment, a change (e.g., materials, thickness ...) which was not anticipated at the design stage would be treated as a modification of the equipment. This modification would have to be addressed through a new conformity assessment of this equipment.
- It is still not clear how long EDF wants to operate each reactor beyond 40 years
- Completion of new recent regulations could affect the implementation of a LTO process.
- Besides the regulatory framework, IRSN’s opinion is that two topics deserve special attention:
  - The ageing management process;
  - The enhancement of the safety level with the aim to reach, when achievable, a level similar to that expected for Gen III reactors like EPR.

4. Please identify any components or systems that are expected to be difficult to inspect and may potentially experience degradation that could challenge the required functionality (i.e. the ability of the components to perform their intended function) of such components or systems under long-term operation. Some examples of relevant components that may be challenging to inspect include cast austenitic stainless steel components (CASS), dissimilar metal welds, certain reactor internals components, electrical cables, thick-section concrete, or buried tanks and piping.

Japan

- Efforts of the research on defect inspection of SCC have been conducted in the following areas;
  1. Verification of inspection technology for low carbon stainless steel components (Objective components and locations include core shroud for BWR)
  2. Non-destructive inspection technologies for the narrow penetrations on reactor vessel (Objective components and locations include bottom mounted instrument for PWR)
  3. Collection of information on improvement of non-destructive inspection of nuclear power plant

Netherlands:

- The welded frame that supports the reactor pressure vessel is unreachable for inspection, rendering it impossible to visually inspect whether there is any degradation of the welding, or corrosion of components due to the influence of boric acid.
- In order to prevent them from degradation, cables in conduits have been suited with fire-proofing. It is therefore difficult to inspect the integrity of these cables.
- Equipment qualification due to the harsh environment will become more difficult due to the closure of German NPPs.

Slovakia

- A problem with NDT and inspections on buried ESW piping has been identified. A feasibility study on replacement of the piping is currently under development: The aim is to develop effective methods of condition monitoring of the concerned piping

Canada

- CANDU Calandria assembly, including Calandria vessel, Calandria Tube, Calandria tube sheet welds, Calandria Tube to LISS nozzle clearance, Guide Tubes, Moderator inlets, and Calandria end shield support

Finland

- Cast austenitic stainless steels,
- Transition welds between components with complex geometry,
- Crevices at thermal shields etc.
- For concrete
  - Pre-stressing tendons (grouted)
  - Steel liners (imbedded)

Belgium

- The regenerative heat exchanger which generates an environment with high dose rate and which may potentially present fatigue issues
- Buried tanks and piping
- Cabling

Switzerland

- Primary steel containment in areas non accessible due to concrete coverage or sand embedding
- Class 1 concrete structures with limited accessibility for inspection
- Volumetric inspection of specific dissimilar welds (e.g. small diameter piping, BMI (bottom mount instrumentation nozzle, etc)
- Vessel internals with limited accessibility and coverage with available NDE-techniques (e.g. core shroud supports)

Sweden

- Inspection of IASCC, PWSCC and IDSCC defects in nickel-based stainless steel welds
- Inspection of cast stainless steel pipes and connection welds
- Inspection of pre-stressed grouted cables.
- Inspection of the embedded steel liner plate
- Inspection of the cylindrical concrete containment wall, due to access restriction and concrete thickness

Slovenia

- Unrealised coverage for ultrasonic inspection of safety Injection nozzles on reactor vessel.
- Gas decay tanks

Czech Republic

- Inspection of swelling in RPV internals in VVER 1000 reactors
- Inspection of condition of bolts in RPV internals in VVER 1000 and VVER 440 reactors
- Condition of concrete behind steel liner

United States

- Inspection of buried tanks and piping - Medium
- Containment liner inspection - Medium
- Inspection of dissimilar metal welds, especially those connecting CASS components - Medium
- Reactor vessel internal components that have limited accessibility – High
- Inspections of the RPV near inner surface from outer surface inspections - Medium
- Inspection of CASS components and other materials that may be sensitive to significant thermal and/or neutron embrittlement – High
- Components susceptible to selective leaching that do not exhibit readily-identifiable degradation (e.g., copper-based alloys) – Low
- Condition (e.g., corrosion and stress corrosion cracking) of prestressed tendons – Medium
- Concrete in spent fuel pools that can be compromised by water penetration and irradiation – High
- Inaccessible concrete areas – Medium
- Inaccessible power cables installed in duct banks, trenches, or direct buried – High

France

- Inspection of buried piping and cables - high
- Reactor vessel internal components that have limited accessibility – high
- Inspection of CASS components and other materials that may be sensitive to significant thermal and/or neutron embrittlement – high
- Inspection of concrete containment using ultrasonic techniques - high

5. Please identify areas of related research that your organisation is currently sponsoring or has sponsored in the past?

Japan

- JNES has conducted research on material degradation and ageing evaluation to develop and verify structural integrity evaluation methods addressing related major ageing mechanism, develop and verify prediction models for material degradation, verify non-destructive testing technology, verify preventive maintenance and repair technology, etc.
- Major research activities conducted by JNES are listed below;
    - Irradiation embrittlement for reactor pressure vessel and core internals
    - Prediction and evaluation of thermal embrittlement for cast stainless steel
    - Fatigue evaluation including effects of environment on fatigue life
    - SCC growth rate and behavior for low carbon stainless steels
    - SCC growth rate and behavior for nickel-based alloys (including PWSCC)
    - Verification of evaluation method of fracture mechanism for Ni-based alloy components
    - Irradiation assisted stress corrosion cracking (IASCC)
    - Non-destructive inspection technology for stainless steel components
    - Non-destructive inspection technology for cast stainless steel components
    - Non-destructive inspection technology for Ni-based alloy welds
    - Non-destructive inspection technology for vessel penetration narrow gap areas
    - Verification of applicability of irradiated material surface improvement technology to l
    - Verification of irradiated material repair welding technology
    - Research on concrete degradation
    - Research on cable ageing
    - Integrity evaluation for electric and I&C facilities
- Currently, safety research activities have also been conducted by SNRA.
- Major topics of safety research are as follows;
    - Structural integrity evaluation methods for reactor pressure vessel and primary pressure boundary components, taking into account material degradation effects during long–term operation
    - Research on concrete characteristics related to long-term integrity of concrete structures
        - Evaluation of decrease in concrete strength due to neutron irradiation
        - Alkali silica reaction (ASR) for concrete structures
    - Research on long-term integrity for electric and I&C equipment
        - Evaluation method of long-term integrity for electric and I&C facility in installations coping with severe accidents etc.
        - Applicability of cable condition monitoring technology to commercial plants

Netherlands

- Not Applicable

Slovakia

- Ageing of RPV materials (base and weld metal, heat affected zone, internals). The aim is to identify and evaluate the effect of power uprates, the use of new generation of fuel, and LTO on RPV materials.
- Thermal ageing of NPP materials.
- Monitoring of flow accelerated corrosion using the acoustic emission method.

Canada

- Consolidated international approach to ageing management programs and LTO
- A roadmap to ageing mechanisms and effects based on research and operational experience
- A common internationally agreed basis on what constitutes an acceptable ageing management programme for plant components, structures, material, and environments,
- Ageing management and long term operation of fuel channel pressure tubes, feeders and steam generators,
- Inspection and/or testing of bonded pre-stressing systems in the concrete containment
- Cable ageing.

Czech Republic Ageing related research sponsored or cosponsored by Czech government or EU and realised in Nuclear Research Institute in last few years:

- Long term life management of Czech NPPs – Plant life management (PLIM) methodologies, Catalogue of degradation mechanisms of Czech NPPs, development of SW Database for PLIM
- Reactor internals ageing
- Primary circuit environment effect on degradation of selected metal materials of VVER nuclear power plants

Finland The Finnish national SAFIR research program have been ongoing since 2003 and was preceded by FINNUS. There are specific activities related to evaluating age-related degradation in SSCs such as a project on the environmental influence on cracking susceptibility.

- For concrete
  - Material and component level failure analyses related to pre-stressing tendons, steel liners and fastening bolts
  - Condition assessment of cooling water channels
  - Structural level failure analyses
  - Service life management system

Belgium

- Development of advanced methods for RPV embrittlement (Belgian Nuclear Research Centre SCK·CEN, sponsored by Electrabel)
- Irradiation Assisted Stress Corrosion Cracking (IASCC). (SCK·CEN, sponsored by Electrabel)
- Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 182 safe-end welds from the Spanish decommissioned Lemoniz plant. (SCK·CEN sponsored by Electrabel)
- Irradiation swelling of stainless steel PWR reactor internals (GONDOLE project). (EDF-CEA-Framatome + EPRI + GDF-SUEZ)
- Test program on internals materials from the decommissioned Spanish plant of Zorita (EPRI program with participation of GDF-SUEZ)
- Effect of reactor coolant environment on fatigue life of reactor materials (Framework Agreement between GDF-SUEZ & SCK·CEN)

Switzerland

- Environmental assisted cracking
  - Environmental effects on fatigue initiation & short crack growth in austenitic stainless steel under PWR & BWR/HWC-conditions
  - Stress corrosion cracking of dissimilar welds: SCC in the Alloy 182-RPV transition region and NDE-reference bodies with SCC cracks
  - Stress corrosion initiation in austenitic SS & low allow steels
- RVP integrity and safety
  - NDE characterisation of RPV irradiation embrittlement

    - Probabilistic integrity & lifetime assessment related to material ageing
    - Assessment of RPV embrittlement using the master curve concept
- NDE-techniques to detect corrosion damage in steel containment
- Noble Metal Deposition Behavior
    - Validation of noble metal deposition behavior in BWRs. Focus is on understanding deposition behavior under LTO situation.
    - Development of non-destructive technique to characterise local surface concentrations on reactor components in Boiling Water Reactors

Sweden

- Stress corrosion cracking (initiation, propagation & development of model, crack initiation in stainless steels & Ni-base weld material),
- Thermal ageing embrittlement,
- Radiation embrittlement
- Ageing of non-metallic materials
- Development of damage databases
- Current and future moisture conditions in the concrete containment walls
- Waterline corrosion on the carbon steel liner cast in concrete at the condensation pool
- Current and future condition and behavior of reinforced concrete structures
- Loss of prestress in reactor containment
- Issues associated with ageing of electrical and I&C equipment
- Issues associated with replacement of electric and I&C equipment with new or different technology.
- Issues associated with ageing of electrical connections

Joint Research Centre

- SCC of stainless steels and ODS steels in LWR water conditions and in super critical water conditions.
- Irradiation of RPV materials with regard to late-blooming phases;
- Irradiation of RPV materials of VVER type reactors;
- Structural integrity assessment of DMWs (modelling of crack propagation and residual stress estimation, residual stress measurements (neutron diffraction));
- Development of RI-ISI approaches (based on POD curves);
- Development of ageing PSA;
- Ultrasonic testing of anisotropic steels;
- Creep and thermal fatigue of metals, conventional steels used for LWRs and ODS steels;
- Hydrogen embrittlement in fuel cladding (and NPPs components);
- Oxide film development on fuel cladding and stainless steels (in SCW);
- Development of thermocouples in high temperature environments;
- Multi-physics modelling (crystal plasticity, modelling of IGSCC along grain boundaries);
- Modelling of creep-fatigue;
- Modelling of defects and cracking processes in metallic parts;
- Development of standardised integrity tests (small-punch test, Mandrel test);
- Promotion of European standards for I&C at NPPs

Slovenia

- Managing of ageing processes in the Krško NPP
    - Overview of regulatory requirements and practices from European countries and USA
    - Theoretical basis of different ageing processes

    - Review of already completed phases of AMP at the Krško NPP
    - Development of procedure for supervision of ageing processes at the Krško NPP
    - Development of software for monitoring the condition of important SSC at Krško NPP
- Evaluation of fatigue due to stratified flow in the pressuriser surge line

Germany

- Investigations on crack growth in nuclear grade materials under cyclic loading
- Consideration of environmental effects on crack formation
- Further development of structural mechanics analysis methods for the integrity assessment of components
- Verification of fracture mechanics analysis methods using irradiated material from German NPPs
- Determination of the changes of material properties due to neutron irradiation
- Qualification of NDT methods pertaining to the probability of detection and the quantification of flaws for determination of the remaining life time of components
- Characterisation of ageing mechanisms relevant for reinforced concrete
- Investigation of the ageing behavior of dowels and anchors

United States The NRC is sponsoring and participating in many research activities that address material degradation. Most of these activities are considering effects due to operation longer than 40 or 60 years in at least part of their scope. Some examples include

- Co-sponsoring the extended materials degradation assessment to identify material susceptibility during LTO for the RPV, internals and piping, concrete, and cables.
- Evaluating RPV embrittlement mechanisms during LTO, especially matrix ageing phenomena that do not saturate with fluence and low flux effects
- Participating in the Zorita Internals Research Project (ZIRP) to evaluate the properties of the Zorita reactor vessel internals
- Conducting research related to concrete ageing, especially due to alkali-silicate reactions
- Evaluating thermal and neutron embrittlement of CASS
- Updating effects of the reactor environmental on fatigue lives
- Conducting research related to void swelling effects at high fluence levels
- Ageing of electrical cables

France

- For LTO, IRSN believes that a strategic approach should be adopted to promote relevant long-term research and development in order to:
    - Improve the knowledge of ageing mechanisms
    - Improve predictive models
    - Qualify enhanced methods of justification by a better assessment of uncertainties and safety margins
    - Improve techniques for the control of degradation
    - Develop repair and replacement methods for equipment.
- This research and development plan should
    - Perform confirmatory research on the most important safety relevant issues in order to maintain or obtain capacities so that the safety authority can make an independent judgement.
    - Promote research work on issues where the industry's research is not judged ot be sufficient
- IRSN is conducting a large effort to prepare for updating and extending research program on ageing and LTO in the following areas
    - Metal components
        - Irradiation embrittlement of reactor vessel internal materials
        - Stress corrosion cracking of nickel alloys

    - Fatigue considering the environmental effects
    - Non destructive examination (NDE) techniques
  - Concrete structures
    - Assessment of long-term behaviour of concrete buildings including creep and shrinkage
    - Concrete pathologies such as
      - Alkali-aggregate reaction
      - Internal sulfate attack
  - Polymeric materials
    - Electrical cables, seals, elastomer bearing pads and epoxy coating systems
    -

6. Are you able to share research results for related research projects that are either ongoing or completed? If not, please discuss limitations, challenges or constraints that must be resolved in order to share research results.

Japan

- Yes.
- JNES has made public the results of safety research related to material degradation and ageing mechanism evaluation though a various kinds of reports and technical papers. The agency will continue to make research results public for academic benefit.
- Research results useful in resolving issues related to nuclear safety regulation are made public as NRA technical report from to ensure transparency and the effective utilisation of the results.
- Technical documents in which results have been obtained from proprietary data require approval from the organisation that owns the proprietary data before making public such technical documents.
- Results of safety research on material degradation and degradation evaluation conducted by JNES are available from NRA website at the following links;
  - JNES-RE-Reports (for safety research outcomes)
    - https://www.nsr.go.jp/archive/jnes/gijyutsu/re_report_index.html
  - Outcome Reports
    - https://www.nsr.go.jp/archive/jnes/gijyutsu/seika/index.html
  - Research Reports
    - https://www.nsr.go.jp/archive/jnes/gijyutsu/itakujigyo/index.html

Netherlands:

- Not applicable, as no (sponsored) research has been or will be performed.

Slovakia

- Experiences from projects are shared in the frame of programmes organised by the IAEA:
  - Coordinated Research Programme "Review and Benchmarking of Calculation Model on Piping Wall Thinning due to Erosion Corrosion in NPPs“
  - International Generic Ageing Lessons Learned Extrabudgetary Programme.

Canada

- Yes, via international corporation through IAEA, or NEA, or bilateral.

Finland

- Publications with the confidentiality definition “public” can be delivered. Other publications may be available with special permission,

Belgium

- Can currently only share publicly available publications related to the program on "Development of advanced methods for RPV embrittlement" (Belgian Nuclear Research Centre SCK.CEN, sponsored by Electrabel).

Switzerland

- ENSI is in principle willing to share research results with other countries and would support a broader utilisation of ENSI research results, especially if research results can be evaluated together with results from other countries

Sweden

- Governmental supported research is normally public and is available; certain commercial or security aspects may be protected by information security classification.

Joint Research Centre

- Sharing of results is to be decided on a case-by-case basis. Most projects have been performed in collaboration with partner organisations and thus require agreement of the whole consortium for spreading results outside the consortium. For some projects results and reports are openly available

Slovenia

- We are able to share the results for related research projects

Germany

- Research results can be shared after release by the sponsoring organisations (Federal Ministry of Economics and Technology (BMWi) or others)

Czech Republic

- Generally yes. For specific projects it depends on sponsor's (Czech government) decision

United States

- Yes, the US has no limitations in sharing research sponsored by the NRC related to materials degradation

France

- Results of IRSN research and development programs on ageing mechanism are generally published and publicly available.
- Sharing of non-published results is made on a case by case basis.
    - Results including information on industrial material or components which is proprietary and/or confidential would require specific agreement with the industry

7. **What future areas of research (or technical issue) are of most interest to your country in conducting a research activity sponsored by CSNI? Please list the research areas in decreasing order of priority. Additionally, for each area of research, please provide the following information:**

   a. your country's rationale or reasons for the research area,
   b. a contact person for the research area, and
   c. a qualitative ranking (i.e. high, medium, or low) associated with the research area.

Note that this question is not asking what current CSNI projects (e.g., those in WGIAGE) is your country most interested in, but what possible future projects might your country be interested in participating in through a CSNI-sponsored activity.

Japan

- Understanding and prediction of RPV irradiation embrittlement mechanism
- Strength decrease and shieling performance decrease for concrete
- Electric cable ageing

Netherlands

- Fatigue (more detailed analysis methods to predict locations) - High
- Degradation of concrete support structure of the primary circuit (ageing because of environmental conditions) - Medium
- Concrete degradation of containment structure (ageing and impact of salt containing air/water) - Low
- Concrete degradation of basemat (ageing because of environmental conditions) - Low

Slovakia

- Ageing of reactor pressure vessels and reactor internals - High
- Piping failure database (CODAP) - High
- Cable ageing (especially ageing of cables covered by fire protection coating) - Medium
- Ageing of concretes (especially concrete structures in spent fuel pools) - Medium

Canada

- Long term operation (LTO) - High
- Age management (AM) - High
- Piping failure database (CODAP) - High
- Regulatory aspects on Leak-before-break (LBB) - High

Finland

- New predictive models for ageing mechanisms of mechanical components
- Condition assessment of prestressing tendons in a containment building
- Condition assessment of steel liners in containment buildings
- Ageing management systems combining theoretical degradation models and practical condition monitoring for concrete structures.

Belgium

- Probably environmental effects on fatigue will remain a topic with high priority

Switzerland

- Development of advanced material models for the prediction of HCF initiation and LCF crack growth and to assess crack networks - Medium
  - Contact: Hans-Peter Seifert (PSI)
- Environmental effects on fatigue initiation and growth and fracture resistance and fracture toughness in austenitic stainless steels and Ni-base alloys fracture resistance and fracture toughness - Medium
  - Contact: Hans-Peter Seifert (PSI)
- Ageing, structural integrity and NDT of the steel/concrete containment - Medium
  - Contact: Klaus Germerdonk (ENSI)
- Application of probabilistic approaches for ageing management - Medium
  - Contact: Markus Niffenegger (PSI)
- NDE-techniques for areas which are difficult to inspect (e.g. corrosion issue in primary containment, buried pipes, hidden internals) - Medium
  - Contact: Klaus Germerdonk (ENSI)

Sweden

- This will be judged case by case for metals and concrete issues (no real answer provided)
- Study and research of new safety and security concerns associated with new programmable digital control systems and particular reactor protection systems

Joint Research Centre

- We are most interested in any research areas listed under our response for question 5.

Slovenia

- Assessed interest in existing projects, no new projects as intended
- PROSIR (high), Atypical fatigue tests on different structures (high), Stress corrosion cracking of Alloy 800 and Ni-based alloys (high), Benchmark KJ (medium), LBB (medium), Hydrotests (low), Buried piping (low), Containment liners ageing (low)

Germany

- General ageing management measures within the time frame of the remaining life of German NPPs
- On-line monitoring techniques
- Advanced NDT technologies

Czech Republic

- Ageing of reactor internals
- Environmentally assisted fatigue of primary circuit materials of VVER plants
- Cable ageing (especially ageing of cables covered by fire protection coating)
- Ageing of concretes (especially concrete structures in spend fuel pools)
- Ageing of reactor pressure vessels
- Motor and air operated valve ageing – diagnostics of MOV and AOV functional capability

United States

- Environmental fatigue effects and prediction
- Ageing of concrete and/or containment structures
- Understanding and prediction of RPV embrittlement mechanisms
- Sharing research among countries related to void swelling effects on reactor internals

France

- Understanding and prediction of RPV embrittlement mechanisms
- Environmental fatigue effects and prediction
- Ageing of concrete and/or containment structures
- Cable ageing