Safety Reports Series

No. 57

Safe Long Term Operation of Nuclear Power Plants

IAEA

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SAFE LONG TERM OPERATION OF NUCLEAR POWER PLANTS

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Sales and Promotion, Publishing Section
International Atomic Energy Agency
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FOREWORD

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

As of June 2007, out of the total number of nuclear power plants operating in the world, approximately 25% had been in operation for more than 30 years, and about 70% for more than 20 years. Consequently, and in line with economic and energy supply growth and environmental quality, in the past decade a number of IAEA Member States have started to consider extended operation of their nuclear power plants beyond the time frame originally anticipated, in other words long term operation.

The IAEA has published Safety Requirements and Safety Guides on the safe operation of nuclear power plants. These mainly deal with current plant operation; however, there are improvements that need to be made to provide guidance for the operation of nuclear power plants beyond the initial time frame for which they were licensed or designed. In addition, more detailed information needs to be provided to assist operating organizations and regulatory bodies in dealing with the following issues:

(a) Principles and overview for carrying out long term operation;
(b) Determining which systems, structures and components and relevant functions need to be specifically reviewed for long term operation;
(c) Providing criteria and guidance for demonstrating that the effects of ageing will be managed for a period of extended operation, including assessment of both the physical status of the plant and existing plant programmes;
(d) Providing guidance for identifying safety analyses that use time limited assumptions that need to be revalidated for long term operation;
(e) Providing criteria and guidance for evaluating safety analyses that use assumed time limits, which are a basic feature of any design.

This Safety Report complements the IAEA Safety Requirements on the Safety of Nuclear Power Plants: Operation and the relevant Safety Guides and provides information on the above list of issues and addresses them in a comprehensive and systematic way.

The contributions of all those who were involved in the drafting and review of this report are greatly appreciated. In particular, the contributions to the preparation of this report provided by A. Duchac, European Commission, and T. Taylor, USA, are acknowledged. The IAEA officers responsible for this report were R. Havel, E. Liszka, L. Wang, T. Inagaki and G. Jones of the Division of Nuclear Installation Safety.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

In recent decades, the number of IAEA Member States giving high priority to continuing the operation of nuclear power plants beyond the time frame originally anticipated for their operation (typically 30–40 years) has steadily increased. This is related both to economic conditions and to the age of the nuclear power plants connected to the grid worldwide. As of June 2007, out of the total number of nuclear power plants operating in the world, approximately 25% had been in operation for more than 30 years, and about 70% for more than 20 years.

Long term operation (LTO) of a nuclear power plant may be defined as operation beyond an established time frame set forth by, for example, licence term, design, standards, licence and/or regulations, which has been justified by safety assessment, with consideration given to life limiting processes and features of systems, structures and components (SSCs).

The currently available IAEA safety standards need enhancement in certain areas to address LTO. Specifically, detailed guidance needs to be provided for evaluating safety analyses that use assumed time limits, which are a basic feature of any design. Reference [1] provides a methodology to review the safety of operating nuclear power plants, and addresses ageing management and other safety factors, but clearer differentiation is needed between requirements for a new nuclear power plant, a nuclear power plant that is approaching the end of its initially anticipated time of operation, and a nuclear power plant that is continuing operation beyond such an initially anticipated time frame. Reference [2] provides guidance and recommendations for managing the ageing of SSCs important to safety in operating nuclear power plants, but needs to be expanded to provide guidance for projecting or demonstrating that ageing effects will be managed in future operations such as LTO. Although existing IAEA safety standards can be used to deal with specific LTO issues, guidance that addresses LTO in a systematic, comprehensive and integrated way needs to be included in order to meet the needs of Member States.

Recognizing the differing levels of development in its Member States, and the need for comprehensive information about international good practices to assist regulatory bodies and operating organizations in dealing with the unique challenges associated with LTO, the IAEA conducted the Extrabudgetary Programme on Safety Aspects of Long Term Operation of Water Moderated Reactors (EBP SALTO) in 2003–2006. This Safety Report was developed based upon the results of the EBP SALTO and on the recommendations of the Technical Meeting on Safety Aspects of Long Term Operation and Ageing Management of Nuclear Power Plants, held in September 2006 [3]. The information provided in this Safety Report takes into account the experience of Member States that have successfully pursued LTO, as well as that of Member States that are preparing for LTO.

This Safety Report fulfils, in part, the need expressed by Member States for information about international good practices that may be referenced when developing national programmes for LTO that focus on the SSCs of nuclear power plants. It provides operating organizations and regulatory bodies with guidance on how to demonstrate and verify the safety of their nuclear power plants during LTO. This Safety Report is also used as the basis of IAEA peer review missions on safe long term operation (SALTO Peer Reviews).

In the future, main key elements of this Safety Report will be incorporated into the revision of the Safety Guide on periodic safety review (PSR) [1], and some elements will be incorporated into the Safety Guide on ageing management [4], since Member States are conducting activities for LTO under their PSR and ageing management activities.

1.2. OBJECTIVE

The objective of this Safety Report is to provide information on key technical considerations and activities to ensure safe LTO of nuclear power plants in accordance with regulatory requirements. This Safety Report takes into account approaches, practices and experience of Member States pursuing LTO. It aims to support operating organizations in demonstrating the safety of their nuclear power plants during LTO and regulatory bodies in verifying their safety. It provides information on a step by step approach that may be taken by operating organizations and regulatory bodies considering LTO.

1.3. SCOPE

This Safety Report provides information on the technical issues of LTO associated with the physical condition of water moderated nuclear power plants (i.e. PWRs, including WWERs, BWRs and PHWRs). The information in this report may be used to develop and implement a process that addresses SSCs that are important to safety or SSCs whose failure could prevent satisfactory accomplishment of, or initiate challenges to, any of the safety functions defined in Section 4. This Safety Report addresses the following LTO related topics:

(a) Overview: principles of and approach to LTO.
(b) Feasibility studies.
(c) Setting the scope and screening of SSCs.
(d) Assessment and management of structures and components (SCs) for ageing degradation for LTO.
(e) Revalidation of safety analyses using time limited assumptions.
(f) Documentation.
(g) Regulatory review.

This Safety Report considers only the SSCs of nuclear power plants and does not address:

(i) The environmental impact of LTO;
(ii) Organizational and administrative aspects of LTO;
(iii) Human factors;
(iv) Economic assessment and long term investment strategies.

1.4. STRUCTURE

This Safety Report is divided into eight sections. Each section describes activities that need to be carried out for LTO to be implemented and provides information on how to accomplish the activities. The LTO process includes all the activities illustrated in Fig. 1. Section 2 provides an overview of the principles and process associated with LTO. Section 3 describes the activities that need to be performed to demonstrate whether LTO is feasible and provides information on evaluating the plant programmes that are considered preconditions for LTO. Section 4 describes a systematic scope setting and screening process that may be used to determine which SSCs are subject to assessment and management of ageing effects for LTO and revalidation of safety analysis involving time limited assumptions. Section 5 discusses assessment of SCs for identification of the effects of ageing degradation and for demonstration that they will be managed for LTO. Section 6 discusses the revalidation of safety analyses using time limited assumptions. Section 7 describes the documentation necessary for assessment in connection with LTO. Section 8 describes a regulatory review process that may be used in accordance with applicable national regulatory requirements.

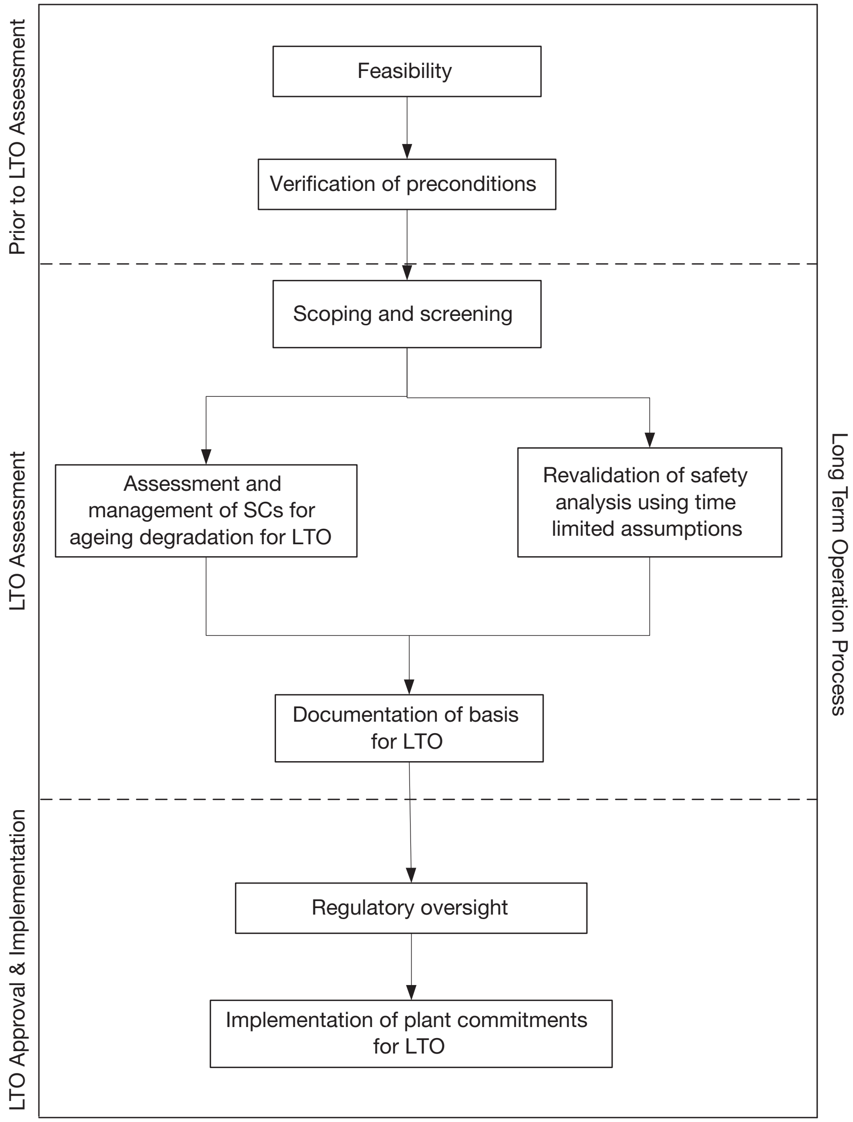

FIG. 1. Overview of activities for LTO.

2. OVERVIEW

The nuclear power plants that are currently in operation were generally designed and built to conservative standards, and in many cases have significant remaining safety margins[1]. Current engineering technology is able to assess the remaining safety margins for the physical condition of SSCs in nuclear power plants and indicate whether safe LTO is technically feasible. In the initial period of operation, national or international regulations often required that nuclear power plants be operated in a conservative manner compared with their design criteria. The combination of both aspects — conservative design, which is now better understood, and conservative operation that follows national and international practices — is an essential basis for continuing operation beyond the initially established time frame.

Operating experience has accumulated over the years in a way that has increased the knowledge of physical ageing phenomena affecting SSCs (e.g. radiation embrittlement, stratification, nickel based alloy corrosion). Continuing research has also contributed to that goal. In cases where the useful life of individual components proved to be less than their intended design life, component replacements have taken place that allowed continued operation of the plant in accordance with safety principles and regulations [6]. In a broader sense, plant surveillance, inspection and maintenance programmes, and consideration of feedback on operating experience, play an essential role in ensuring the safe operation of nuclear power plants in the current design period as well as in LTO.

2.1. PRINCIPLES OF LONG TERM OPERATION

The approach to LTO is based upon the following principles:

(a) Current operational practices meet national regulations and follow international guidelines as applicable and are adequate to ensure safe operation of the plant in the current design period.
(b) The existing regulatory process is adequate to maintain safe operation of the nuclear power plant for the current authorized period and focuses on

[1] The safety margin is the distance between an acceptance criterion and a safety limit. For more details, see Ref. [5].

the effects of ageing that need to be properly managed for the planned period of LTO.

(c) The current licensing basis[2] (CLB) provides an acceptable level of safety [7] for the current authorized period and is continued over the planned period of LTO in the same manner and to the same extent, with the exception of any changes specific to LTO[3].

(d) Existing nuclear power plant programmes may be credited for use in LTO provided that they are consistent with the nine elements described in Section 5.3.

The requirements for LTO of existing nuclear power plants need to be specified within a regulatory framework.

2.2. APPROACH TO THE LONG TERM OPERATION PROCESS

The following engineering process may be used to ensure that CLB requirements will be continued in the planned period of LTO. The process also ensures that plant programmes used to support the management of ageing effects are reviewed and are consistent with the nine elements described in Section 5.3. The engineering process for LTO involves the following main steps:

(a) Use of a scope setting and screening process to ensure that SCs important to safety will be evaluated for LTO (Section 4).

(b) Demonstration that the effects of ageing will continue to be identified and managed for each SC for the planned period of LTO. This step is a two part assessment that includes the following:
   (i) Review of existing plant programmes and practices to ensure that they will remain effective for the planned period of LTO. This review will identify modifications and/or new programmes necessary to ensure that SSCs are able to perform their designated safety function for the planned period of LTO (Section 5).

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[2] The CLB is a collection of documents or technical criteria that provides the basis upon which the regulatory body issues a licence for the siting, design, construction, commissioning, operation or decommissioning of a nuclear installation valid for the current authorized period.

[3] It is recognized that Member States may have complementary national requirements, such as review and possible upgrading of the CLB on a one-time basis or in the context of PSR (usually every 10 years).

(ii) Review of each SC within the scope of LTO to ensure that the effects of ageing are managed properly so that the SC is capable of performing its designated safety function. The review includes a technical explanation of the management of ageing effects for each SC identified that demonstrates whether the intended function of the SC will be maintained throughout the planned period of LTO in a manner that is consistent with the CLB.

(c) Review of SCs that were subject to analyses with time limited assumptions to ensure that the analyses continue to be valid for the planned period of LTO or that the ageing effects will be managed. The evaluation of such analyses demonstrates whether the intended function of the SC will remain within design safety margins throughout the planned period of LTO (Section 6).

3. LONG TERM OPERATION FEASIBILITY

3.1. FEASIBILITY STUDIES

The decision of an operating organization to pursue LTO is based upon an evaluation that covers, as a minimum, the following elements:

(a) Strategic elements such as the need for electric power and issues concerning supply diversity;
(b) Applicable regulatory requirements, including an assessment of the adoption of new requirements;
(c) A technical assessment of the physical condition of the nuclear power plant, including identification of enhancements or modifications to the physical facility if necessary, and of the impact of changes on nuclear power plant programmes and procedures necessary for continued safe operation;
(d) A technical assessment of the environmental impact of LTO;
(e) An economic assessment.

A decision to proceed with LTO is made only if the results of the activities indicated in Fig. 1 demonstrate that the nuclear power plant can be operated safely for the planned period of LTO.

3.2. PRECONDITIONS FOR LONG TERM OPERATION

The existing nuclear power plant programmes and documentation are essential in developing the foundation for successful LTO. The existence of the following nuclear power plant programmes and documentation, which impact upon all SCs of nuclear power plants and all areas of safe plant operation, is considered a precondition for LTO:

(a) Plant programmes as detailed in Section 3.3;
(b) A management system that addresses quality assurance and configuration management[4] [8, 9];
(c) Original safety analyses involving time limited assumptions;
(d) Current safety analysis report or other licensing basis documents.

Each precondition needs to be properly documented in the current safety analysis reports or in other licensing basis documents and clearly and adequately describes the CLB or the current design basis requirements for nuclear power plant operation.

3.3. PLANT PROGRAMMES

This section describes each of the plant programmes considered as preconditions.

Plant programmes are a planned series of events or a set of related long term measures or activities that are performed and conducted in a certain order or manner to achieve the purpose for which the plant was constructed. Plant programmes in the five areas listed below are considered preconditions for LTO and are necessary to support the modifications for LTO associated with ageing management:

(a) Maintenance;
(b) Equipment qualification;
(c) In-service inspection (ISI);
(d) Surveillance and monitoring;
(e) Monitoring of chemical regimes.

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[4] Quality assurance and configuration management address quality control, design basis management, and the means to control and track the quality of the material, structure, component or system to predetermined requirements.

These plant programmes are selected because they impact upon all SSCs of the nuclear power plant.

The following information emphasizes both current plant programme activities for LTO [2] and those specifically indicated for LTO based on the results of the EBP SALTO; more detailed information is provided in Ref. [3] with respect to other plant programmes relevant for LTO.

3.3.1. Maintenance

Maintenance programmes are reviewed and evaluated for effectiveness in maintaining the intended function of each SSC within the scope of LTO. The review provides a technical basis that demonstrates whether the degradation mechanisms will be adequately managed by the proposed activities. Obsolescence of components in the life of a power plant including the proposed period of LTO is also addressed. A programme to address obsolescence does not need to be a separate programme, but may be part of the normal plant maintenance programme [2].

Maintenance programmes for structures based on standard preventive maintenance may not be adequate to support an LTO programme. The effectiveness of the maintenance programme is monitored using, for example, a ‘condition based’ assessment.

Maintenance programmes for LTO clearly identify the links with ageing management programmes, including the frequency of maintenance activities and specific information on the tasks and records and on their evaluation and storage. Existing maintenance programmes credited for LTO are evaluated against the nine elements listed in Section 5.3.

The effectiveness of maintenance in detecting and characterizing degradation mechanisms is documented. The documentation includes all maintenance activities, such as those for instrumentation and control, pumps, valves and sensors. The documentation provides technical references to support findings and conclusions.

A systematic approach to maintenance addresses technical aspects such as development of acceptance criteria, reliability centred maintenance, condition based maintenance and risk informed methods.

3.3.2. Equipment qualification

Equipment qualification establishes that equipment, while being subject to environmental conditions, is capable of performing its intended safety functions or that it will be replaced/repaired so that its intended safety functions will not be compromised during the planned period of LTO.

Equipment qualification also demonstrates whether the environmental and seismic qualification of equipment will remain valid over the expected period of LTO. The demonstration supports the technical justification that the material degradation and ageing effects will be managed effectively.

Equipment designed in accordance with earlier standards is reviewed and requalified, if necessary, under a comprehensive programme. Timely replacement of equipment that cannot be qualified for the planned period of LTO is considered. A specific programme is developed for replacement of mechanical and electrical equipment with qualified or stated lifetimes less than the planned LTO period. The availability of qualified manufacturers and products needed for plant modifications for LTO is considered.

Qualification results for safety related electric and instrumentation and control equipment located in the containment are verified and further developed. The qualification results specify whether the equipment has been qualified to perform its safety functions in environmental conditions equivalent to design basis accident conditions for the planned period of LTO.

A plant specific list that specifies environmentally qualified cables and connectors on safety related equipment, as well as cables and connectors on non-safety related equipment that has an impact on the performance of safety related systems, is updated regularly.

3.3.3. In-service inspection

ISI programmes are evaluated for effectiveness in detecting degradations of each SC. The review process provides a technical basis that demonstrates whether the ageing phenomena will be adequately detected with the proposed inspection or monitoring activities.

If risk informed ISI (RI-ISI) programmes are to be used for the planned period of LTO: (a) consideration is given to developing comprehensive regulatory requirements for implementation of RI-ISI; and (b) the effectiveness of RI-ISI is evaluated as discussed in Section 5.3. This is because RI-ISI programmes have limited operational experience, and also to allow for limitations in the probabilistic analysis supporting the RI-ISI.

The methodology, equipment and personnel that are part of the ISI process are qualified in accordance with national standards, regulatory requirements and IAEA recommendations [2], and the qualification process includes requirements that provide a quantitative measure of the effectiveness of the ISI process (e.g. ultrasonic testing (UT) detection capability and UT flaw characterization error) through blind (and/or open) trials on test blocks.

ISI results should be correctly documented in order that a comparative analysis of the inspection results obtained from inspection can be carried out, especially when the inspections are performed in separate areas and at different periods of time.

A database is developed and maintained that provides data to document the adequacy of non-destructive examination in detecting and characterizing degradation of the SCs. The database provides the technical bases to support the findings and conclusions necessary for LTO.

3.3.4. Surveillance and monitoring

The surveillance programme confirms the provisions for safe operation that were considered during the design phase, checked during construction and commissioning, and verified throughout operation. The programme will continue to supply data to be used for assessing the service life of SSCs for the planned period of LTO, for example through existing or additionally installed diagnostic systems. At the same time, the programme verifies that the safety margins are adequate and provides a high tolerance for anticipated operational occurrences, errors and malfunctions. Particular attention is paid to the following aspects:

(a) Integrity of the barriers between radioactive material and the environment (primary pressure boundary and containment);
(b) Availability of safety systems such as the protection system, the safety system actuation systems and the safety system support features [10];
(c) Availability of items whose failure could adversely affect safety.

Surveillance programmes using representative material samples addressing time limiting mechanisms are extended or supplemented for LTO, if necessary.

The basis for the supplementary surveillance programme takes the following into account:

(i) The design considers all available specific data of the reactor pressure boundary, for example the initial state characteristics (subcomponents, geometry, chemical composition, manufacturing procedures, mechanical properties), the operational history (operational regimes, local power history of the external fuel elements, pressure tests, abnormal events, thermal annealing), the available surveillance programme results and the available representative materials.
(ii) All relevant generic data and knowledge on embrittlement effects (e.g. re-embrittlement, if relevant) and kinetics are considered for predicting the expected material properties during LTO and designing the

supplementary surveillance programme in detail. This includes reliable and accurate neutron dose evaluations (experimental and analytical). Advanced testing procedures and evaluation methods are considered for defining the set of specimens to be included in the supplementary surveillance programme, at least for alternative assessments.

3.3.5. Monitoring of chemical regimes

Control of water chemistry is important and may be used to minimize the harmful effects of chemicals, chemical impurities and corrosion on plant systems for LTO. The operating organization reviews its water chemistry programme to ensure that the programme is effective in maintaining the water quality required by the technical specifications and is consistent with the nine elements listed in Section 5.3.

The water chemistry programme specifies scheduling, analytical methods used to monitor chemistry (some programmes use automated on-line monitoring equipment, while others use wet chemical methods) and verification of the effectiveness of the chemistry programme. The water chemistry programme also provides the necessary chemical and radiochemical assistance to ensure safe operation, the long term integrity of SSCs and control and reduction of radiation levels in work areas.

4. SETTING THE SCOPE AND SCREENING

A systematic process determines which of the many SSCs that make up a nuclear power plant are to be included in the scope of the LTO. SSCs determined to be within the scope of LTO evaluation are subject to a screening assessment to determine which SCs are subject to revalidation of analyses that involved time limited assumptions and which SCs require evaluation of programmes for managing ageing.

The following sections describe processes for scope setting and screening that, if applied properly, will ensure that SSCs that perform identified safety functions are evaluated for their suitability for LTO. The scope setting process described is carried out at the SSC level, and the screening process described is at the SC level. It may be convenient for a plant to set the scope for SSCs using more than one method. For example, a system based scope setting approach may be used for mechanical systems, and a component or commodity based scope setting approach may be used for electrical systems.

4.1. SCOPE SETTING PROCESS

The SSCs within the scope of LTO are those that perform the following safety functions [11]:

(a) All SSCs important to safety that ensure the integrity of the reactor coolant pressure boundary;
(b) All SSCs important to safety that ensure the capability to shut down the reactor and maintain it in a safe shutdown condition;
(c) All SSCs important to safety that ensure the capability to prevent accidents that could result in potential off-site exposure or that mitigate the consequences of such accidents.

Other SSCs within the scope of LTO are those whose failure may impact upon the safety functions specified above.

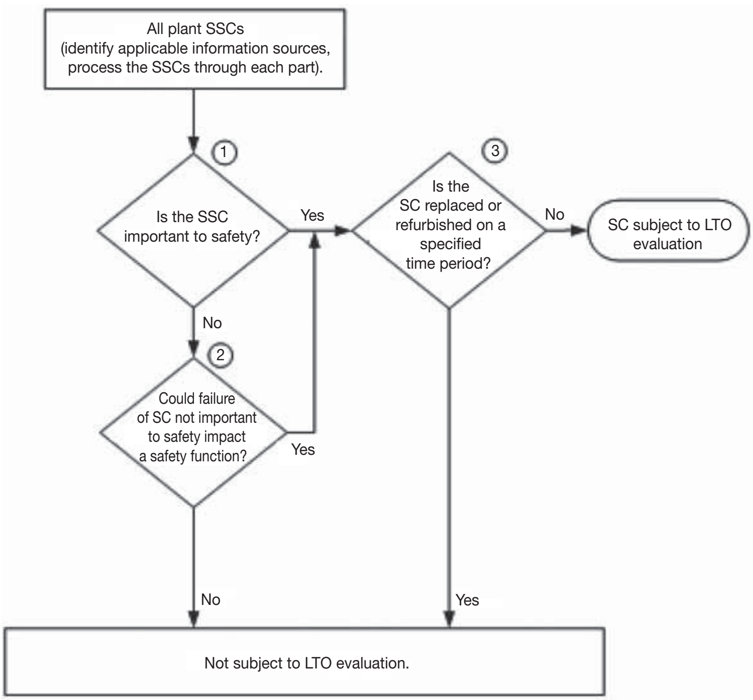
All SCs within the scope of LTO and not subject to replacement based on a qualified life or specified time period are identified and included for further reviews for LTO.

Some national regulations also require that all SSCs that are credited in a safety analysis to perform a function that mitigates certain types of events also be included in the scope of reviews for LTO. Such events are:

(i) Fires and floods;
(ii) Extreme weather conditions;
(iii) Earthquakes;
(iv) Pressurized thermal shock;
(v) Anticipated transient without scram;
(vi) Station blackout.

The operating organization may also consider assessing SSCs that are not safety related but that remain important for nuclear power plant operation beyond an established time frame.

Figure 2 illustrates a systematic scope setting process that may be used to determine which SCs are within the scope of evaluation for LTO. The results of the scope setting process are documented in a manner that complies with the requirements of the quality assurance programme. The information to be



(1) SSCs important to safety that perform the safety functions specified in Section 4.1.
(2) SCs whose failure may impact safety functions specified in Section 4.1.
(3) SCs on a replacement or refurbishment schedule that are replaced based on a qualified life or specified time period; these are not subject to LTO evaluation.

FIG. 2. Scope setting process for LTO.

documented includes: (a) identification of the plant SSCs that meet the description above; and (b) the information sources used to accomplish the scope setting and any discussion needed to clarify their use.

4.2. SCREENING PROCESS

For the SCs determined to be within the scope of evaluation for LTO, the operating organization identifies which of those SCs are subject to an assessment that demonstrates whether the effects of ageing degradation will be managed for the planned period of LTO. SCs subject to evaluation for LTO include those SCs that perform a safety function as described in Section 4.1.

Such SCs include, but are not limited to: the reactor pressure vessel, the reactor coolant system pressure boundary, steam generators, the pressurizer, piping, pump casings, valve bodies, the core shroud, component supports, pressure retaining boundaries, heat exchangers, ventilation ducts, the containment, the containment liner, electrical and mechanical penetrations, equipment hatches, seismic category I structures, electrical cables and connections, cable trays and electrical cabinets. SCs excluded are, but are not limited to: pumps (except casing), valves (except body), motors, diesel generators, air compressors, snubbers, the control rod drive, ventilation dampers, pressure transmitters, pressure indicators, water level indicators, switchgears, cooling fans, transistors, batteries, breakers, relays, switches, power inverters, circuit boards, battery chargers and power supplies.

The results of the screening process are documented in a manner that complies with the requirements of the quality assurance programme. The information to be documented includes: (a) identification of the plant SCs that meet the description above; and (b) the information sources used to accomplish the screening and any discussion needed to clarify their use.

Figure 3 shows a systematic screening process to identify SCs for which safety analyses need to be revalidated or for which plant programmes need to be reviewed and modified.

5. ASSESSMENT AND MANAGEMENT OF STRUCTURES AND COMPONENTS FOR AGEING DEGRADATION FOR LONG TERM OPERATION

Once the scope setting and screening process has been completed, the SCs necessary for safe LTO are identified. The next activity is to assess the conditions of SCs and provide a justification that their physical status will be managed consistent with the CLB for the planned period of LTO. This process, which is called an ageing management review in some Member States, consists of the following steps:

(a) Assessment of the current physical status of the plant;
(b) Identification of ageing degradation effects;
(c) Review of the existing plant programmes and proposed programmes for ageing management;

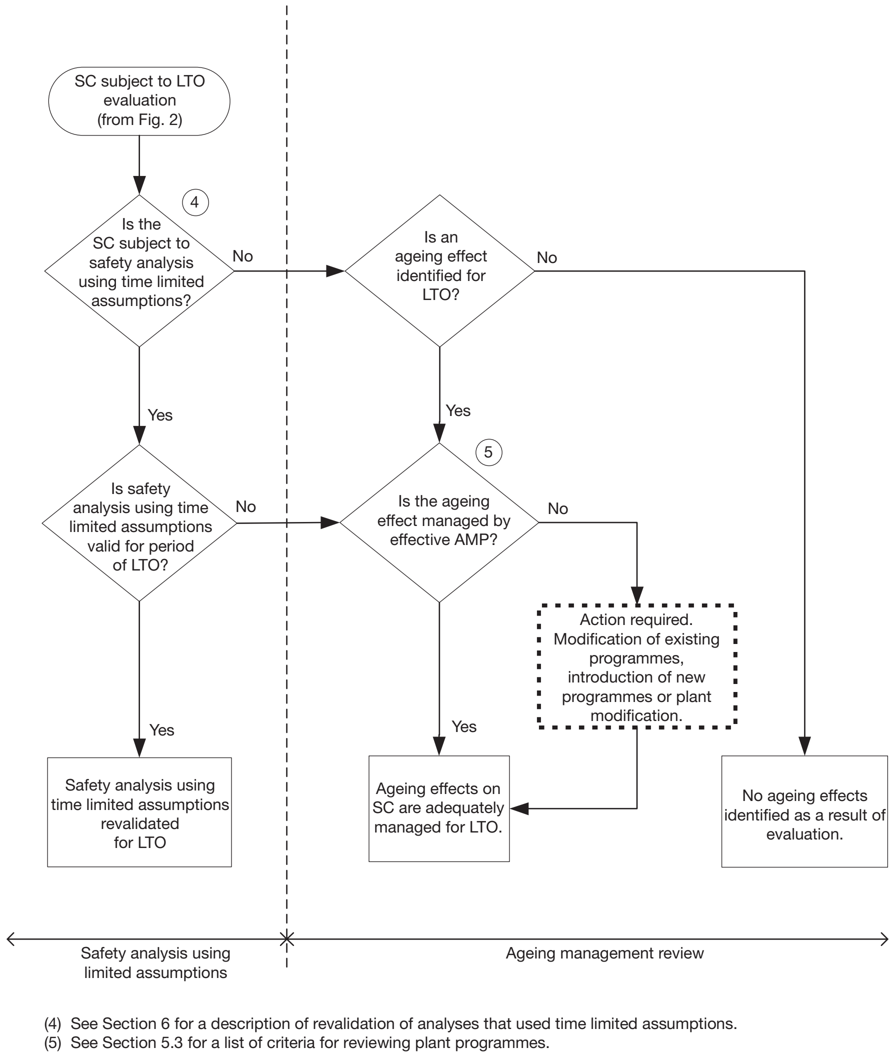


FIG. 1. Screening process for LTO.

(d) Demonstration that the effects of ageing degradation are being managed;

(e) Documentation of the evaluation and demonstration that the effects of ageing for SCs will be managed for the planned period of LTO.

5.1. ASSESSMENT OF THE CURRENT PHYSICAL STATUS OF THE PLANT

An engineering assessment of the current status of SCs within the scope of LTO is carried out. An adequate engineering assessment requires knowledge of:

(a) The design, including applicable codes and regulatory requirements, the design basis and design documents, including the safety analysis;
(b) The fabrication, including material properties and specified service conditions;
(c) The operation and maintenance history, including commissioning, operational transients and events, generic operating experience such as power uprating, modification and replacement, surveillance and any trend curves;
(d) Results of inspections;
(e) The environment inside and outside the SCs;
(f) Results of research.

Unless the engineering assessment confirms that the status of SCs is within the predicted scope of the design, remedial measures will need to be taken.

5.2. IDENTIFICATION OF AGEING DEGRADATION EFFECTS

There are various techniques used to identify and assess ageing effects. For some SCs, design margins and/or material properties are known and can be reviewed. In such cases, an analysis may be sufficient to demonstrate whether the effects of ageing are managed.

For other SCs, performance or maintenance history is available and can be reviewed to assist in demonstrating whether the effects of ageing are managed. These and other considerations point to the need to determine the appropriate level of review for the type of structure, component or commodity grouping and for the plant specific conditions.

Assessing the appropriate level of review involves examining information from various investigations and developing a scope statement to describe the depth of review needed for the structure, component or commodity grouping. As appropriate, the assessment includes the following activities:

(a) Assembling of information relating to the structure or component material properties and design margins. If components are made from different materials or are subject to distinctly different ageing effects, a separate review of each may be needed.
(b) Identification of the ageing effects potentially affecting the ability of SCs to perform their intended functions.
(c) Review of the design or material properties to determine if certain ageing effects can be shown by analysis not to affect the capability of the structure or component to perform its intended function throughout the intended period of extended operation. Of particular interest are parameters such as corrosion allowance, fatigue cycles, loading conditions, fracture toughness, tensile strength, dielectric strength, radiation exposure and environmental exposure.
(d) Review and assessment of the operating and maintenance history of the structure or component. The focus of the review may include the service duty, operational transients, past failures or unusual conditions that affected the performance or condition of the structure or component. Of particular interest is how the performance or degraded condition of the structure or component has affected the capability of the structure or component to perform its intended function and the safety significance of the structure or component. The review also may include an examination of repairs, modifications or replacements for their relevance to ageing considerations.
(e) Assessment of industry operating experience and its applicability to decisions made for the plant.

To determine the ageing effects requiring management, the operating organization considers and addresses the materials, environment and stressors that are associated with each structure, component or commodity grouping under review.

In addition to the consideration of materials, environment and stressors, the operating organization considers and addresses the plant specific CLB, plant and industry operating experience and existing engineering evaluations in order to identify the ageing effects requiring management for the structure or component subject to an ageing management review. The ageing effects requiring management are those that have been identified using the considerations described above and that adversely affect the SC such that their intended functions may not be maintained consistent with the CLB for the planned period of extended operation.

For example, the process used to perform an ageing management review of a component or commodity group for a specific environmental stressor is as follows:

(a) Identification of all component or commodity group construction materials that have potential ageing effects when exposed to the environmental stressor.
(b) Determination of the value of the bounding environmental parameter to which the components in the area to be reviewed are exposed.
(c) Estimation of the ageing characteristics of the identified materials within the bounding environment and determination whether the components will be able to maintain their intended functions for the planned period of LTO.

An operating organization may be able to demonstrate by analysis that it is not possible for an ageing effect to result in a loss of the intended function of the structure or component under design basis conditions. The demonstration ultimately will determine whether there is reasonable assurance that the CLB will be maintained for the planned period of LTO and therefore whether the effects of ageing need not be managed.

5.3. REVIEW OF EXISTING PLANT PROGRAMMES AND PROPOSED PROGRAMMES FOR AGEING MANAGEMENT

Ageing management is a cross-cutting activity that involves maintenance, surveillance, equipment qualification, ISI and other relevant plant programmes. It provides a methodical process to detect and mitigate ageing degradation. This process is used as part of the justification for safe LTO.

Any existing and new plant programme that supports LTO and manages the ageing effects identified for LTO is reviewed to determine whether it includes the nine elements described below. In addition, the plant programmes discussed in Section 3.3 are also reviewed with respect to the information given in Section 3.3.

(a) A defined programme scope. The scope of the programme is the specific SCs subject to an ageing management review.
(b) Identification of preventive and mitigatory actions and of parameters to be monitored or inspected. Actions to prevent or mitigate ageing degradation and parameters to be monitored or inspected for the

intended functions of the particular structure or component are identified.

(c) Detection of ageing degradation/effects. Ageing effects need to be detected before there is a loss of the intended functions of a structure or component. The method or technique (i.e. visual, volumetric, surface inspection), frequency, sample size, data collection and timing of new/one time inspections need to be addressed to ensure timely detection of ageing effects.

(d) Monitoring and trending, including frequency and methodologies. Monitoring and trending provide predictability of the extent of degradation, and make possible timely corrective or mitigatory actions.

(e) Acceptance criteria. The need for corrective action evaluated against acceptance criteria, to ensure that the intended functions of a structure or component are maintained under all CLB conditions throughout the planned period of LTO.

(f) Corrective actions if a component fails to meet the acceptance criteria. Corrective actions, including root cause determination and prevention of recurrences, need to be timely.

(g) Confirmation that required actions have been taken. A confirmation process ensures that preventive actions are adequate and that appropriate corrective actions have been completed and are effective.

(h) Administrative controls that document the programme's implementation and actions taken. Administrative controls provide a formal review and approval process.

(i) Operating experience feedback. Operating experience of the ageing management programme, including past corrective actions resulting in programme enhancements or additional programmes, provides objective evidence to support the conclusion that the effects of ageing will be managed adequately so that the intended functions of a structure or component will be maintained throughout the planned period of LTO.

If the operating organization concludes, after reviewing the existing plant programmes and/or ageing management programmes, that the management of ageing effects is not adequate, the operating organization modifies the existing programme or develops a new programme or inspection mechanism for the purpose of LTO.

The new programme or inspection mechanism includes a methodology for analysing the results of the inspection against applicable acceptance criteria. The methodology is capable of determining the ability of the structure or component to perform its intended function for the planned period of LTO under the design conditions required by the regulator.

5.4. DEMONSTRATION THAT THE EFFECTS OF AGEING DEGRADATION ARE MANAGED

A proper LTO assessment demonstrates whether the effects of ageing will be adequately managed so that the intended safety functions will be maintained consistent with the plant's CLB for the planned period of LTO. To demonstrate whether the ageing degradation effects are properly managed, the ageing management tools discussed in Sections 3.3, 5.2 and 5.3 are used.

In performing the demonstration, an operating organization considers all plant programmes and activities associated with the structure or component. Plant programmes and activities that apply to the structure, component or commodity groupings are reviewed to determine if they include actions to detect and mitigate the effects of ageing.

Plant programmes that are reviewed according to the tools presented in Section 5.3 include four types of activities — prevention, mitigation, condition monitoring and performance monitoring.

(a) Prevention precludes the ageing effect from occurring (e.g. coating programmes to prevent external corrosion of a tank).
(b) Mitigation attempts to slow the effects of ageing (e.g. chemistry programmes to mitigate internal corrosion of piping).
(c) Condition monitoring inspects and examines for the presence and extent of ageing effects (e.g. visual inspection of concrete structures for cracking and ultrasonic measurement of pipe walls for erosion or corrosion induced wall thinning).
(d) Performance monitoring tests the ability of a structure or component to perform its intended functions (e.g. heat balances on heat exchangers for the heat transfer function of the tubes).

In some cases, more than one type of ageing management programme may be implemented to ensure that the ageing effects are adequately managed and that the intended function of the structure or component is maintained for the planned period of LTO. For example, managing the internal corrosion of piping may rely on a mitigation programme (water chemistry) to minimize susceptibility to corrosion and a condition monitoring programme (ultrasonic inspection) to verify that the corrosion is insignificant.

When demonstrating whether the effects of ageing are being managed, the plant operator may choose to rely on a single ageing management activity or on a combination of activities. Once the operator has determined the approach for making the demonstration (i.e. single activity or multiple activities), documentation is made available that helps show logically how the effects of ageing are managed. The documentation addresses the elements of plant programmes listed in Section 5.3.

When a programme used to manage ageing effects involves inspection, sampling may be used to evaluate a group of structures or components. If sampling is used, a plant programme is developed that describes and justifies the methods used for selecting the population and the sample size. A sample consists of one or more structures or components drawn from the scope.

The operating organization determines a sample size that is adequate to provide reasonable assurance that the effects of ageing on the structure or component will not prevent the performance of its intended function throughout the planned period of LTO. Choice of the size of the sample is based on consideration of the specific ageing effects, location, existing technical information, materials of construction, service environment, previous failure history, etc. The sample is taken from locations most susceptible to the specific ageing effects of concern. The results of the inspection are also evaluated to assess whether the sample size is adequate or if it needs to be expanded.

Plant references as well as generic industry references may also be used to demonstrate methods for managing ageing effects; they are reviewed and included as part of the demonstration that ageing effects are being appropriately managed. References provide a clear link to existing plant programmes that are used to manage ageing effects. Any differences between plant programmes and references are identified. The operator justifies that the conclusions of the selected references still apply. The justification may be based on plant specific features, plant operating and maintenance history, and/or industry developments since the selected references were issued.

5.5. DOCUMENTATION OF THE EVALUATION AND DEMONSTRATION FOR MANAGEMENT OF AGEING EFFECTS

The operating organization develops and retains in an auditable and retrievable form all information and documentation required by the regulator. Documenting the identification of SCs subject to review for ageing management includes:

(a) An identification and listing of SCs subject to an ageing management review and their intended functions;
(b) A description and justification of the methods used to determine the SCs that are subject to an ageing management review;
(c) The information sources used to accomplish the above, and any discussion needed to clarify their use.

Documenting the demonstration that ageing effects will be managed includes:

(i) An identification of the ageing effects requiring management;
(ii) An identification of the specific programmes or activities that will manage the effects of ageing for each structure, component or commodity grouping listed;
(iii) A description of how the programmes and activities will manage the effects of ageing;
(iv) A discussion of how the determinations were made;
(v) A list of substantiating references and source documents;
(vi) A discussion of any assumptions or special conditions used in applying or interpreting the source documents;
(vii) A description of inspection programmes for LTO.

The information documented and retained by the operating organization will form the basis of the information reviewed by the regulator when reviewing and/or approving LTO.

6. REVALIDATION OF SAFETY ANALYSES THAT USED TIME LIMITED ASSUMPTIONS

This section describes the treatment of those plant specific safety analyses for which time limited assumptions were included in the original calculations to determine the design life of plant specific SCs. When the original design life of a particular SC is to be exceeded, these calculations need to be revalidated with respect to LTO.

Time limited assumptions are based on an initially assumed period of operation and on design considerations or licence terms. Such safety analyses are sometimes termed ‘time limited ageing analysis’ or ‘residual life assessment’.

Safety analyses that are to be revalidated for LTO are those that:

(a) Involve SSCs within the scope of LTO;
(b) Consider the effects of ageing degradation;
(c) Involve time limited assumptions defined by the current operating term;

(d) Were determined to be relevant in making safety determinations as required by national regulations;
(e) Involve conclusions or provide the basis for conclusions related to the capability of the SSC to perform its intended functions;
(f) Are contained or incorporated by reference in the CLB.

Assuming the intended period of LTO, an evaluation of time limited analyses that have the six characteristics specified above is conducted. For safe LTO to be allowed, the evaluation needs to demonstrate that the safety analyses meet one of the following criteria:

(i) The analysis remains valid for the intended period of LTO;
(ii) The analysis has been projected to the end of the intended period of LTO; or
(iii) The effects of ageing on the intended functions of the structure or component will be adequately managed for the intended period of LTO.

The revalidation of safety analyses that involve time limited assumptions is documented in an update to the safety analysis report. Examples for which the safety analysis typically involves time limited assumptions and therefore requires revalidation are:

- Irradiation embrittlement of the reactor pressure vessel;
- Thermal and mechanical fatigue;
- Thermal ageing;
- Loss of preload;
- Loss of material.

6.1. GENERAL CONSIDERATIONS

6.1.1. Operational limits and conditions

The stressors given in the design specifications or CLB are to be used for assessment of SCs and their supports. The time variation of stressors is corrected in accordance with data from surveillance programmes and measured or monitored by diagnostic systems or special measurement (see Section 3.3).

To carry out safety analysis for SCs in the scope of LTO, the limits established in the design or CLB are to be used. If the necessary limits are not given in the design specifications, the limits given in the appropriate regulatory documents or safety reports apply. The calculation considers the impact of effects that increase ageing degradation.

6.1.2. Mechanisms of material damage

SCs and their supports can experience various degradation mechanisms in operation, due to:

(a) Fatigue of the material by cyclic loading;
(b) Corrosion (pitting corrosion, corrosion cracking under permanent load and corrosion fatigue under accidental cyclic loading);
(c) Flow accelerated erosion;
(d) Cyclic loading induced fatigue crack growth from flaws possibly present in the material;
(e) Radiation damage;
(f) Material ageing under elevated temperatures;
(g) Material creep under elevated temperatures.

Plant SCs are typically subjected to several degradation mechanisms simultaneously. In such cases the calculation is performed in a conservative manner, to evaluate possible synergy of ageing effects. The gradual degradation of material properties in the lifetime of the nuclear power plant is taken into account.

6.1.3. General provisions for revalidation

Safety analyses for LTO of SCs demonstrate structural integrity and typically contain the following revalidation and analysis:

(a) Assessment of SCs from the point of view of fracture;
(b) Assessment of SCs from the point of view of fatigue damage;
(c) Assessment of SCs from the point of view of corrosion mechanical damage;
(d) Assessment of acceptability of flaws found in SCs in ISIs;
(e) Assessment of the residual life of SCs with such flaws for the intended period of LTO;
(f) Final assessment of the lifetime of SCs for the intended period of LTO.

Safety analysis is revalidated for all types of SCs in the scope of LTO, subject to an analysis with time limited assumptions. For the plant specific safety analyses that involve time limited assumptions, only codes verified in accordance with the relevant legislation can be used for calculations.

6.1.4. Documentation of revalidation

The documentation of analysis covers, as a minimum, the following elements as applicable:

(a) Technical terms of reference;
(b) Justification of the computational model used;
(c) Calculation of the stresses, strains and temperature fields;
(d) Calculation of the residual lifetime throughout the intended period of LTO;
(e) Conclusions and recommendation of measures for LTO.

6.2. ASSESSMENT

The assumed period of LTO and the technical lifetime of SCs, given for example by design, are verified by the successful completion of the assessments according to Section 6.1.

The lifetime of the SCs is to be based on the shortest lifetime determined by assessments executed in accordance with Section 6.1. If the period is shorter than the assumed period of LTO, it will be necessary to take the appropriate measures for operation management and maintenance in accordance with the operational programmes described in Section 3.3, or, if necessary and possible, to implement specific corrective measures.

7. DOCUMENTATION

The activities and results of the LTO evaluation are recorded and documented in a systematic and auditable manner that complies with the quality assurance programme in effect at the plant, and in accordance with the requirements of the national regulatory body. The documentation reflects the goal of evaluation for LTO, which is to justify that there is reasonable assurance that: (a) operational programmes with integrated ageing management functions will manage degradation such that SSCs within the scope of LTO will perform their intended functions in accordance with their licensing and design basis for the intended period of LTO; and (b) all safety analyses involving time limited assumptions have been revalidated for the intended period of LTO.

The results of the LTO evaluation are documented in a format consistent with other plant documentation practices and regulatory requirements. The operating organization uses the quality assurance programme in effect at the plant when documenting the results of the LTO.

Documentation supporting LTO includes:

(a) Results of feasibility studies;
(b) The CLB and design basis;
(c) The plant programmes that are credited to support safe LTO;
(d) The processes followed, supporting technical justifications and the results of the scope setting and screening, as outlined in Section 4;
(e) Documented results of the review of the ageing management programme and condition assessment and development of a technical justification that supports the conclusion that the SSCs within the scope of LTO will fulfil their intended functions for the proposed period of LTO;
(f) Documentation of the revalidation of safety analyses involving time limited assumptions;
(g) Revisions to existing plant programmes and procedures, and any new plant programmes identified as being required to support safe LTO;
(h) Regulatory submissions, such as an updated safety analysis report with an implementation plan or other regulatory documentation.

The submissions to the regulatory body need to justify that the intended safety functions of SCs will be maintained with sufficient safety margins for the whole period of LTO. The implementation of plant activities for LTO is properly documented in an updated safety analysis report or other licensing documents, together with an integrated implementation plan that includes results of the engineering process and constitutes the basis documents for application for and approval of LTO. The implementation plan identifies the corrective actions and/or safety improvements required to be implemented for safe LTO, and includes formal commitments from the operating organization to implement these within a reasonable schedule. The documents are subject to the approval of senior plant management and are then submitted to the regulatory body for review and decision in accordance with national regulatory requirements.

8. REGULATORY OVERSIGHT

The regulatory review verifies that the operating organization carries out a comprehensive evaluation and implements appropriate corrective actions and/or safety improvements within the agreed time, in accordance with national requirements. A main part of this task is the assessment of document submissions by the operating organization in order to demonstrate that SSCs will perform their intended functions in accordance with their licensing and design basis for the planned period of LTO. Some of the key activities that are considered by the regulatory body when reviewing LTO documentation submitted by the operating organization include:

(a) Verification that the process used to identify the SSCs within the scope of LTO is consistent with the process outlined in Section 4 and that the process is supported by a technical justification.
(b) Verification that the programmes credited for LTO support the conclusion that the intended functions of SSCs and the required safety margins will be maintained. This verification addresses the following topics:
  (i) A description of the intended functions of the SCs;
  (ii) Identification of applicable ageing effects based on materials, environment, operating experience, etc.;
  (iii) Identification and description of operational programmes and of ageing management programmes;
  (iv) Demonstration that the programmes for ageing management are adequate.
(c) Verification that the review performed for the SSCs within the scope of LTO is consistent with the process outlined in Section 5 and that technical justification is provided that:
  (i) Demonstrates that the effects of ageing will be adequately managed for each SC;
  (ii) Ensures that nuclear power plant operational experience and industry experience are appropriately reflected in assessing ageing effects of SCs.
(d) Verification that safety analyses involving time limited assumptions have been revalidated and that the evaluation includes:
  (i) Identification of safety analyses involving time limited assumptions, in accordance with the six characteristics specified in Section 6;
  (ii) Revalidation of each identified safety analysis involving time limited assumptions in a manner that meets the revalidation requirements specified in Section 6.

(e) Verification that the operating organization has identified and will implement all necessary activities before entering LTO.

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CONTRIBUTORS TO DRAFTING AND REVIEW

Blahoianu, A.	Canadian Nuclear Safety Commission, Canada
Duchac, A.	Directorate General, Joint Research Centre, European Commission
Havel, R.	International Atomic Energy Agency
Hoehn, J.	Consultant, Germany
Hoffman, S.	Nuclear Regulatory Commission, United States of America
Inagaki, T.	International Atomic Energy Agency
Katona, T.	Paks nuclear power plant, Hungary
Kirkhope, K.	Canadian Nuclear Safety Commission, Canada
Liszka, E.	International Atomic Energy Agency
Medvedev, P.	Rosenergoatom, Russian Federation
Monette, P.	AREVA, France
Svab, M.	State Office for Nuclear Safety, Czech Republic
Taylor, T.	Pacific Northwest National Laboratory, United States of America
Van der Wiel, L.	Ministry of Housing, Spatial Planning and the Environment, Netherlands
Wang, L.	International Atomic Energy Agency

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