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Challenges in Long-term Operation of Nuclear Power Plants

Implications for Regulatory Bodies

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 30 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, 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, as well as
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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.

Also available in French under the title:

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Cover photo: Calvert Cliffs nuclear power plant, United States (Fotowerkstatt).

Foreword

The Committee on Nuclear Regulatory Activities (CNRA) of the OECD Nuclear Energy Agency (NEA) is an international body made up of senior representatives from nuclear regulatory authorities. The committee guides the NEA programme concerning the regulation, licensing and inspection of nuclear installations with respect to safety. It acts as a forum for exchange of information and experience, and for review of developments which could affect regulatory requirements.

Following discussions at the CNRA meeting held on 7-8 June 2010, the Senior Task Group on Long-term Operation was established to prepare a document on regulatory challenges for long-term operation of nuclear power plants. The group was to review the principles and criteria that should be considered in making a regulatory decision to approve an operator's application for operation of a nuclear power plant beyond the operation period considered in the plant's design. During the preparation of this document, the 2011 Fukushima Daiichi nuclear power plant accident occurred. As a consequence, the CNRA requested that aspects of the event related to long-term operation should also be addressed in the review.

This report has been prepared by the Senior Task Group on Long-term Operation, in collaboration with the International Atomic Energy Agency (IAEA), on the basis of discussions and input by members of the group and consideration of information from a wide array of documents produced by the NEA, its member countries and other international organisations.

Kunihisa Soda (Japan) chaired the meetings and the work of the group. Other members of the group were Frederik Van Wonterghem (Belgium), Hatem Khouaja (Canada), Martti Vilpas (Finland), Nicolas Osouf (France), S. Harikumar (India), Hiroki Ishigaki (Japan), Toru Osaki (Japan), Tomoho Yamada (Japan), Lennart Carlsson (Sweden), David Shepherd (United Kingdom), Melanie Galloway (United States), Ervin Liszka (IAEA), Miroslav Svab (IAEA), Ken Pereira (NEA Consultant) and Alejandro Huerta (NEA).

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1. Introduction

Nuclear power reactors have become a major source of electricity supply in many countries since the start of operation of the first nuclear power reactor in 1957. Based on the experience of safe and reliable operation, many operators have sought and have received authorisation for long-term operation, whereby plant operation continues beyond the period assumed in the design of the plant. It is likely that the operators of many other nuclear power plants around the world will also seek authorisation of long-term operation as the plants approach the end of their assumed design lives and/or their licence periods.

Acceptance of a nuclear power plant for long-term operation must be based on evidence that the plant will comply with the "licensing basis" over the extended period of service. How this is achieved will depend on regulatory strategies in individual countries. In general, this requires an assessment of the current and projected condition of the plant and, in particular, of the systems that perform fundamental safety functions, to ensure that these systems will continue to perform their safety functions during the extended operating period. The strategy used could range from an approach that mainly addresses the impact of ageing to one that seeks changes in safety level based on the expectations for newer plants.

Programmes for long-term operation must be informed by operating experience. The Fukushima Daiichi event is an example of the importance of consideration of operating experience in strategies for continued operation.

In addition to consideration of plant safety for long-term operation, the environmental impacts of long-term operation may also need to be considered and assessed.

Approvals by regulatory bodies of long-term operation have been based on reviews of safety assessments completed by operators. Whilst different strategies have been applied as the bases for these approvals, experience gained now enables compilation of consensus guidance for approval of long-term operation of nuclear power plants.

This guidance is presented in the next section of this document as fundamental and key principles that should govern decisions on authorisation for long-term operation. These principles allow for differences in national regulatory strategies and expectations while ensuring that safe performance can be achieved in long-term operation.

A review is also presented of regulatory challenges and considerations that may arise in an assessment of a plant for long-term operation. The aim is to promote an understanding of the scope of strategies and assessments that may be necessary for assurance of compliance with the fundamental and key principles.

Important challenges will be the development of a regulatory framework and defining the level of regulatory assessment for long-term operation. Other aspects discussed include strategies for oversight of the plant and assessment of the acceptability of the plant in long-term operation.

Finally, the document presents a summary and recommendations on strategies for authorisation of long-term operation of nuclear power plants.

2. Principles related to the regulation of long-term operation

This section presents the basic premise for consideration of long-term operation called the fundamental principle. This principle should be the underpinning of any programme on extended operation. Beyond that, this section provides three high-level key principles that are intended to define and shape the development of a long-term operation programme.

2.1. Fundamental principle

"The safe operation of the nuclear power plant needs to be ensured during the period considered for long-term operation."

To achieve this, the regulatory body has the responsibility to evaluate, monitor and regulate the operator's activities to ensure that the requirement of safe operation is met. This includes a requirement for assurance of the fitness of the plant and the operator for safe and reliable operation over the projected period of continued operation. The operator has the primary responsibility for ensuring safe operation of the nuclear power plant for long-term operation as for normal operation. The operator should demonstrate an effective process for learning from operating experience and applying relevant knowledge to improve the plant and its operation. It is noted that the approaches applied by regulatory bodies may differ but each regulatory body needs to ensure that the safety objectives are achieved within the regulatory framework, and monitor the operator's performance against these objectives.

2.2. Key principles

Beyond the fundamental principle, three key principles should be considered. The consideration of these key principles is contingent upon the regulatory approach whether for licence renewal or periodic safety reviews[1] (see Appendix A) that the regulatory body[2] may choose as the framework for its long-term operation programme. The following key principles should be taken into account to support the above-mentioned overriding fundamental principle for long-term operation.

1. IAEA Safety Standards Series No. NS-G-2.10, *Periodic Safety Review of Nuclear Power Plants*, Vienna, 2003.
2. For regulatory body, see IAEA Safety Series SF-1, *Fundamental Safety Principles.*, Vienna, 2006.

Key principle 1: the regulatory body must be organised to regulate long-term operation

As a starting point, the regulatory body needs to understand that different and additional considerations apply to long-term operation. Once this is understood, the regulatory body (regulator) needs to be prepared to ensure that a regulatory framework exists that will respond effectively to long-term operation. Such a framework is needed to define safety requirements and regulations, as well as a system of licensing, assessment and inspection for long-term operation. For instance, high-level requirements include the need for the regulator to have adequate legal authority, technical and managerial competence, along with human and financial resources, to fulfil its responsibilities in establishing an adequate framework. Since long-term operation may not have been considered at the time the current/existing regulatory framework was developed, the applicability of the framework to long-term operation should be evaluated, and the framework should be amended as needed. Further, the regulator must be effectively independent of the operator and of any other body, so that it is free from any undue pressure from interested parties.

For the assessment and regulation of long-term operation, the required scope of competence in technical matters could be different than for nuclear power plants in the initial period of operation. The regulator must commit to, and ensure availability of, adequate technical resources for the review of documentation related to long-term operation, including sufficient technical knowledge and experience with the design under review.

Key principle 2: the goals and safety level required for long-term operation need to be clearly defined

The regulator, within its regulatory framework, needs to define what operators have to achieve (goals) through the process of endorsing long-term operation and thus what the required safety level should be during long-term operation. Clearly defining these goals is the essential starting point for articulating the regulatory requirements.

Important considerations for defining the acceptable level of safety during long-term operation include the following:

- the time period of long-term operation;
- the operational history and experience at the plant;
- the physical condition of the plant;
- the ageing of safety-related systems, structures and components; and
- the degree of certainty about the long-term performance of safety components.

In the licence renewal option, the starting premise is that the current licensing basis of the plant will continue to ensure safe operation during the period of long-term operation. This current licensing basis is dynamic in that it changes over time to account for plant modifications and operational changes. It will also be modified

as part of the licence renewal process to account for ageing management activities deemed necessary to ensure safe operation during the period of long-term operation. In addition, routine plant changes will occur as part of the normal licensing process to support day-to-day plant operations. The goal of the licence renewal option for continued safe plant operation during the long-term operation period is achieved through maintaining the current licensing basis of the plant and effectively managing ageing of systems, structures and components within the scope of licence renewal. Consideration of further safety enhancements is part of the broader regulatory framework.

The periodic safety review option incorporates an integrated safety review of the operation of the plant to confirm safety of ongoing operation and to identify safety improvements judged to be practicable to support the period of long-term operation. This option uses the process of endorsing long-term operation as an opportunity to increase safety margins beyond their current level or to reduce risk from plant operation as far as practicable. It also seeks to apply improvements in technology and methods to correspondingly improve plant safety as part of its assessment of long-term operation. In addition, execution of the periodic safety review process for long-term operation serves to demonstrate that the nuclear power plant will continue to maintain a high level of compliance with modern codes and standards to support extended operation.

Within the regulatory framework, "end of operation" would be determined at the end of the operating licence or when the operator is no longer able to demonstrate that the plant can be operated safely consistent with the safety basis for the plant and regulatory requirements, or when the operator opts to cease operations. In most of the cases requiring a decision with respect to "end of operation", the consideration of ageing and safety of non-replaceable components or systems is likely to be an important factor. The selection of the goals and the required safety level to be achieved (such as improving versus maintaining nuclear safety[3]) is an important decision for any regulator formulating its long-term operation programme.

Key principle 3: the operator's proposed programme for long-term operation needs to be evaluated

Irrespective of the option chosen by the regulator, the operator's proposal to extend the life of its plant needs to be evaluated by the regulator. This evaluation will be consistent with the defined goals and safety objectives to be achieved.

For those regulators utilising a licence renewal approach, the evaluation should focus on the operator's ageing management programmes to ensure continued safe operation in the extended licence period. Since the licence renewal approach focuses on assessment of ageing effects that can impede safe plant operation and programmes to manage this ageing, a thorough review of the applicant's technical case in these areas should be performed by knowledgeable experts. In this approach, the use of audits and inspections specific to long-term

3. NEA (2002), *Improving Versus Maintaining Nuclear Safety*, OECD, Paris.

operation activities is an important part of the regulatory evaluation to ensure the effectiveness of the applicant's programme.

In cases where regulators adopt a periodic safety review approach, the evaluation should confirm compliance of the plant with the established licensing basis and should assess the effects of ageing, modifications of the plant, changes in operating procedures and anticipated ageing on the safety of the plant. In addition, the review should include the assessment of potential improvements in plant safety level taking into consideration requirements in modern safety standards and internationally recognised good safety practices. The regulator's assessment should include the expected safety benefits of the improvements as well as the adequacy of the assessment method utilised.

3. Regulatory challenges and considerations

Consideration of a nuclear power plant for long-term operation will require strategies and decisions on the part of the regulator in diverse areas. There will be a number of challenges and considerations that arise from the assessment of the fitness of the plant for continued operation.

The following discussion is structured around four functions of the regulator. These functions, each of which is tied to a key principle introduced in the preceding section, are:

- developing a regulatory framework that is compatible with long-term operation;
- defining the scope of the regulatory assessment for long-term operation;
- assessing the safety basis of long-term operation; and
- ensuring oversight of the plant in long-term operation.

The first function derives from Key Principle 1, "The regulatory body must be organised to regulate long-term operation". The second function arises from Key Principle 2, "The goals and required safety level for long-term operation need to be clearly defined." The third and fourth functions arise from Key Principle 3, "The operator's proposed programme for long-term operation needs to be evaluated".

3.1. Developing a regulatory framework compatible with long-term operation

A regulatory framework that is compatible with long-term operation needs to be in place. The regulator should determine:

- the applicability of the existing regulatory framework during long-term operation; and
- the need for new regulatory requirements for long-term operation.

Regulatory framework

Requirements for changes in the regulatory framework will depend on the regulatory approach in specific countries as outlined in Appendix A.

Existing regulatory frameworks include provisions that are already applicable for long-term operation. However, assurance of safety during long-term operation

will require a comprehensive safety review by the regulator, and enhanced consideration of the impact and management of materials ageing on the safety functionality of critical systems, structures and components.[1] The regulator's evaluation of the operator's safety basis for long-term operation should be informed by operating experience and the outcome of any needed confirmatory research work. The regulatory framework should also include inspections and audits, as needed, to verify and validate the sufficiency of actions proposed by the operator to support long-term operation.

The operator should be required to provide a comprehensive safety review in a format and time frame agreed in advance with the regulator. The review should identify how the operator proposes to address technical issues that arise when considering long-term operation of the plant, including implementation of any plant modifications, procedural changes or new plant programmes aimed at improving or underpinning the overall plant safety.

In many countries, safety capability relative to modern standards is reviewed, and appropriate enhancements are identified through a periodic safety review system or a similar process. These provisions require the operator to assess the practicability of upgrading the design of its nuclear power plant to approach the safety level of newer plants.

Countries that use the licence renewal approach to long-term operation include licence renewal as part of a broader regulatory system. This broader system is a robust and comprehensive framework that allows safety considerations on a continuous basis. This broad framework includes elements such as ongoing technical evaluation and oversight, an onsite resident inspector programme, generic issue identification, a robust operating experience programme, and an ability to impose requirements (through new regulations and orders) that improve plant safety. These elements apply to all plants irrespective of whether the plant has applied for licence renewal. Licence renewal then is not used to effect change beyond that needed for ageing management; implementation of the broader system achieves that purpose. Beyond this regulatory system, the plant operator identifies and initiates, generally with regulatory approval, plant-specific hardware or operational modifications that improve plant safety. These activities are typically performed independent of the licence renewal process and are implemented through the current regulatory framework.

The regulator should also determine whether new requirements are needed to supplement the framework for long-term operation. An assessment of the adequacy of the existing framework for long-term operation requires a thoughtful review, considering the fundamental and key principles presented previously in this document. This review should take into account the particular national regulatory objectives and approaches. However, once the framework is established, it needs to be sufficiently flexible to accommodate changes necessary as a result of operating experience.

1. IAEA Safety Standards Series No. NS-G-2.12, *Ageing Management for Nuclear Power Plants*, Vienna, 2009.

The licensing framework needs to be supplemented by ageing management reviews and programmes specific to the long-term operation of the plant. For the licence renewal approach, these programmes focus on passive components because active components are effectively regulated as part of the regulatory framework for all operating reactors, regardless of the age of the plant.

Where the approach involves a periodic safety review, the regulatory framework may be adequate for approval of additional operating periods. It may be supplemented with provisions that mandate more frequent reviews and inspections as the plant approaches the end of its period of operation.

Openness and transparency

Public interest in long-term operation projects and decisions is high, so it is desirable that the regulatory framework include guidance with respect to availability of information to the public for both environmental assessments and long-term operation reviews. The operator should be encouraged to provide information about ongoing long-term operation reviews through readily accessible means. Regulators should make available to the public information, such as review plans, and provide access to regulatory reviews.

Public interest may encompass a number of areas, for example, issues related to the safety impact arising from ageing or differences in safety and security levels between existing reactors and new reactors. In many cases, demonstrating the acceptability of aged and potentially-degraded plants requires detailed technical consideration and state-of-the-art knowledge. Often this is not easily understood by the general public, and sometimes depends on proprietary information that cannot be released. This is an important challenge that is particularly prevalent in the case of long-term operation.

This challenge implies enabling the public to have access to relevant information on the plant-specific circumstances and to understand the decision-making process used by the regulator. Access to information should be facilitated not only by the regulator, but also by the plant operator. The information should cover safety issues of interest to the public, which could include the safety of workers at the plant if such a requirement is part of the country's regulatory framework. Avoiding technical jargon is a key aspect in achieving effective communication with the general public. As for public participation, it should be noted that the involvement level of the public may vary depending on the plant licensing phase (e.g. plant siting and initial licensing as compared with long-term operation) and the country's regulatory framework.

In some regulatory frameworks, the public has the right to participate in regulatory reviews through legal processes that entail hearings on certain aspects of the matter under review. In such situations, members of the public who seek to participate must identify specific matters of concern and must demonstrate that they would be directly affected if the operator's request were approved by the regulator.

The political environment in a given country will provide the framework within which the regulator is making decisions. Notwithstanding this

consideration, the regulator must be independent to make safety judgements within the regulatory framework, including decisions on continued operation of nuclear power plants. In any case, the operator must assure safe operation of the plant prior to authorisation of continued or long-term operation.

3.2. Defining the scope of the regulatory assessment for long-term operation

A key principle for regulation of long-term operation is the clear definition of the goals and of the required safety level for long-term operation. For example, some countries may aim at maintaining the existing safety level, while others choose to improve it through the long-term operation process. This in turn has implications on the scope of the regulatory assessment that is required before long-term operation can be authorised. In many areas, this assessment effort will need to be sustained beyond the initial authorisation for assurance of safety over the period of long-term operation.

The long-term operation safety assessment can include the following topics, depending on the country's regulatory framework:

- ageing management for long-term operation;
- environmental assessments;
- operating experience;
- safety improvements;
- security improvements; and
- emerging issues.

Ageing management for long-term operation

Ageing management addresses physical ageing that could result in degradation of systems, structures and components such that safety functionality could be impaired. Physical ageing includes a variety of degradation modes, including cracking, loss of material (e.g. corrosion, wear, etc.) and changes in material properties. Physical ageing is usually governed by the levels of stress and environmental factors such as water quality, temperature, humidity and radiation. Ageing management helps to ensure that systems, structures and components that are important to safety are capable of performing their required safety functions. This is a broad activity that involves maintenance, surveillance, equipment qualification, in-service inspection, water chemistry control, and other plant programmes. It provides a methodical process to detect, assess and correct, as necessary, the effects of ageing. Thus, an effective ageing management programme is a key element of safe and reliable operation of nuclear power plants during the originally planned operation time frames, as well as for periods of long-term operation.

A systematic process should be in place to determine which systems, structures and components should be subject to ageing management programmes. Time-limited ageing analysis may be required for major structural and safety

components to assess the effects of ageing, fatigue and relaxation (creep), as well as degradation due to environmental conditions. Safety analyses which use time-limited assumptions must be updated to include additional time periods for long-term operation and to determine whether any additional ageing management is required.

To demonstrate safe long-term operation, the operator needs to develop a comprehensive ageing management programme. Ideally, the operator will have ageing data over the entire operating life that contributes to the demonstration that ageing has not reduced the effectiveness of plant systems, structures, and components below the design basis requirements. A comprehensive ageing management programme includes co-ordinating, integrating and modifying existing programmes and activities that relate to managing the ageing of systems, structures and components and developing new programmes that may be needed for long-term operation. These programmes and activities include inspection, monitoring and assessment, to detect and characterise degradation, and maintenance to provide timely mitigation and correction of degradation.

The operator's ageing management programmes should identify parameters to be monitored or inspected and preventive and remedial actions that may be necessary. The programme should be capable of early detection of ageing effects to reduce risks of loss of functionality of impacted systems, structures and components. Monitoring and trending will provide better predictability of the extent of degradation and make possible timely corrective or remedial actions. It is also of importance to utilise operating experience feedback to support the conclusions that the effects of ageing will be managed adequately so that the intended functions of a system, structure or component will be maintained throughout the planned long-term operation period.

The implementation of an effective ageing management programme throughout the service life of the systems, structures and components requires the operator to apply a systematic approach that provides a framework for co-ordinating all activities and programmes that are needed in this process. It is essential that the operator obtain a comprehensive understanding of the plant's ageing behaviour which is the foundation for a well-functioning ageing management programme. This foundation consists of systematic data on numerous issues such as material and fabrication data, operational conditions and stressors, possible ageing mechanisms, as well as the location and consequences of ageing and failures.

Although plants may have internal programmes that assure safety in one aspect or another, one implication of long-term operation is to put these programmes into an environment of heightened regulatory significance and oversight, commensurate with the possibilities and significance of the degradation. The development of new or revised programmes that address long-term operation may therefore be needed.

The regulator should ensure that the operator reviews data and information collected from ageing management programmes to confirm that safety analysis assumptions, credited parameters and predictions remain valid, and that limiting criteria and required design margins continue to be met as the plant ages. The

operator should be able to predict the cumulative effect of ageing on systems, structures and components over the period considered for long-term operation in order to decide what actions or measures need to be taken.

Ageing management for long-term operation should take into account credit that may be given for existing programmes (such as in-service inspection and maintenance programmes) and consideration of ageing of non-replaceable components and structures.

The operator should consider not only the physical ageing of systems, structures and components but also technological ageing (obsolescence) that may arise in plant systems, structures and components. The rapid changes seen in technology over the past few decades mean that some systems, structures and components can become obsolete. Therefore, the operator should manage the situation by seeking to ensure long-term availability of spare parts or by being prepared to replace obsolete equipment. In the regulatory framework of some countries, the regulator sets performance criteria for equipment, and the operator would be required to address obsolescence when the performance criteria cannot be met.

Environmental assessment

The environmental impact of the long-term operation of a nuclear power plant may need to be assessed if such a requirement is part of the country's regulatory framework. Some countries do not consider environmental issues when evaluating long-term operation. For those that do, there are a variety of different approaches taken to assess environmental issues in the context of long-term operation. The types of issues that may be considered include all or some of the following: uranium fuel cycle impacts, management of waste, surface water quality, aquatic ecology, groundwater use and quality, terrestrial resources, threatened or endangered species, air quality, land use, human health, socioeconomics, postulated accidents, decommissioning and environmental justice. Environmental issues may also involve public participation, depending on a country's regulatory framework.

Operating experience

Both the regulator and the operator should consider operating experience from a variety of sources, both domestic and international, on a continuous basis. These sources include:

- plant-specific experience;
- experience from similar plant designs (i.e. the same class of plants);
- experience from similar materials, operating conditions, and systems, structures and components; and
- relevant experience, regardless of plant type, that contributes to the judgements on acceptability for long-term operation (e.g. the accident at Fukushima Daiichi).

Adverse operating experience which identifies ageing-related degradation can be used to identify new ageing phenomena that require ageing management during long-term operation, either from the perspective of new ageing mechanisms or new locations of known mechanisms.

Specific consideration of the effectiveness of ageing management programmes implemented by the operator, including past corrective actions that result in programme enhancements or additional programmes or activities, can provide objective evidence to ensure that the effects of ageing are adequately managed and will continue to be managed during the period of long-term operation. Regulatory review of adverse operating experience from all sources is critical in providing robust regulatory oversight, assuring that appropriate short-term operator actions are taken and long-term ageing management adjustments are planned for implementation.

Similarly, positive operating experience that identifies no ageing-related degradation has an important role in assuring safe long-term operation. Positive operating experience, such as that derived from first-of-a-kind or one-time examinations that have been implemented to support long-term operation, or similar practices, broadens the knowledge base of what is working properly in the plant and allows for re-focusing of resources to areas that may be more problematic.

The operator should evaluate operating experience to derive lessons learnt and to identify any precursors of conditions that are adverse to safety. The evaluation should, where appropriate, result in clear recommendations for appropriate and timely corrective actions so that any necessary corrective action can be taken before serious conditions arise.

Safety improvements

When the objective is to assess the safety level against modern standards, the regulator may include, in the regulatory assessment, safety improvements or broader modifications to the safety approach. Improvements that may be needed can be identified based on an assessment of:

- evolution of regulations, safety objectives and practices (nationally and internationally); and
- lessons learnt from other plants or equipment involving risk.

The comparison with more recent nuclear power plants (nationally and internationally) can lead the regulator to take into account safety improvements that were not considered in the original licensing process (including changes that arise from events such as the Fukushima Daiichi accident). Based on the objectives defined by the regulator for the safety improvement, the operator should develop a methodology which enables identification of areas for improvement. Examples of such changes that would enhance safety are:

- modification of the layout of the plant (such as improvement in the segregation of electrical and mechanical equipment);

- improvements that enable compliance of all safety-related systems with the single failure criterion;
- enhanced resistance to external hazards (such as earthquakes, high winds, tsunami, floods and loss of offsite power) and internal events (such as fires, pipe breaks, and station black-out);
- improvements in redundancy, diversity and integrity of systems (such as alternate power sources), plant control facilities (such as main and emergency control rooms) and critical areas in the plant (such as spent fuel pools);
- improvements with respect to capacity to mitigate the consequences of severe accidents (including the establishment of severe accident management guidelines);
- implications from multi-units events; and
- considerations related to enhancing emergency preparedness and response.

There is a general recognition that newer safety requirements should be accommodated to the extent that is reasonably practicable, taking account of the potential safety gains and costs involved. On the basis of the identified improvements, an implementation plan should be agreed between the regulator and operator to be monitored as part of the ongoing oversight process.

Countries that use the licence renewal process for long-term operation incorporate a regulatory system that provides a continual consideration of the need for safety enhancements as a part of the ongoing regulatory activities outside of the licence renewal process. Considerations include requirements for plant upgrades during the life of the plant (including the period of long-term operation). As new technical information indicating a possible safety concern is identified, the regulator reviews the potential safety concern and may conclude that existing programmes or regulations need to be revised or that new programmes or regulations are needed to assure an acceptable level of safety.

Within this regulatory system, operating experience is evaluated to determine needed changes to ensure adequate protection (i.e. safety level), including redefining adequate protection at an enhanced level as necessary. Such changes can be achieved through rule changes, orders to operators, or written communications to all operators. In addition, during the life of the plant, an operator may request approval of licence amendments from the regulator. The amendments often involve changes to make the plant safer or more reliable. In addition, operators regularly update their licensing basis to apply newer versions of codes and standards which have been endorsed by the regulator. By regulation, the operator is required to update the plant's licensing basis on a biennial basis to ensure that the final safety analysis report contains the latest information.

Accidents, such as that at Fukushima Daiichi, provide insights into required protection at nuclear power plants. When such significant nuclear events occur, regulators are expected to evaluate and potentially define new safety levels that operators need to achieve to continue to operate safely. Regulators may

incorporate safety improvements from such operating experience through regulatory changes that apply to all operating plants regardless of their stage in operating life. If considered appropriate, regulators may incorporate these new safety improvements as part of the long-term operation process.

Security improvements

Older nuclear power plants may not have been designed and constructed to the same physical security standards that apply at new plants. The long-term operation review should examine the extent to which provisions for physical security can be augmented if such a requirement is part of the country's regulatory framework.

This review should serve to confirm that, in long-term operation of the plant, there would not be any impediments to implementation of security measures that may be required to respond to anticipated physical threats and risks.

As with safety improvements, some countries continually monitor the adequacy of physical plant security and require improvements, as necessary, to ensure adequacy. In such cases, there is no need for a specific re-consideration of physical plant security to support long-term operation.

Emerging issues

The start of the period of long-term operation could occur a number of years after the submission of the operator's application for authorisation of long-term operation. Consequently, the regulator should ensure that the operator has established a process for responding to any issues that might emerge during this intervening period.

This process will identify:

- the approach for consideration of new operating experience and research results or revisions of codes, standards and practices; and
- a methodology for assessing the safety significance of differences with revised codes, standards and practices.

The safety of long-term operation should be kept under review by both the regulator and the operator throughout this period and modifications to planned ageing management activities should implemented as necessary to ensure safe operation during the period of long-term operation.

3.3. Assessing the safety basis of long-term operation

For each of the aspects discussed in the previous section, the regulator should determine whether the operator's safety basis is acceptable.

As detailed in Appendix A, there are two approaches to regulation of long-term operation. Both approaches require the effects of plant ageing to be addressed. In the case of the periodic safety review strategy, the approach to ageing is supplemented by safety improvements based on an associated review of modern

safety standards and approaches relative to those existing at the time of original design. It is important that the regulator be prepared to respond constructively and effectively to any proposals for long-term operation and provide clear and timely guidance on scope of regulatory requirements.

In general, the design of a nuclear power plant includes consideration of the degradation that could be caused by ageing mechanisms that were known at the time of design. Consequently, the designs incorporated suitable margins to account for degradation over the projected lifetime, based on the technical knowledge available. Over an extended period of service, there will likely be degradation beyond the provisions allowed in the design of the plant. In some situations, it will be feasible to address ageing issues through refurbishment or replacement of degraded systems, structures or components. However, it must be recognised that such remediation work may not be feasible in some systems or areas of the plant.

Period to be considered for long-term operation

In the case of the licence renewal approach, the maximum permissible period for the renewed licence is generally specified by regulation, and the operator may request a specified additional operating period up to that maximum.

For the periodic safety review approach, several options are available to the regulator. One option is based on consideration of the long-term operation period requested by the operator. In this case, the time period considered for the approval is based on the operator's intent at the time of long-term operation application. The operator may nevertheless not be entirely free to choose the length of this period due to limitations other than safety arising from economic considerations.

An alternative would be to base the long-term operation period on an estimation of the remaining lifetime of the plant. Assessing the remaining plant lifetime independently from the operator's intent may, however, prove difficult.

Assessment approach

For the licence renewal approach, the general methodology to assess the licence renewal application entails a deterministic review of the operator's application considering the scope of the application, the ageing management review, and the safety analysis using time-limiting assumptions and proposed ageing management programmes. The purpose of this assessment is to ensure that the proposed ageing management programmes will provide adequate management of ageing throughout the long-term operation period, such that safety functions are maintained in the plant. This assessment includes the use of audits and inspections to verify acceptability of the proposed ageing management programmes, and validation of safety analysis using time-limiting assumptions.

For the periodic safety review approach, in addition to ageing management, there is a goal of improving plant safety informed by requirements in modern standards. Cost-benefit analysis and engineering judgement informed by operating experience and other factors may be used to prioritise improvements.

If the operator proposes to apply an accepted cost-benefit analysis approach, the analysis should be conducted in a manner that is consistent with modern codes, standards and practices that are acceptable to the regulator. The approach to address any improvement in plant condition must be demonstrated and the remaining risk demonstrated to be as low as reasonably practicable. In making these judgements, a reasonably reliable projection of planned operating life is required to enable appropriate judgements to be made, i.e. for a modification which may not be justified on the basis of "as low as reasonably practicable" for five years of planned operation may well be justified for a proposed operating life of ten years or longer. The regulator should therefore clarify its view on the plant operation time that should be considered to assess the long-term operation safety basis.

Research and development

Fundamentally, it is the obligation of the operator to demonstrate the safety basis for long-term operation, in particular from the perspective of the ageing of materials. The operator may need to obtain relevant information from research and development investigations to supplement information from operating experience and trend indicators as well as inspection, monitoring, and maintenance history data. It is essential that the operator demonstrate a full understanding of these factors and that the operator make a diligent effort to detect and manage possible new ageing phenomena well in advance of a transition to long-term operation. To support ageing management, there should be a commitment to research and development effort to enable sufficient understanding of the ageing phenomena to permit effective prediction and management of ageing issues.

In support of this long-term operation assessment, the regulator may need to undertake technical studies and research and development work to confirm the adequacy of the operator's technical basis for long-term operation. The scope of these confirmatory programmes should be compatible with the scope of the regulatory assessment for long-term operation. In particular, the following topics may be covered in this confirmatory research and development effort:

- knowledge of the mechanisms and rate of ageing;
- approaches for prevention (control) and identification (surveillance) of ageing; and
- methods for mitigation of the impacts of ageing.

In addition, when the goal is to improve safety, as in the periodic safety review approach, the following areas of interest can be added to the previous list focused on ageing:

- lowered probability of severe accidents;
- mitigation of severe accidents; and
- minimised radiological consequences of accidents.

End of operation

An important consideration that will go into decision-making with respect to long-term operation is the projected "end of operation" of the plant. The decision regarding "end of operation" may be influenced by a number of factors including ageing and residual life of critical non-replaceable components of the plant, fitness for safe operation (as emerging from the regulatory assessment and oversight) and economic viability (operator's consideration).

In both approaches for regulating long-term operation, clearly, the underlying regulatory goal of maintenance or improvement of safety, as identified by the specific approach, should be the paramount consideration in decision-making with respect to "end of operation". In most of the cases requiring a decision with respect to "end of operation", the consideration of ageing and safety of non-replaceable components or systems is likely to be an important factor.

Other than the end of the operating licence, "end of operation" would be determined when the operator is no longer able to demonstrate that the plant can be operated safely consistent with regulatory requirements. For the licence renewal approach, the "end of operation" is governed by the end of the plant's operating licence, although this can be extended through licence renewal. The end of the operating licence defines the "end of operation" unless an application is made to extend the licence and a decision is taken by the regulator. Otherwise, there are no regulatory requirements that identify a specific "end of operation" lifetime.

In addition to component ageing, the periodic safety review approach requires safety improvement based on modern safety standards and operational experience feedback. Inability to adequately address any such safety issue could be one of the considerations that could lead to a decision with respect to "end of operation".

For the periodic safety review approach, cost-benefit analysis is an important tool for evaluating and informing decisions with respect to various alternatives put forth to address the issues identified in the long-term operation safety basis. The operator should submit the proposed cost-benefit analysis approach for acceptance, if required by the regulator, in order to demonstrate that the residual risk is as low as reasonably practicable.

In the countries that have decided to phase-out nuclear power, the "end of operation" of the nuclear power plant may be decided more on the basis of societal, political or legal considerations rather than technical, safety or economic factors. Presently existing examples of criteria for phase-out in some of the countries include a predetermined limit on amount of electricity generated from the plant and a fixed operation time limit. The phase-out processes are, however, not necessarily incompatible with the concept of long-term operation.

It is important that the considerations related to determining when it is time for "end of operation", as applicable to the prevailing regulatory framework and approach, be identified as unambiguously as possible, and agreed in advance by the regulator and operator, in order to enable a clear and effective strategy of entering the "safe enclosure" or decommissioning phase.

3.4. Ensuring oversight of the plant in long-term operation

Once long-term operation has been authorised, the regulator should ensure adequate implementation of long-term operation programmes through inspections or audits. This oversight should, in particular, evaluate the effectiveness of the implementation of ageing management programmes and of safety improvements when such improvements are required to support long-term operation.

The regulator may choose in some cases to strengthen its inspections and audits during long-term operation with regard to existing oversight and inspection programmes. In particular, the frequency of inspections and corresponding modification programmes may be increased for specific systems, structures and components particularly subject to ageing, such as the reactor vessel.

For continued safe plant operation in the period of long-term operation, the effectiveness of ageing management programmes must be evaluated and maintained by the operator to provide confidence that the continued functionality of safety-related systems, structures and components will be assured during plant operation. The regulator should have appropriate oversight activities to verify the adequacy of the operator's activities in this area.

Ensuring human capability

The regulator should require confirmation that the operator has qualified and experienced personnel available to operate and maintain the plant in the period of long-term operation, if such a requirement is a part of the country's regulatory framework. The regulator should monitor the operator's training capability and its availability of certified staff particularly as it relates to operation and maintenance during long-term operation, as it does for the initial operating period. In some regulatory regimes, the requirement for maintaining qualified staff must be met by the operator regardless of the operating phase of the plant.

4. Summary and recommendations

Nuclear power reactors have become a major source of electricity supply in many countries in the past half a century. Based on this experience, many operators have sought and have received authorisation for long-term operation, whereby plant operation continues beyond the period considered in the design of the plant.

Acceptance of a nuclear power plant for extended service should be based on assurance of the fitness of the plant and the operator for safe and reliable operation over the entire period considered for long-term operation. This assurance may be obtained by establishment of appropriate regulatory requirements, specification of goals and safety levels and regulatory assessment and oversight of the operator's programme for long-term operation. The operators and regulators should ensure that operating experience continues to be evaluated during long-term operation to ensure that any relevant lessons are effectively applied.

Other considerations for assurance of safe operation are effective management of ageing, possible need for safety improvements, application of lessons learnt from operating experience, evaluation of environmental impacts, adequate staff resources and performance, review of security at the plant, action in response to emerging issues, and openness and transparency in the transition to long-term operation. Even though most of these considerations are addressed under the regulatory framework that applies to the initial operating period, additional regulatory activities in these areas may be necessary for long-term operation.

Although there can be significant differences in regulatory approaches used by different countries for evaluating acceptability of long-term operation, there is general agreement on the purposes and goals of the regulatory reviews. An authorisation of long-term operation could involve a licence renewal or a periodic safety review or an approach that melds elements of both. This report presents guidance that is intended to foster improved alignment of strategies for regulatory authorisation and oversight of long-term operation of nuclear power plants and presents options for regulatory assessment and oversight of operators' programmes for long-term operation of nuclear power plants. The report suggests that regulators should establish appropriate regulatory frameworks and specify goals and safety levels required for long-term operation of the nuclear power plants.

Appendix A
Typical regulatory approaches for assurance of safety in long-term operation

Licence renewal and periodic safety review are two basic regulatory approaches that have been adopted for authorisation of long-term operation of nuclear power reactors. Some countries use aspects from one or both approaches in determining whether, and under what conditions, to allow long-term operation.

Licence renewal

In countries where the licence is granted for a given operating period, a formal licence renewal process is used as part of a broader regulatory system. This broader system is a robust and comprehensive framework that allows safety considerations on a continuous basis. It includes elements such as ongoing technical evaluation and oversight, an onsite resident inspector programme, generic issue identification, a robust operating experience programme, and an ability to impose requirements that plants improve safety through new regulations and orders. These elements apply to all plants irrespective of the licence renewal status of the plant.

The license renewal process itself has two tracks: one for the review of safety issues and another for review of environmental issues. A basic assumption of the license renewal process is that "the current licensing basis" is acceptable, as supplemented for long-term operation to account for ageing effects. Another basic assumption is that the current regulatory process is acceptable, as supplemented for specific challenges associated with long-term operation.

The operator must supply to the regulator a licence renewal application which is the principal document used to both request and justify long-term operation. The licence renewal application is used to demonstrate that adequate safety levels will be maintained for long-term operation and to provide an assessment of potential environmental impacts from long-term operation.

The licence renewal application includes technical information to demonstrate that the intended functions of systems, structures and components will remain within the design safety margins, and the current licensing basis of the plant will remain valid throughout the planned long-term operation period, supplemented as necessary with additional actions required for licence renewal. An applicant must identify and analyse the ageing-related issues for certain critical systems, structures and components at the facility during the period of the renewed licence and describe how these issues will be managed during long-term operation.

As part of the licence renewal application, the operator must also prepare an environmental report on the potential impact on the environment of continued plant operation. This environmental report includes a description of the action (e.g. continued operation of the plant through license renewal), the purpose of the action and a description of the environment affected.

The regulator performs a review of the licence renewal application, including inspections and audits as necessary. The regulator's decision to grant or deny a licence renewal is based on whether the applicant has demonstrated that the facility can be safely operated for an additional licence period with no significant adverse environmental impacts.

Periodic safety review

In countries that have chosen the periodic safety review approach, the operator is required to periodically perform such a review to assess the capacity of the nuclear power plant to continue operation in a safe manner. Based on an analysis of the operator's review results, the regulator can authorise the continued operation of the plant up to the end of the next periodic safety review cycle (usually ten years). The periodic safety review is required to (i) confirm the compliance of the plant with its licensing basis, and (ii) provide an assessment of the plant safety level with regard to modern safety standards and internationally recognised good practices. All reasonably practicable improvement measures have to be taken by the operator as a result of the review. Safety improvements can be related not only to plant design (plant modification) but also to operational issues (such as the management system and operating procedures). Thus the periodic safety review should not only confirm that the safety level is maintained, but should also usually result in a step-improvement of the safety level. This periodic safety review approach, which has been applied in various countries before entering long-term operation, is, or will be, applied for safety assessment of long-term operation.

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Défis de l'exploitation à long terme des centrales nucléaires

Les réacteurs nucléaires sont devenus une source majeure de production d'électricité dans de nombreux pays et, sur la base d'une exploitation sûre et fiable, de nombreux exploitants ont demandé et obtenu une autorisation d'exploitation à long terme au-delà de la durée prévue à la conception. L'acceptation de l'exploitation à long terme d'une centrale doit être basée sur la preuve que la sûreté sera maintenue pendant la période de prolongement de sa durée de vie. Il est nécessaire d'évaluer l'état actuel et prévu de la centrale et, en particulier, des systèmes qui assurent les fonctions fondamentales de sûreté, afin de garantir que ces systèmes vont continuer à réaliser ces fonctions pendant la période d'exploitation supplémentaire. Les programmes d'exploitation à long terme doivent utiliser et évaluer le retour d'expérience d'exploitation et prendre également en compte les impacts sur l'environnement.

Ce guide vise à aider les autorités de sûreté dans l'analyse et l'approbation des évaluations de sûreté soumises par les exploitants pour l'exploitation à long terme. Il expose les principes fondamentaux sur lesquels doivent être basées les décisions d'autorisation d'exploitation à long terme. Il décrit également les défis et les considérations qui peuvent survenir dans l'évaluation d'une centrale pour l'exploitation à long terme.

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