IAEA Safety Standards
for protecting people and the environment

Ageing Management for Research Reactors

Specific Safety Guide
No. SSG-10

IAEA
International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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

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AGEING MANAGEMENT FOR
RESEARCH REACTORS

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

IAEA SAFETY STANDARDS SERIES No. SSG-10

AGEING MANAGEMENT FOR RESEARCH REACTORS

SPECIFIC SAFETY GUIDE

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FOREWORD

The IAEA's Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA's assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA's safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA's safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and all Member States are urged to make use of them.

Regulating nuclear and radiation safety is a national responsibility, and many Member States have decided to adopt the IAEA's safety standards for use in their national regulations. For the contracting parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by designers, manufacturers and operators around the world to enhance nuclear and radiation safety in power generation, medicine, industry, agriculture, research and education.

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures[1] have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered ‘overarching’ requirements, are expressed

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[1] See also publications issued in the IAEA Nuclear Security Series.

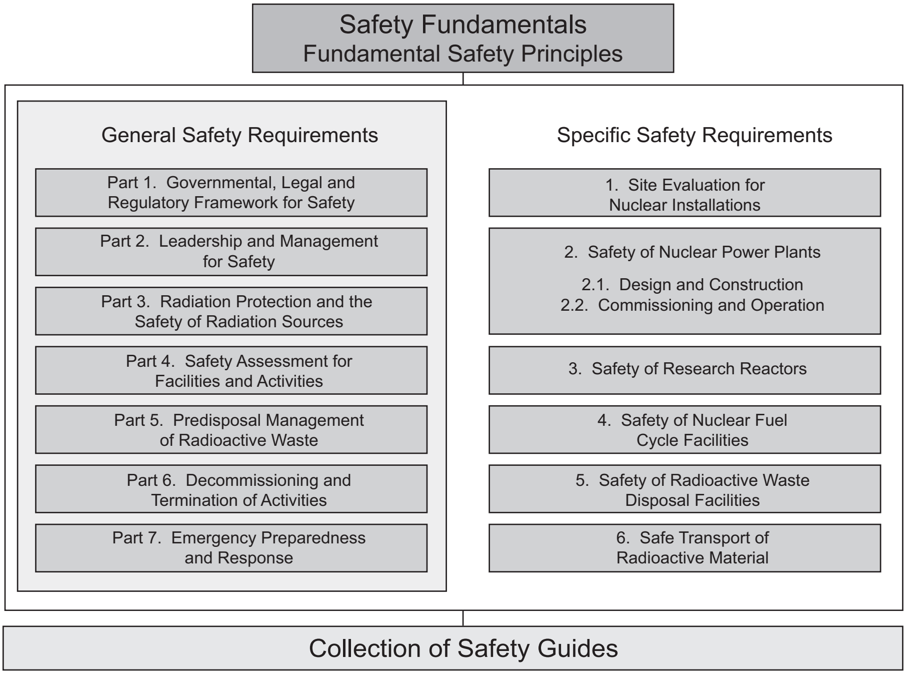

FIG. 1. The long term structure of the IAEA Safety Standards Series.

as ‘shall’ statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and four safety standards committees, for nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

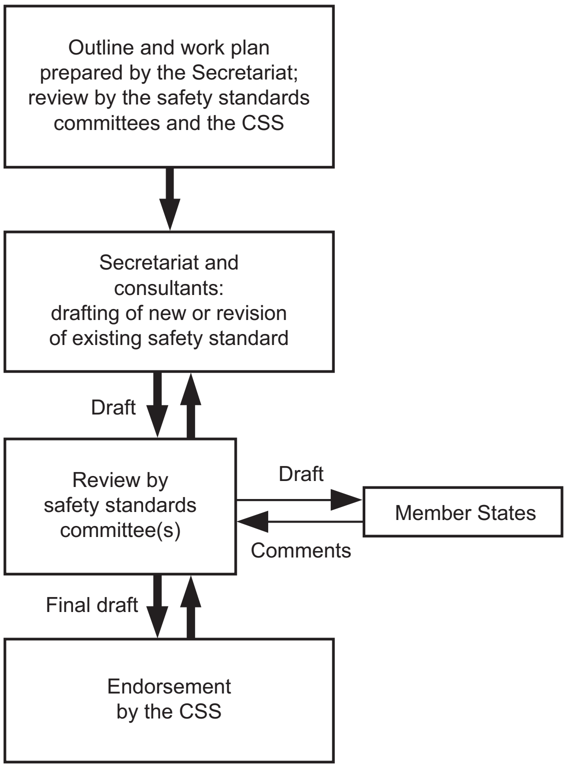

FIG. 2. The process for developing a new safety standard or revising an existing standard.

All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards. It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see http://www-ns.iaea.org/standards/safety-glossary.htm). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide was developed under the IAEA programme for safety standards for research reactors, which covers all the important areas of research reactor safety. It supplements and elaborates upon the safety requirements for ageing management of research reactors that are established in paras 6.68–6.70 and 7.109 of the IAEA Safety Requirements publication, Safety of Research Reactors [1].

1.2. The safety of a research reactor requires that provisions be made in its design to facilitate ageing management. Throughout the lifetime of a research reactor, including its decommissioning, ageing management of its structures, systems and components (SSCs) important to safety[1] is required, to ensure continued adequacy of the safety level, reliable operation of the reactor, and compliance with the operational limits and conditions.

1.3. Managing the safety aspects of research reactor ageing requires implementation of an effective programme for the monitoring, prediction, and timely detection and mitigation of degradation of SSCs important to safety, and for maintaining their integrity and functional capability throughout their service lives.

1.4. Ageing management is defined as engineering, operation, and maintenance strategy and actions to control within acceptable limits the ageing degradation of SSCs [2]. Ageing management includes activities such as repair, refurbishment and replacement of SSCs, which are similar to other activities carried out at a research reactor in maintenance and testing or when a modification project takes place. However, it is important to recognize that effective management of ageing

[1] Items important to safety: An item that is part of a safety group and/or whose malfunction or failure could lead to radiation exposure of the site personnel or members of the public. Items important to safety include:

(a) Those SSCs whose malfunction or failure could lead to undue radiation exposure to site personnel or members of the public;
(b) Those SSCs that prevent anticipated operational occurrences from leading to accident conditions;
(c) Those features that are provided to mitigate the consequences of malfunction or failure of SSCs [2].

requires the use of a methodology that will detect and evaluate ageing degradation as a consequence of the service conditions[2], and involves the application of countermeasures for prevention and mitigation of ageing degradation.

OBJECTIVE

1.5. The objective of this Safety Guide is to provide recommendations on managing ageing of SSCs important to safety at research reactors on the basis of international good practice. This Safety Guide is intended for use by operating organizations in establishing, implementing and improving ageing management programmes for research reactors. It may be used by regulatory bodies in verifying that ageing of research reactors is being effectively managed.

1.6. While the intention is not to recommend ways in which to make the operation of a research reactor more effective or more efficient, the recommendations provided in this Safety Guide on managing ageing of SSCs to ensure safety will undoubtedly contribute to the enhancement of their long term reliability and availability.

SCOPE

1.7. This Safety Guide covers all aspects relating to the establishment, implementation and continuous improvement of an ageing management programme. It not only focuses on managing the physical ageing of SSCs important to safety but also provides guidance on safety aspects of managing obsolescence (non-physical ageing).

1.8. In formulating the recommendations in this Safety Guide, consideration has been given to the recommendations in the IAEA Safety Guide, Ageing Management for Nuclear Power Plants [3]. Where appropriate, in consideration of differences in hazard potential and complexity of systems between nuclear power plants and research reactors, certain provisions of Ref. [3] have been adopted.

[2] Service conditions are actual physical states or influences during the service lives of SSCs, including operating conditions (normal and erroneous included), design basis event conditions, and conditions following a design basis event [2].

1.9. The recommendations provided in this Safety Guide are intended to be applicable to research reactors having limited hazard potential to the public and the environment. It deals with all types of heterogeneous, thermal spectrum, research reactors having a power rating of up to several tens of megawatts. Additional guidance may be necessary for research reactors of higher power, specialized reactors (e.g. fast spectrum reactors and homogeneous reactors) and reactors with specialized facilities (e.g. hot or cold neutron sources, or high pressure and high temperature test loops).

1.10. Research reactors having a power rating of up to several tens of kilowatts and critical assemblies may need a less comprehensive ageing management programme than that outlined here. While consideration should be given to all the recommendations made in this Safety Guide, some may not be applicable to these low power research reactors. For these reasons, the recommendations in this Safety Guide should be graded[3] for their applicability to the specific research reactor under consideration (see Ref. [1], paras 1.11–1.14).

1.11. A graded approach may be applied in determining the appropriate frequency of inspections, in selecting detection methods, as well as in establishing measures for prevention and mitigation of ageing effects. The graded approach may be based on the estimated service lives of the SSCs, their complexity and their ease of replacement. A graded approach may also be applicable to the resources necessary to implement the ageing management programme. While a dedicated organizational unit may be needed to implement the ageing management programme for higher power research reactors, the ageing management activities for research reactors having a low power may be performed by the maintenance personnel. A Safety Guide on the use of a graded approach in the application of the safety requirements for research reactors is in preparation.

1.12. Although managing succession for the personnel of research reactors and knowledge management are important issues in relation to safety at research reactors, they are outside the scope of this Safety Guide. Recommendations relating to the ageing of research reactor personnel are provided in Ref. [4].

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[3] The recommendations should be graded, for example, by considering — using sound engineering judgement — the operational importance of the item or activity, its importance to safety, and its maturity and complexity.

STRUCTURE

1.13. This Safety Guide consists of seven sections and two annexes. Section 2 covers the management system for ageing management. Section 3 presents the basic concepts and explanations of the terms used in this Safety Guide, and an overview of ageing effects and their relation to safety at research reactors. Section 4 provides recommendations on proactive considerations on ageing during the various stages of the lifetime of a research reactor. Section 5 sets out the elements of a systematic ageing management programme, and provides advice on implementation of the associated actions or activities. Section 6 presents recommendations on management of SSCs during their obsolescence. Section 7 discusses different technical aspects relating to ageing management, such as maintenance, periodic testing and inspection, periodic safety review, equipment qualification, design basis reconstitution, configuration management and continued safe operation. Annex I presents ageing mechanisms and their effects for different categories of service conditions. Annex II provides an example of screening of SSCs for ageing management for open pool, light water and heavy water moderator research reactors.

2. MANAGEMENT SYSTEM FOR AGEING MANAGEMENT[4]

GENERAL

2.1. A documented management system that integrates the safety, health, environmental, security, quality and economic objectives of the operating organization of a research reactor is required to be in place [5]. The documentation of the management system should describe the system that controls the planning and implementation of all activities at the research reactor throughout its lifetime, including ageing management activities. Approval of the management system (or parts thereof) by the regulatory body may be required. The management system should cover four functional categories: management responsibility; resource

[4] The recommendations provided in this section can also be used, as applicable, to establish a management system for managing the obsolescence of SSCs.

management; process implementation; and measurement, assessment and improvement. In general:

(1) Management responsibility includes the support and commitment of management necessary to achieve the objectives of the operating organization.
(2) Resource management includes the measures necessary to ensure that the resources essential to the implementation of strategy and the achievement of the objectives of the operating organization are identified and made available.
(3) Process implementation includes the activities and tasks necessary to achieve the goals of the organization.
(4) Measurement and assessment provide an indication of the effectiveness of management processes and work performance compared with objectives or benchmarks; it is through measurement and assessment that opportunities for improvement are identified.

The requirements for the management system are established in Ref. [1], paras 4.5–4.13, and in Ref. [5], and further recommendations are provided in Ref. [6].

2.2. As part of the integrated management system, a system for ageing management should be established and put into effect by the operating organization. For a new research reactor project, the management system for ageing management should be established early on in the design stage. The system should cover all items, services and processes important to safety and should include a means of establishing control over ageing management activities, thereby providing confidence that they are performed according to the established requirements. In determining how the requirements of the management system for ageing management are to be applied, a graded approach based on the relative importance to safety of each item or process should be used.

2.3. The objective of the management system as applied to ageing management is to ensure that the facility meets the requirements for safety as derived from:

— The requirements of the regulatory body;
— Design requirements and assumptions;
— The safety analysis report;
— Operational limits and conditions;
— The administrative requirements established by the management of the research reactor.

2.4. The management system should support the development, implementation and enhancement of a strong safety culture in all aspects of the ageing management programme.

MANAGEMENT RESPONSIBILITY

2.5. The management system for ageing management should provide a framework for managing, performing and assessing the activities necessary to prevent, detect, monitor, assess and mitigate ageing effects. The documentation of the management system for ageing management should include descriptions of the organizational structure, functional responsibilities, levels of authority and interactions of those managing, performing and assessing the adequacy of the ageing management activities. It should also cover other management measures, including planning, scheduling, resource allocation and human factors.

2.6. The management system for ageing management should be outlined in a description of the ageing management programme and should be documented in operating procedures. The operating procedures should address all applicable requirements specified in the integrated management system established by the operating organization.

2.7. The ageing management activities should be planned and performed, and their results recorded, in accordance with approved procedures and instructions, which should be included in the documentation of the management system for ageing management.

2.8. Successful implementation of the ageing management programme requires:

(a) Planning and prioritization of work;
(b) Addressing all relevant regulatory requirements, codes and standards;
(c) Addressing the requirements derived from the operational limits and conditions, and from the safety analysis report;
(d) Ensuring the availability of spare parts, special tools and equipment;
(e) Following up inspection and test results in a timely fashion;
(f) Ensuring the provision of qualified personnel with suitable skills;
(g) Establishing appropriate operating procedures following relevant standards, including procedures for assessing and correcting non-conforming items;
(h) Identifying, disseminating and using information on good practices from designers, manufacturers and other operating organizations;
(i) Performing and adequately documenting the required inspections and tests;

(j) Performing root cause analyses of significant degradation of SSCs and incorporating lessons learned from experience.

RESOURCE MANAGEMENT

2.9. The operating organization should provide adequate resources (both human resources and financial resources) to execute the ageing management programme. The management of the operating organization, in particular the reactor manager, should participate in the ageing management activities by:

(a) Determining the required staff competences and providing training where appropriate;
(b) Preparing and issuing specifications and procedures for the ageing management programme;
(c) Having frequent personal contact with staff, including observation of work in progress;
(d) Supervising external personnel (including suppliers) who perform ageing management activities, and ensuring that these personnel are adequately trained and qualified;
(e) Supporting and participating in ageing evaluations.

2.10. The management system for ageing management should include provisions to ensure that the ageing management activities are planned, performed and controlled in a manner that ensures effective communication and clear assignment of responsibility.

PROCESS IMPLEMENTATION

2.11. The operating organization should nominate the person who has the responsibility and accountability for implementing the ageing management programme. This person is usually the reactor manager or a staff member acting on behalf of the reactor manager.

2.12. Significant changes or failures of any SSCs important to safety should be recorded, and the data should be analysed and trends discerned, to identify the causes of these changes or failures. Where the causes of failures have been determined, the information should be used as input to improvement of the ageing management programme.

2.13. The scope and frequency of tests and in-service inspections should be specified and they should be consistent with the operational limits and conditions and regulatory requirements. The recording and presentation of test results should permit easy comparison with the results of previous inspections and tests, to enable detection of any changes since previous tests and any deviations from reference values (baseline data).

2.14. Valid monitoring and measurements should be performed to provide evidence of conformity to requirements and satisfactory performance in service.

2.15. Equipment used for monitoring, data collection, and inspections and tests should be calibrated. The equipment calibration should be documented to demonstrate that this calibration is up to date. Inspection and tests should be performed by qualified personnel and be in accordance with approved procedures.

2.16. The management system for ageing management should include measures to control records essential to the performance of ageing management activities and to verification of the results achieved. The records process should provide for the identification, approval, review, filing, retrieval and disposal of records.

MEASUREMENT, ASSESSMENT AND IMPROVEMENT

2.17. Measures should be established to ensure that ageing management activities are accomplished as specified in the appropriate procedures. Such measures should include:

- — Reviews of procedures;
- — Verification by inspection, witnessing and surveillance;
- — Checks of non-conformances and implementation of corrective actions;
- — Follow-up of the adequacy and timeliness of corrective actions.

2.18. An independent assessment of the ageing management programme should be conducted. This task may be performed by the safety committee (see paras 4.15, 7.25 and 7.26 of Ref. [1]) or by another competent body.

2.19. Audits should be performed to determine the adequacy and effectiveness of all aspects of the implementation of the ageing management programme and its adherence to the requirements of the management system for ageing management. The operating organization should evaluate the results of independent assessment, including audits, and should take any necessary actions to make improvements.

3. AGEING AND SAFETY OF RESEARCH REACTORS

BASIC CONCEPTS

3.1. Ageing is defined as a general process in which the characteristics of SSCs gradually change with time or use [2]. Research reactors experience two kinds of time dependent changes:

(1) Degradation of SSCs (physical ageing), i.e. gradual deterioration in their physical characteristics;
(2) Obsolescence of SSCs (non-physical ageing), i.e. their becoming out of date in comparison with current knowledge, standards and technology.

3.2. Physical ageing eventually leads to degradation of materials subjected to normal service conditions. These include the normal operational conditions under which SSCs are required to operate and the anticipated operational occurrences under which SSCs are required to continue functioning properly. The ageing effects of accident conditions (design basis accidents and beyond design basis accidents) need to be evaluated on a case-by-case basis.

3.3. Degradation may result in a reduction or loss of the ability of SSCs to function within their acceptance criteria. The safety and utilization of the facility will be affected unless preventive measures are in place and timely appropriate corrective actions are taken.

3.4. Physical ageing reduces the safety margins provided in the design of SSCs. If reductions in these margins are not detected, research reactor safety could be compromised unless mitigatory actions are taken before loss of functional capability occurs.

3.5. During the lifetime of a research reactor:

(a) Advances will occur in technology, resulting in the introduction of new components or techniques. This may lead to difficulties in obtaining spare

parts. Introduction of new components may also lead to changes in failure modes (e.g. modern instrumentation contains microprocessors that have different failure modes from those of their older components).
(b) Changes will occur in standards and regulations, which may necessitate changes in hardware or software and may interfere with the operation of the reactor.

3.6. Operating personnel need to have current knowledge of the operational systems and their associated documentation; therefore, ongoing training is necessary for personnel at all levels. Section 4 of Ref. [4] provides recommendations on training programmes and qualifications for research reactor personnel.

3.7. Evaluation of the cumulative effects of both physical ageing and obsolescence on the safety at a research reactor is an ongoing process, and is assessed in periodic safety reviews or equivalent systematic safety reassessment programmes (e.g. peer reviews); see paras 7.4–7.7 of this Safety Guide.

3.8. In practice, the ageing management programme at a research reactor is accomplished by coordinating existing programmes, including maintenance, periodic testing and inspection programmes (see Ref. [7]), as well as applying good operational practices, research and development (of material behaviour, radiation effects, chemistry, etc.), and incorporating lessons learned from operating experience.

3.9. An effective ageing management programme will contribute to ensuring the availability of the basic safety functions by:

(a) Shutting down the reactor and maintaining it in a safe shut down state for all operational states or design basis accidents, including, for example, ensuring the availability of the emergency control room;
(b) Providing for adequate removal of heat after shutdown, in particular from the core, including for design basis accidents;
(c) Confining radioactive material in order to prevent or mitigate its unplanned release to the environment.

3.10. In an effective ageing management programme, it is recognized that safety documents (such as the safety analysis report, operational limits and conditions, operating procedures and the emergency plan) may also become outdated or even obsolete. Periodic updating of such documents is needed to maintain their conformity with the actual status of the reactor facility and to take into account feedback from operating experience. Updating will also be necessary when modification[5] of existing (or installation of new) experimental devices[6] is being introduced.

AGEING AND DEFENCE IN DEPTH

3.11. Fundamental Safety Principles [8] establishes principles for ensuring protection and safety of workers, the public and the environment. The activities covered by this Safety Guide are directly related to the defence in depth concept[7], which is associated with Principle 8 on prevention of accidents: “All practical efforts must be made to prevent and mitigate nuclear or radiation accidents.”

3.12. Physical ageing of SSCs may increase the probability of common cause failures (i.e. the simultaneous degradation of physical barriers and redundant components), which could result in the impairment of one or more levels of protection provided by the defence in depth concept. Therefore, in the screening process of SSCs for ageing management, no account should be taken of component redundancy or diversity, on the basis that ageing degradation should be regarded as a common cause failure mechanism and that diversity may not provide protection against all potential failures caused by common ageing mechanisms.

3.13. Defence in depth is achieved by multiple physical or functional barriers. The ageing process may affect defence in depth through the failure of one or more of these barriers (e.g. because of corrosion of the cladding material of fuel elements, corrosion of the reactor pool liner or corrosion of piping for primary cooling). An

[5] Modification is the deliberate changing of, or addition to, an existing reactor configuration, with possible implications for safety, intended to permit continuation of operation of a reactor. Modifications may affect safety systems, safety related items or systems, procedures, documentation or operating conditions.

[6] An experimental device is a device installed in or around a reactor to utilize the neutron flux and ionizing radiation from the reactor for research, development, isotope production or other purposes.

[7] Defence in depth is a hierarchical deployment of different levels of diverse equipment and procedures to prevent the escalation of anticipated operational occurrences and to maintain the effectiveness of physical barriers placed between a radiation source or radioactive material and workers, members of the public or the environment, in operational states and, for some barriers, under accident conditions [2].

effective ageing management programme should provide for maintaining defence in depth through:

(a) Incorporation of good design and engineering features providing safety margins, mainly by use of design, technology and materials of high quality and reliability;
(b) Compliance with the requirements of the operational limits and conditions;
(c) Execution of relevant tasks and activities, in accordance with approved operating procedures and by following good practices.

Recommendations on establishing operational limits and conditions, including those relating to ageing, and on establishing operating procedures for research reactors are provided in Section 3 of Ref. [9].

SERVICE CONDITIONS AND AGEING

3.14. In the ageing management programme, account should be taken of the fact that service conditions are the major contributors to ageing of SSCs, through chemical and physical processes that affect material properties or functional capabilities. Service conditions include:

(a) Stress and/or strain;
(b) Temperature;
(c) Pressure;
(d) The chemistry regime;
(e) Environmental factors such as radiation, high humidity, or the presence and use of chemically active liquids and gases;
(f) Service wear, including changes in dimensions and/or the relative positions of individual parts of assemblies.

3.15. Limiting values for service conditions (e.g. the maximum temperature of fuel cladding, the pressure in cooling lines and across filters, the vibration levels of primary cooling pumps, the content of non-dissolved solids in water coolant, and the water coolant chemistry parameters such as electrical conductivity and pH) should be included in the limiting conditions for safe operation[8] of the

[8] Limiting conditions for safe operation are established constraints on equipment and operational parameters that must be adhered to during startup, operation, shutting down and shutdown to provide an acceptable assurance of safety at a research reactor according to the licence conditions and within applicable regulations.

operational limits and conditions. Further recommendations on the factors to be considered in establishing limiting conditions for safe operation of a research reactor are provided in Appendix I of Ref. [9].

3.16. There are three main categories of service conditions that should be considered in the ageing management programme. These categories are:

(1) Service conditions associated with normal operation;
(2) Service conditions associated with anticipated operational occurrences;
(3) Environmental conditions.

Service conditions lead to degradation of SSC materials through, for example, one or more of the following ageing mechanisms[9]:

(a) A change in physical proprieties (e.g. swelling, chemical decomposition, and changes in material strength, ductility or resistivity);
(b) Irradiation and thermal embrittlement;
(c) Creep;
(d) Fatigue, including thermal fatigue;
(e) Corrosion, including galvanic corrosion, corrosion erosion and corrosion assisted cracking;
(f) Wear (e.g. fretting) and wear assisted cracking (e.g. fretting fatigue).

Further information on the categories of service conditions and the associated ageing mechanisms can be found in Section 3 of Ref. [10]. Annex I of the present Safety Guide describes the effect of ageing for different categories of service conditions.

[9] An ageing mechanism is a specific process that gradually changes the characteristics of an SSC with time or use.

4. AGEING CONSIDERATIONS IN DIFFERENT STAGES OF THE LIFETIME OF A RESEARCH REACTOR

GENERAL

4.1. Ageing management of SSCs important to safety should be implemented proactively (i.e. with foresight and anticipation) throughout the lifetime of the research reactor, i.e. in design, fabrication and construction, commissioning, operation (including utilization and modification) and decommissioning. Particular consideration should be given to ageing management for periods of extended shutdown. Reference [1] requires that “Ageing effects shall be taken into account for all operational states, including periods of maintenance and shutdown.”

4.2. The operating organization should be able to demonstrate that regulatory requirements for ageing management are met and that relevant issues specific to the ageing of a research reactor are clearly identified and documented in the safety analysis report and supporting documents throughout the lifetime of the reactor. The safety analysis report should include (or should reference documents that contain) information that confirms that all materials of SSCs important to safety have been selected to withstand the service conditions to which they are subjected, without unacceptable degradation of the performance of their intended safety functions. The safety analysis report should also describe the conduct of the in-service inspection programme, and should provide information on SSCs to be inspected, as well as their inspection frequency and criteria. Further guidance on the preparation of safety analysis reports for research reactors is provided in the Appendix of Ref. [11].

4.3. Feedback from relevant experience at other reactors, including nuclear power plants, should be used by the operating organization in evaluating the ageing management measures proposed by designers and suppliers.

4.4. An independent review of the ageing management programme and any subsequent modifications to this programme at various stages throughout the lifetime of the research reactor should be performed by the safety committee or other competent body. Any proposed modifications to the ageing management programme should be submitted to the regulatory body for review and assessment, if so required by national regulations. Paragraphs 3.5–3.9 of Ref. [12] provide further information on categorization of research reactor modifications.

DESIGN

4.5. For the design of a research reactor, including modifications and new experiments, the following requirements apply in respect of selection and ageing of materials:

> "At the design stage, an appropriate safety margin shall be adopted to allow for the anticipated properties of materials at the end of their useful lifetime" (para. 6.68, Ref. [1]).
>
> "To ensure the capability of all items important to safety to perform their safety functions, appropriate margins shall be provided in the design to take account of relevant ageing effects and potential ageing related degradation" (para. 6.69, Ref. [1]).
>
> "Provisions shall also be made for the necessary monitoring, testing, sampling and inspection for the detection, assessment, prevention and mitigation of ageing effects" (para. 6.70, Ref. [1]).

4.6. In the design of, and any modification to, a research reactor, including installation of new experimental devices or changes to existing equipment, consideration should be given to the needs of the operating organization with regard to ageing management and reactor utilization [12].

4.7. The design of, and any modification to, a research reactor or experimental device should facilitate inspections and testing aimed at detecting ageing mechanisms and their degrading effects on SSCs, while maintaining the principle that radiation exposure of inspection personnel should be kept as low as reasonably achievable. Particular consideration should be given to SSCs that are difficult to inspect or maintain. Further recommendations on design for inspectability can be found in paras 4.17 and 4.18 of Ref. [7].

4.8. The operating organization should document the ageing management programme and should thereby be able to demonstrate that ageing issues have been adequately addressed in the design for the entire lifetime of the research reactor.

4.9. In procurement documents for SSCs, the operating organization should specify requirements to facilitate ageing management, including information to be included in documents received from suppliers.

4.10. In the reactor design:

(a) It should be ensured that ageing effects are taken into account in equipment qualification[10] activities, with consideration given to all the conditions established in the design basis (including anticipated operational occurrences and design basis accidents).
(b) All potential ageing mechanisms for passive and active[11] SSCs that could affect the ability to perform the safety functions of the SSCs during their design life should be identified, evaluated and taken into account. In doing this, the importance of the SSCs to safety should be identified, and account should be taken of the particular service conditions, required mode of operation, expected service life and ease of replacement.
(c) Relevant ageing management experience from nuclear installations (including other research reactors and nuclear power plants) and other industrial installations, as well as research results, should be reviewed and taken into account.
(d) Consideration should be given to the use of advanced materials (and their production processes) with greater ageing resistance properties (e.g. materials with a high resistance to corrosion, or high strength); consideration should also be given to the combined effects of several ageing mechanisms acting simultaneously.
(e) Consideration should be given to maintenance requirements and the need for material testing programmes, including surveillance specimens, to monitor ageing degradation.
(f) Consideration should be given to the use of compatible materials, especially materials used for welding.

4.11. Ageing management should be included as a topic in the general design criteria and should address the following points:

(a) Different types of SSCs important to safety (concrete structures, mechanical components and equipment, electrical and instrumentation, and control equipment and cables, etc.) and measures to monitor their potential degradation;

[10] Equipment qualification is the generation and maintenance of evidence to ensure that equipment will operate on demand, under specified service conditions, to meet system performance requirements [2].

[11] A passive component is a component whose functioning does not depend on an external input such as actuation, mechanical movement or supply of power. Any component that is not a passive component is an active component [2].

(b) General principles stating how the environment of SSCs is to be maintained within specified service conditions (location of ventilation, insulation of hot SSCs, radiation shielding, damping of vibrations, avoidance of submerged conditions and selection of cable routes);
(c) Proposals for appropriate monitoring and sampling programmes for materials in cases where it is found that ageing degradation may occur that may affect the capability of SSCs to perform their safety function throughout the lifetime of the reactor.

FABRICATION AND CONSTRUCTION

4.12. The operating organization should ensure that:

(a) Relevant information on factors affecting ageing management, including service conditions, is provided to SSC manufacturers, and, through audits of the manufacturers' management system, this information is properly taken into account in the fabrication and construction of SSCs.
(b) Current knowledge about relevant ageing mechanisms and degradation as well as possible mitigation measures is taken into account in the fabrication and construction of SSCs.
(c) Reference (baseline) data, including manufacturing and inspection records, as well as records on shipment and storage conditions, are collected and documented.
(d) Surveillance specimens for specific ageing monitoring programmes are made available and installed in accordance with design specifications.

COMMISSIONING

4.13. The operating organization should establish a systematic programme for measuring and recording baseline data relevant to ageing management for SSCs important to safety. This includes mapping the actual environmental conditions at each critical spot of the reactor to ensure that they are in compliance with the design specifications.

4.14. Special attention should be paid to identification of hot spots in terms of temperature and dose rate, to measurement of vibration levels, and to characterization of thermal insulation or electrical isolation. All parameters that can influence ageing degradation should be identified in commissioning and should be tracked throughout the reactor lifetime (see also paras 7.4–7.6 and

A.20(*p*) of Ref. [13]). Acceptance criteria for these parameters should also be established.

OPERATION

4.15. The following issues should be taken into account in implementing a systematic ageing management programme:

(a) Support for the ageing management programme by the management of the operating organization;
(b) Early implementation of an ageing management programme;
(c) A proactive approach based on an adequate understanding of SSC ageing, rather than a reactive approach responding to SSC failures;
(d) Optimal operation of SSCs to slow down the rate of ageing degradation;
(e) Proper implementation of maintenance and testing activities in accordance with operational limits and conditions, design requirements and manufacturers' recommendations, and following approved operating procedures;
(f) Minimization of human performance factors that may lead to premature degradation, through enhancement of staff motivation, sense of ownership and awareness, and understanding of the basic concepts of ageing management;
(g) Availability and use of correct operating procedures, tools and materials, and of a sufficient number of qualified staff for a given task;
(h) Appropriate storage of spare parts and consumables susceptible to ageing, to minimize degradation while in storage and to control their shelf life properly;
(i) Availability of the necessary competences for dealing with complex ageing issues;
(j) Effective internal and external communication;
(k) Feedback of operating experience (both generic and plant specific operating experience, including operating experience from non-nuclear plants), to learn from relevant ageing related events (see paras 2.15 and 2.16 of Ref. [1]);
(l) Follow-up of possible degradation trends in SSCs between successive periodic testing;
(m) Use of databases on SSC reliability and maintenance histories;
(n) Use of adequate and qualified methods of non-destructive testing and ageing monitoring for early detection of flaws possibly resulting from intensive use of equipment.

4.16. The operating organization should identify and address the following potentially significant common weaknesses of ageing management:

(a) Insufficient understanding and predictability of ageing at the time of design and construction of a research reactor;
(b) Premature ageing of SSCs in research reactors (i.e. ageing degradation that occurs earlier than expected) caused by non-compliance with the requirements of the management system, unforeseen ageing phenomena, or operation of SSCs beyond their design specifications or in service conditions more severe than the normal environmental conditions.

4.17. The operating organization should identify and justify possible changes in operational conditions (e.g. radiation levels, flow distribution, coolant velocity and vibration) that could cause accelerated or premature ageing and failure of some SSCs, in the event of:

— Uprating of the reactor power[12];
— Installation of new experimental devices or changes in the utilization programme;
— Implementation of modifications, including changes to safety analysis;
— Replacement of SSCs.

4.18. If a new ageing mechanism is discovered (e.g. through feedback from operating experience or research), the operating organization should perform an appropriate review of the ageing management programme to determine the effects, if any, on SSCs important to safety which are operating at similar conditions; the operating organization should put in place appropriate ageing management measures.

4.19. For SSCs important to safety, the operating organization should consider preparing contingency maintenance plans to deal with the potential degradation or failure of these SSCs caused by potential ageing mechanisms and effects.

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[12] Examples of significant ageing effects due to power uprating include radiation embrittlement of the reactor vessel, flow accelerated corrosion and vibration of primary system piping.

UTILIZATION AND MODIFICATIONS

4.20. Research reactors are frequently modified to incorporate new experimental devices or to improve the efficiency of normal operation. This and the fact that the frequency of testing and repair may also need to be changed due to ageing or obsolescence of SSCs are particularly important for the maintenance programme (which, in practice, forms the basis for the ageing management programme). Consideration should be given to reactor modifications, including temporary ones, with regard to the possible acceleration of ageing phenomena or the appearance of phenomena that have not previously been considered.

4.21. Consideration should be given to the proper cooling of experimental facilities and reactor structures such as thermal columns and concrete shields, as well as to electrical and instrumentation cables, which may be located in unventilated hot areas.

4.22. Particular consideration should be given to:

(a) Experimental devices operating at high temperature gradients, high temperatures and/or pressures causing creep and fatigue of materials, and beam tubes;
(b) Degradation of mechanical properties of experimental devices due to radiation induced embrittlement, or due to vibration induced by water flow;
(c) Irradiation of capsules containing materials (e.g. copper or mercury) that can cause corrosion in aluminium alloys.

4.23. The documentation for a research reactor may become obsolete due to changes in the reactor utilization programme (e.g. due to installation of a new experimental device or changes to an existing experiment) or modifications. Requirements on updating of operating procedures, drawings and other technical documentation should be included in the ageing management programme.

EXTENDED SHUTDOWN

4.24. Reference [1] requires that “The operating organization shall take appropriate measures during an extended shutdown to ensure that materials and components do not seriously degrade.” The following measures should be implemented:

(a) Unloading of the fuel elements from the reactor core to storage racks as appropriate;
(b) Removing components for protective storage;
(c) Maintaining water chemistry within specifications and maintaining appropriate environmental conditions (e.g. humidity and temperature) to prevent accelerated ageing (e.g. corrosion).

Further information on safety considerations for research reactors in extended shutdown is provided in Ref. [14].

4.25. Periods of extended shutdown should be used for additional inspections that are not included in the operational limits and conditions for SSCs during normal operation (e.g. because the core cannot be unloaded or the beryllium reflector cannot be dismantled). Such additional inspections include:

— Inspection of the reactor vessel or core support structure;
— Inspection of the core structure internals, including connection bolts;
— Dimensional control and alignment of the core internals and reactivity control mechanisms[13];
— Inspection of bellows, strainers, valves and other piping of SSCs important to safety;
— Inspection of beam ports.

4.26. Particular consideration should be given to inspections for degradation of civil structures (including biological shielding) and mechanical and electrical SSCs. Documentation and software should also be evaluated for obsolescence.

DECOMMISSIONING

4.27. Appropriate arrangements should be made to ensure that the required equipment and SSCs (e.g. means of confinement, radiation monitoring, long term cooling, lifting equipment and condition monitoring equipment) remain available and functional, to facilitate decommissioning activities.

[13] Reactivity control mechanisms are devices for controlling the reactivity, including regulating rods, control rods, shutdown rods and blades, and devices for controlling the moderator level.

5. ELEMENTS OF AGEING MANAGEMENT PROGRAMMES

GENERAL

5.1. Ageing management programmes for research reactors should be aimed at identification and implementation of effective and appropriate ageing management actions and practices that provide for timely detection and mitigation of ageing effects in SSCs.

5.2. A systematic ageing management programme for the research reactor should be applied, comprising the following elements:

- — Screening of SSCs for ageing management review;
- — Identification and understanding of ageing degradation;
- — Minimization of ageing degradation;
- — Detection, monitoring and trending of ageing degradation;
- — Mitigation of ageing degradation;
- — Continuous improvement of the ageing management programme;
- — Record keeping.

5.3. The ageing management programme should be applied at all stages during the lifetime of the research reactor, including the design stage.

SCREENING OF SSCs FOR AGEING MANAGEMENT REVIEW

5.4. A research reactor has a large number and variety of SSCs, some of which are more important to safety than others. There are also considerable differences in the extent to which these SSCs are susceptible to ageing degradation. It is neither practicable nor necessary to evaluate and quantify the extent of ageing degradation in every individual SSC. A systematic approach should therefore be applied to focus resources on those SSCs, including experimental devices, that can have a negative impact on the safe operation of a reactor and that are susceptible to ageing degradation.

5.5. The safety based approach outlined in the following should be applied to the screening of SSCs for a review of the management of ageing:

(1) First level screening: The existing list of SSCs important to safety, which should have been developed during the design stage, should be reviewed for completeness (Annex II). If such a list is not available, first level screening should be performed to identify those SSCs that are important to safety, on the basis of whether or not a failure[14] could lead (directly or indirectly) to the loss or impairment of a safety function.
(2) Second level screening: For each of the SSCs identified as being important to safety, the specific structural elements[15] and components that are important to safety should be identified, i.e. those whose failure could lead (directly or indirectly) to the loss or impairment of a safety function.
(3) Third level screening: From the list of structural elements and components important to safety, those for which ageing degradation has the potential to cause component failure should be identified, and a justification should be provided for the components that are excluded.

An outline of this screening process is given in Fig. 1.

5.6. Alternative screening methodologies (e.g. approaches based on probabilistic safety assessment) may also be acceptable provided that they are carried out in accordance with the established requirements for research reactor safety. The specific screening methodology used should be justified and documented.

5.7. Annex II provides a sample list of SSCs that need to be considered in the ageing management programme of open pool, light water research reactors and heavy water moderated research reactors. It is emphasized that the ageing management programme for a specific research reactor need not be limited to the SSCs presented in Annex II. The SSCs specific to the given research reactor should also be considered.

5.8. In the ageing management programme, consideration should be given to SSCs important to safety for normal operation and design basis accidents. These SSCs should be identified by applying the approach set out in para. 5.5. For efficiency, consideration should be given to grouping similar components (e.g. valves, pumps and small diameter piping) that operate in comparable service conditions (e.g. pressure, temperature and water chemistry).

[14] Failure is the inability of an SSC to function within acceptance criteria [2].

[15] Structural elements include both simple structures and elements of complex structures. The term ‘structural element’ is used only for this screening process. In subsequent paragraphs, structural elements are again referred to as ‘structures’.

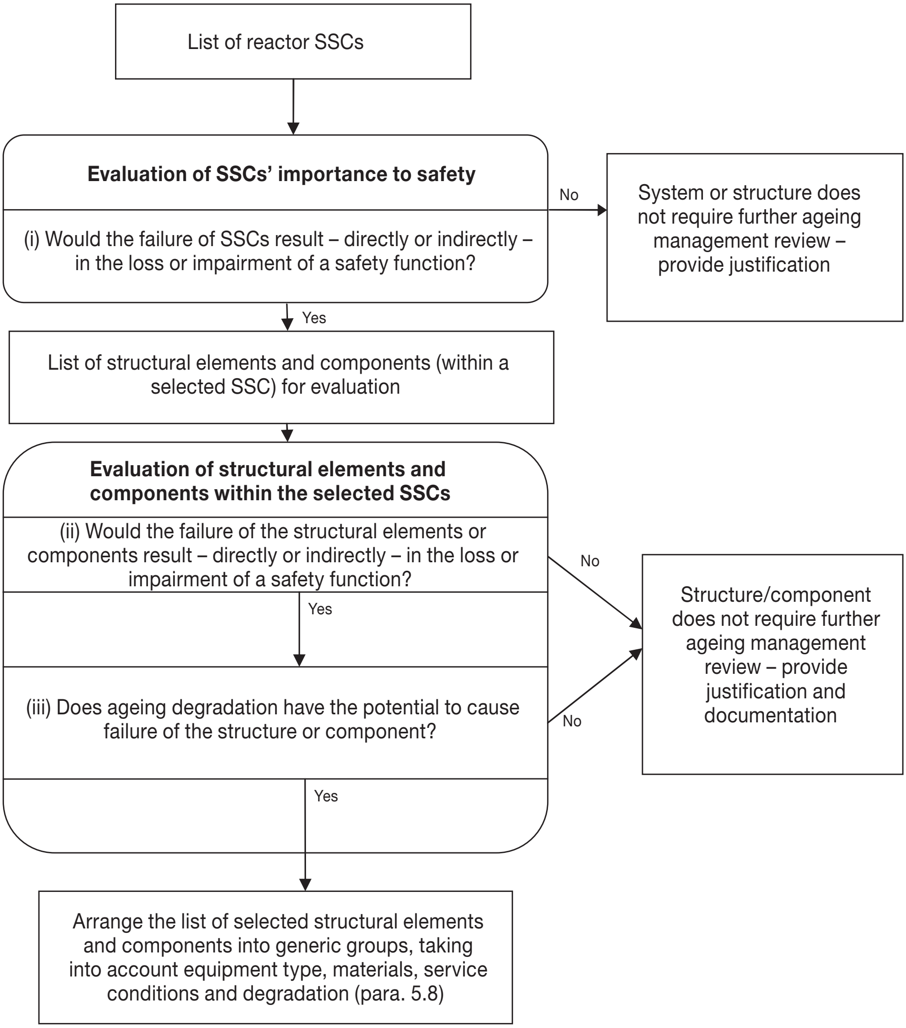

FIG. 1. Outline of the process for screening SSCs for ageing management.

IDENTIFICATION AND UNDERSTANDING OF AGEING DEGRADATION

5.9. To understand the ageing degradation of a structure or component, its ageing mechanisms and effects should be identified and understood; understanding ageing is the basis for the effective monitoring and mitigation of ageing effects.

5.10. Interactions between materials, and service conditions, should be assessed to identify degradation mechanisms. This assessment should be performed using available analytical or empirical models for evaluating past ageing degradation and predicting future ageing degradation.

5.11. Existing methods for inspection, testing, surveillance, monitoring and assessment should be evaluated, with account taken of relevant operating experience and research results, to determine whether they are effective for timely detection of ageing degradation before failure of the structure or component occurs.

MINIMIZATION OF AGEING DEGRADATION

5.12. In order to limit the effects of ageing degradation, preventive actions should be taken. Ideally, preventive actions should be determined during the design stage of the research reactor. Preventive actions should be continuously improved, with account taken of relevant operating experience and research results, and should include:

(a) An assessment of the effectiveness of current maintenance and restoration methods and practices (including refurbishment and periodic replacement of parts and consumables) to control ageing degradation of components;
(b) Establishment of appropriate operating conditions and implementation of practices that minimize ageing degradation of components;
(c) Possible changes in design, materials or environmental conditions, where applicable, to minimize ageing degradation of components.

5.13. Periodic reviews should be undertaken at appropriate intervals to determine the effectiveness of actions and practices for preventing ageing degradation of SSCs. Information obtained in periodic reviews should be documented. If the effectiveness of the preventive actions in place is determined not to be acceptable, appropriate corrective actions should be implemented.

DETECTION, MONITORING AND TRENDING OF AGEING DEGRADATION

5.14. An assessment of various examination methods should be performed to select those methods that are appropriate for detecting effects of the identified ageing mechanisms. Such examination methods should include:

— Inspections;
— Monitoring;
— Performance tests;
— Periodic testing;
— Non-destructive testing, including visual examination.

5.15. The results of these examinations should be evaluated using baseline data collected in previous examinations, to determine whether the conditions[16] of the SSCs are acceptable for continued safe operation or whether remedial measures need to be taken. The examination results should be added to the baseline data for use in subsequent examinations, and records should be kept of any remedial measures.

5.16. The capability and feasibility of detection methods should be periodically evaluated to check their adequacy (including whether they are sufficiently sensitive, reliable and accurate).

5.17. The frequency of examination of an SSC should be in accordance with the recommendations of the designer and/or manufacturer. The frequency may be adjusted on the basis of the likelihood of failure of the SSC and on the basis of experience, including experience acquired from similar facilities. Any proposed changes to the frequency of examinations should be justified.

5.18. Inspection activities should include:

(a) Observation of the condition of SSCs (e.g. leaks, noise and vibration); this is normally done during periodic walkdowns of the research reactor.
(b) Sampling of water coolant for chemical[17] or radiochemical analysis.

5.19. Ageing effects may be detected by a change in measurable operating parameters (e.g. control rod drop time, water chemistry parameters, temperature, flow rate and pressure). Parameters that can be predictive of ageing degradation should be routinely monitored (either on-line or periodically). Readings should

[16] Condition assessment of an SSC is an assessment to determine its current performance and condition (including assessment of any ageing related failures or indications of significant material degradation), and to predict its expected future performance, future ageing degradation and residual service life.

[17] Use of electrochemical techniques for on-line monitoring of corrosion is also suitable for low temperature environments such as research reactor pools.

be assessed and trends determined, in order to predict the onset of ageing degradation in a timely manner.

5.20. Ageing effects can be detected by checking the performance of SSCs. The results of performance tests undertaken as part of the maintenance programme should be periodically examined for evidence of trends that indicate ageing degradation.

5.21. The results of periodic testing performed to verify compliance with the operational limits and conditions should be evaluated to detect and correct abnormal conditions before they give rise to significant consequences for safety.

5.22. Non-destructive testing methods should also be used to detect ageing degradation.[18] Various non-destructive testing methods and their capabilities, together with the associated techniques, are given in Table 1. Further information on non-destructive testing methods and techniques that can be used for detecting ageing of SSCs in research reactors can be found in Ref. [15].

MITIGATION OF AGEING DEGRADATION

5.23. The effectiveness of existing methods and practices for mitigating ageing degradation of a component should be evaluated, with account taken of relevant operating experience and research results. Methods and practices to be evaluated

TABLE 1. NON-DESTRUCTIVE TESTING METHODS AND ASSOCIATED TECHNIQUES

Method	Type of defect	Techniques
Visual examination	Scratches, wear, cracks, corrosion or erosion of surfaces	Television cameras, underwater telescopes, binoculars and mirrors
Surface examination	Surface or near surface flaws or discontinuities	Liquid penetrant and magnetic particles
Volumetric examination	Depth or size of a surface breaking or subsurface flaw	Radiographic, ultrasonic and eddy current techniques

[18] For removable SSCs, destructive tests may be envisaged if the results of non-destructive tests have indicated abnormal values.

should include maintenance, refurbishment and periodic replacement of components, modification of SSCs, and altering of operating conditions and practices that may affect the rate of ageing degradation of components.

5.24. It should be noted that while mitigatory and preventive actions are conceptually different, some preventive actions (e.g. maintaining water chemistry parameters within specifications) are also mitigatory actions.

5.25. Once ageing degradation has been detected or predicted, methods for mitigation of ageing effects should be evaluated and mitigatory actions should be taken.

CONTINUOUS IMPROVEMENT OF THE AGEING MANAGEMENT PROGRAMME

5.26. The management of the research reactor should establish provisions for performance review and continuous improvement of the ageing management programme. Ageing evaluations and condition assessments should be periodically reviewed and updated, and the effectiveness of ageing management activities for individual SSCs should be periodically evaluated in the light of current knowledge and adjusted as appropriate. Current knowledge should be acquired from information on the operation of SSCs, surveillance and maintenance records, lessons learned from other similar facilities and information from the results of research. Consideration should be given to the fact that new ageing degradation mechanisms or unexpected ageing degradation locations may be identified as a consequence of analysis of an incident occurring at another research reactor.

5.27. The following actions should be taken for continuous improvement of ageing management programmes:

(a) At least once a year, a review should be carried out of the performance of SSCs, indicating the effectiveness of the ageing management programme in monitoring ageing degradation trends and identifying any weaknesses and opportunities for improvement;
(b) Use of the results of the performance reviews.

5.28. The effectiveness of the ageing management programme should be reviewed periodically, in accordance with the established management system and in the light of current knowledge and experience. The ageing management programme should be updated as appropriate.

5.29. The result of reviews of the ageing management programme and of assessments of the SSCs, including inspection results and proposed updates, should be submitted to the reactor safety committee (or another competent body) for review and, if required, to the regulatory body for review and assessment.

5.30. Consideration should be given to arranging for peer reviews of the ageing management programme, to obtain an independent assessment, in order to establish whether the ageing management programme is consistent with accepted practices and to identify areas for improvement (see also paras 7.4–7.7 of this Safety Guide).

RECORD KEEPING

5.31. The operating organization should establish a data collection and record keeping system, which should be defined in the safety analysis report (see also paras 2.15 and 2.16 of Ref. [1]), in order to provide information for the following ageing management activities:

(a) Identification and evaluation of degradation, failures and malfunctions of SSCs caused by ageing effects;
(b) Prediction of the future performance of SSCs, which is required for continued safe and reliable operation of the research reactor;
(c) Decisions on the type and timing of preventive maintenance actions, including calibration, repair, modification, refurbishment and replacement, and decisions on adaptations of ageing management programmes;
(d) Optimization of operating conditions and practices that reduce ageing degradation;
(e) Identification of new emerging ageing effects before they jeopardize the safety, reliability and service life of the research reactor.

5.32. The data required in relation to ageing management may be divided into the following three categories (see Annex II of Ref. [3] for examples of relevant data):

(1) Baseline information, consisting of data on the design of the reactor and/or of the SSCs and on the conditions at the beginning of the service life of the SSCs;

(2) Reactor operating records, covering service conditions of the SSCs, including transient data, and data on SSC availability, testing and failure;
(3) Maintenance records, including information on the condition of the SSCs.

5.33. All records should be retained as specified in the operational limits and conditions.

6. MANAGEMENT OF OBSOLESCENCE

6.1. This section addresses obsolescence (non-physical ageing), which occurs when SSCs become out of date in comparison with current technology, knowledge, standards and regulations or when documentation becomes out of date.

6.2. Obsolescence of SSCs should be identified, and corrective actions should be taken before the occurrence of any decline in reliability or availability of a research reactor.

6.3. Obsolescence of SSCs important to safety should be managed proactively (i.e. with foresight and anticipation) throughout their service life.

6.4. The operating organization should establish activities for the management of obsolescence throughout the lifetime of the research reactor. These activities should be reviewed by the safety committee (or other competent body) and should be submitted to the regulatory body for review and assessment, if required by national regulations. Conditions that can lead to obsolescence and that can thus affect reactor safety include:

(a) Changes in technology;
(b) Changes in regulations;
(c) Documentation becoming out of date (e.g. if it is not correctly updated following modifications of SSCs or changes in the utilization programme).

6.5. Table 2 summarizes these conditions and their effects, and suggests actions that should be considered for managing obsolescence.

6.6. Attention should be paid to the management of obsolescence of technology (which, in general, occurs in systems such as electrical and instrumentation systems, and the radiation monitoring system).

6.7. It should be noted that some of the activities relating to the management of obsolescence will require review and updating of the documentation for the reactor (the safety analysis report, operational limits and conditions, emergency plan, radiation protection programme and operating procedures).

6.8. The documentation for a research reactor should be updated when changes in regulations and standards occur, to prevent its obsolescence.

TABLE 2. TYPES OF OBSOLESCENCE AND ASSOCIATED AGEING EFFECTS, AND RECOMMENDED AGEING MANAGEMENT ACTIONS

Conditions	Ageing effects	Management actions
Changes in technology (safety systems)	Incompatibility between old and new equipment Unavailability of suppliers Shortage or lack of spare parts	Ensure systematic identification of useful service life and anticipated obsolescence Prepare a modification project for future replacement of obsolete SSCs Provide spare parts for planned service life or identify alternative suppliers
Changes in standards and regulations, advances in knowledge	Outdated knowledge of practices, standards and regulations Deviations from current standards and regulations	Ensure compliance with current standards and regulations Consider the modification of SSCs important to safety, as required
Documentation becoming out of date	Lack of the information needed for safe operation	Establish an effective integrated management system, including configuration management

7. INTERFACES WITH OTHER TECHNICAL AREAS

INTRODUCTION

7.1. This section addresses the technical areas that interface with, or are closely related to, the ageing management programme and ageing management activities. It provides guidance on the issues that should be considered, to enhance an ageing management programme, in implementing the activities in these areas. These technical areas are:

— Maintenance, periodic testing and inspection;
— Periodic safety reviews;
— Equipment qualification;
— Reconstitution of the design basis;
— Configuration management;
— Continued safe operation;
— Post-service surveillance and testing.

MAINTENANCE, PERIODIC TESTING AND INSPECTION

7.2. The objective of maintenance, periodic testing and inspection programmes is to ensure that the SSCs function in accordance with the design intentions and requirements, as well as in compliance with the safety analysis report and the operational limits and conditions. The activities in these programmes are closely related to those that should be established in the framework of an ageing management programme in the sense that:

(a) Preventive maintenance consists of regularly scheduled inspections, testing, servicing, overhauls and replacement activities, which are established inter alia to detect and prevent incipient failures, and to ensure the continuing capability of SSCs to perform their intended functions.
(b) Corrective maintenance consists of repair and replacement activities not occurring on a regular schedule.
(c) Periodic testing is carried out to ensure compliance with the operational limits and conditions.
(d) Inspection, while an activity inherent to all maintenance and periodic testing, is an examination of SSCs for ageing degradation, to determine whether they are acceptable for continued safe operation or whether remedial measures should be taken. Inspection also refers to non-routine

examination for assessment of ageing effects. Inspection is sometimes referred to as in-service inspection.

Further guidance on the interrelationship between maintenance, periodic testing and inspection, and their relation with ageing management for research reactors, is provided in paras 3.5 and 3.6 of Ref. [7].

7.3. In the maintenance programme, it should be taken into account that the maintenance frequency, testing methods and procedures, and repair methods and procedures may need to be adjusted with time, as inadequate maintenance in conjunction with service conditions, as well as improper maintenance, may accelerate ageing degradation of SSCs. The maintenance programme should be evaluated and, if considered necessary, updated on the basis of the findings of the ageing management programme.

PERIODIC SAFETY REVIEW

7.4. In Ref. [8], the text accompanying Principle 3 on leadership and management states that “For operations that continue over long periods of time, assessments are reviewed and repeated as necessary. Continuation of such operations is subject to these reassessments demonstrating to the satisfaction of the regulatory body that the safety measures remain adequate.” Concerning such safety reassessment, the operating organization should carry out periodic safety reviews, including reviews of modifications, changes in utilization and ageing management.

7.5. In the framework of the periodic safety review, the operating organization should assess the effects of ageing on the safety of the research reactor, the effectiveness of the ageing management programme and the need for improvements.

7.6. Outcomes of the review of ageing management within the periodic safety review should be used:

(a) To determine whether the research reactor or individual SSCs important to safety can be operated safely for a specified future period (e.g. the period between the current safety review and the next one);
(b) To provide inputs for improvement of the scope, frequency and procedures for maintenance, surveillance and inspection, for updating of the safety

analysis, and for modifications of operating conditions or design (including possible changes to the design basis of any SSCs).

Further recommendations and information on periodic safety review for research reactors are provided in paras 2.65–2.68 of Ref. [4].

7.7. In performing a periodic safety review, self-assessment or audits by the operating organization, or peer reviews, the information provided in Ref. [16] should be taken into account. This publication covers the preparation, execution, reporting and follow-up of safety reviews of research reactors, and is applicable inter alia for reassessment of research reactor safety, in order to monitor continued adherence to good safety practices, and for long term safety reviews when ageing of a research reactor may be a point of concern.

EQUIPMENT QUALIFICATION

7.8. Equipment qualification activities should provide for minimization of ageing degradation, through the surveillance, maintenance and periodic replacement of installed equipment or age sensitive parts. The ageing of individual items of equipment should be managed by using the concept either of 'qualified life'[19] or of 'qualified condition'[20] established by equipment qualification (see also paras 7.5–7.8 of Ref. [3]).

RECONSTITUTION OF THE DESIGN BASIS FOR SSCs

7.9. The design basis for SSCs is the information that identifies the specific functions to be performed and the controlling design parameters and specific values, or ranges of values, for these parameters.

7.10. The design basis should be reconstituted if it has not been supplied in full to the operating organization, or if it is not adequately documented. This is

[19] The qualified life is the period for which an SSC has been demonstrated, through testing, analysis or experience, to be capable of functioning within acceptance criteria during specific operating conditions while retaining the ability to perform its safety functions in a design basis accident or earthquake [2].

[20] The qualified condition is the condition of equipment expressed in terms of one or more measurable condition indicators for which it has been demonstrated that the equipment will meet its performance requirements.

particularly important in the case of installation of a new experiment with major safety significance, or where SSCs have been significantly modified and/or may become vulnerable to ageing degradation. The ageing management programme should be used to demonstrate that, in spite of ageing degradation, the design basis for SSCs important to safety remains valid.

CONFIGURATION MANAGEMENT

7.11. Configuration management is the process of identifying and documenting the characteristics of a research reactor's SSCs [2]. The operating organization, within its management system, should establish a configuration management process aimed at ensuring that changes to characteristics of SSCs due to ageing are properly assessed, recorded and incorporated into the documentation of the research reactor.

CONTINUED SAFE OPERATION

7.12. With proper implementation of the ageing management programme, the lifetime of a research reactor may be extended. The lifetime of a research reactor is usually determined by the reactor's continued usefulness and by its operational costs. In order to assess the continued safe operation of a research reactor, data from the ageing management programme should be analysed and the following actions should be carried out:

(a) A safety review of the reactor should be performed, including inspection, to establish the actual status of SSCs.
(b) An overview of potential refurbishment needs should be developed by establishing a comprehensive list of SSCs.
(c) SSCs important to safety should be selected and relevant ageing mechanisms should be identified, in order to perform a preliminary evaluation.
(d) The technical and economic feasibility of a refurbishment programme should be established.

7.13. Before commencing a large scale refurbishment project, a strategic plan (or other equivalent study) should be prepared. In addition to commercial and utilization issues, this plan should consider safety issues such as satisfaction of regulatory requirements as well as the technical status of SSCs and experimental devices that are not part of the refurbishment project.

POST-SERVICE SURVEILLANCE AND TESTING

7.14. After final shutdown of a research reactor and before its decommissioning, a post-service surveillance and testing programme should be applied to detect and assess continuing ageing effects. This programme should continue to be applied as long as particular SSCs of the reactor are required to remain in operation and the decommissioning process has not yet been completed.

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Annex I

EFFECT OF AGEING FOR DIFFERENT SERVICE CONDITIONS

I–1. The basic cause of ageing degradation of an SSC is the service conditions, which support the actuation of particular ageing mechanisms and lead, unless ageing is properly managed, to loss of the safety function capability of the SSC. Service conditions can be categorized as normal operation, anticipated operational occurrences and environmental conditions.

I–2. The possible effects of ageing (consequence/failure) for service conditions associated with normal operation, with anticipated operational occurrences and for environmental conditions, with associated ageing mechanisms, are summarized in Tables I–1 to I–3, respectively.

TABLE I–1. POSSIBLE EFFECTS OF AGEING ON SERVICE CONDITIONS ASSOCIATED WITH NORMAL OPERATION

Condition	Ageing mechanism	Consequence/failure
Radiation	Change of properties	Chemical decomposition Change of strength Change of ductility Swelling Change of resistivity Burnup
Temperature	Change of properties	Change of strength Change of resistivity Change of ductility
Stress (pressure)	Creep	Changes of geometry (e.g. a breakage or collapse)
Cycling of temperature, flow and/or load Flow induced vibrations	Motion	Displacement Change of position or set point Loose connections Material damage (cracks)
	Fatigue	Breakage or collapse Deformation Material damage (cracks)
	Wear	Deterioration of surface Change of dimensions

TABLE I–1. POSSIBLE EFFECTS OF AGEING ON SERVICE CONDITIONS ASSOCIATED WITH NORMAL OPERATION (cont.)

Condition	Ageing mechanism	Consequence/failure
Flow	Erosion	Change of strength
Fluids chemistry	Corrosion/galvanic cells	Release of radioactivity Reduction of strength Deposition of particles Short circuits Leakage

TABLE I–2. POSSIBLE EFFECTS OF AGEING ON SELECTED SERVICE CONDITIONS ASSOCIATED WITH ANTICIPATED OPERATIONAL OCCURRENCES

Condition	Ageing mechanism	Consequence/failure
Power excursion	Thermal and/or mechanical stresses	Deterioration of core components Accelerated ageing of core components
Unbalanced control rod positions	Thermal stresses	Reduction of strength Accelerated ageing
Power–flow mismatch (error in fuel loading)	Thermal stresses	Reduction of strength Accelerated ageing
Primary pump failure	Thermal and mechanical stresses	Accelerated ageing
Erroneous maintenance or operation	Mechanical damage and adverse chemical conditions	Deterioration of systems Corrosion Accelerated ageing

TABLE I–3. POSSIBLE EFFECTS OF AGEING ON SELECTED ENVIRONMENTAL CONDITIONS

Condition	Ageing mechanism	Consequence/failure
Humidity and salinity	Corrosion	Leakage Release of radioactive material Reduction of strength Short circuits
Chemical agents	Chemical reactions	Corrosion Deterioration of SSCs
Wind, dust and sand	Erosion and deposition	Change of strength Deterioration of surface Malfunction of mechanical and electrical components

Annex II

EXAMPLE OF SCREENING OF RESEARCH REACTOR SSCs FOR AGEING MANAGEMENT PURPOSES

II–1. Table II–1 provides examples of screening, for ageing management, of the SSCs of pool type, light water research reactors, as well as of heavy water moderated research reactors. The table lists SSCs, and indicates their importance to safety and their ease of replacement, as well as the relevant ageing mechanism. The abbreviations used in Table II–1 are explained following the table.

TABLE II–1. TYPICAL RESEARCH REACTOR SSCs TOGETHER WITH THEIR EASE OF REPLACEMENT AND POSSIBLE AGEING MECHANISMS

SSC	Important to safety?	Ease of replacement	Ageing mechanisms
Pool and reactor internals (for light water moderated reactors)			
Pool structure and vessel	Y	A/B	1, 2, 4, 5, 6
Core structure	Y	B	1, 4, 5, 6, 7
Reflector	Y	B/C	1, 4, 5
Control rods and mechanisms	Y	C	1, 4, 5
Shielding	Y	C	1, 5
Beam tubes	Y	B/C	1, 3, 5
Liner	Y	B/C	1, 3, 5
Fuel assemblies and storage in reactor pool	Y	C	1, 5
Reactor internals (for heavy water moderated reactors)			
Reactor tank	Y	A/B	1, 2, 5, 6
Core structure	Y	B	1, 2, 5
Control rods and mechanisms	Y	C	1, 4, 5
Fuel assemblies	Y	C	1, 5
Cooling systems			
Primary	Y	B/C	1, 3, 4, 5, 6, 7
Pool	Y	A/B	1, 3, 4, 5, 6
Emergency	Y	B/C	3, 4, 5, 6
Make-up	N	C	5

TABLE II–1. TYPICAL RESEARCH REACTOR SSCs TOGETHER WITH THEIR EASE OF REPLACEMENT AND POSSIBLE AGEING MECHANISMS (cont.)

SSC	Important to safety?	Ease of replacement	Ageing mechanisms
Purification	Y	C	1, 2, 5
Secondary	N	C	4, 5, 6, 7
Hot water layer	Y	C	4, 5, 6
Heavy water storage	Y	B/C	5
Collection of heavy water leaks	Y	B/C	5
Cover gas circulation	Y	C	4, 5
Confinment/containment			
Structure	Y	A	2, 3, 4, 5
Biological shield	Y	A/B	1, 2, 3, 4, 5
Ventilation: normal	M	C	2, 5, 6
Ventilation: emergency	Y	B/C	5, 6
Penetrations	Y	C	1, 2, 4, 5
Isolation system	Y	C	4, 5
Stack	Y	B/C	6
Controls and instrumentation			
Shutdown systems	Y	C	4, 5
Protection system	Y	B	4, 5
Control system	Y	C	2, 4, 6
Control console	M	B/C	2, 6
Radiation monitoring	Y	C	5
Process systems	M	B	4, 5, 6
Annunciators	Y	C	2, 4, 6
Instrumentation	M	C	1, 2, 4, 6
Cabling	M	B/C	1, 2, 5
Remote shutdown and remote monitoring	Y	C	5
Pneumatic system	M	C	4, 5
Data acquisition	M	C	4, 5
Seismic protection	Y	C	4, 5
Auxiliaries			
Electrical power system	M	B	6
Emergency power system	Y	B/C	5, 6

TABLE II–1. TYPICAL RESEARCH REACTOR SSCs TOGETHER WITH THEIR EASE OF REPLACEMENT AND POSSIBLE AGEING MECHANISMS (cont.)

SSC	Important to safety?	Ease of replacement	Ageing mechanisms
Fire protection	Y	B	5
Lightning protection	M	B/C	5
Flood protection	M	C	5
Communications	M	C/D	5
Cranes	Y	B/C	4, 5
Handling and storage facilities	Y	D	5
Transfer casks and fuel casks	Y	B/C	1, 4, 5
Handling, storage and disposal of radioactive waste	Y	B/C	1, 2, 5, 6
Hot cells	M	B	1, 5, 6, 8
Compressed air	M	C	4, 5, 6
Laboratories	N	C	5, 6, 8
Heavy water auxiliaries, including recombination	Y	C	5, 6
Spare parts	M	B/C	8
Experimental facilities			
Cold and hot sources	Y	B/C	1, 2, 3, 4, 5, 6
Shielding	Y	C	1, 5
Rigs and loops	Y	B/C	1, 2, 3, 4, 5, 6
Beam tube lines	Y	C	1, 3, 4, 5
Isotope production and irradiation facilities	M	C	1, 2, 3, 4, 5, 6
Rabbit systems	M	C	1, 5, 6
Thermal columns	M	C	1, 2, 3, 5
Dry irradiation rooms	N	C	1, 5
Reactor block			
Reflector	Y	A/B	1, 4, 5
Thermal shield	Y	A/B	1, 2, 5
Biological shield	Y	A/B	1, 2, 4, 5
Reactor block cooling system	Y	B	2, 5

TABLE II–1. TYPICAL RESEARCH REACTOR SSCs TOGETHER WITH THEIR EASE OF REPLACEMENT AND POSSIBLE AGEING MECHANISMS (cont.)

Other factors (non-SSC)	Important to safety?	Ease of replacement	Ageing mechanisms
Documentation			
Design	M	B/C	10
Safety analysis report	Y	B/C	9, 10
Operational limits and conditions	Y	B/C	10
Operating procedures	Y	B/C	10
Management system	Y	B/C	9, 10
Reviews and assessment	Y	C	9, 10
Industrial safety	N	B/C	8, 9
Licensing	Y	B/C	9

Abbreviations used in Table II–1

Important to safety?	Ease of replacement	Ageing mechanisms
Y: Yes	A: Very difficult	1: Changes of properties due to neutron irradiation
N: No	B: Difficult technically or costly	2: Changes of properties due to temperature service conditions
M: Maybe, depending on specific reactor design and features; see also footnote 1 on page 1.		3: Stress or creep (due to pressure and temperature service conditions)
	C: Normal	4: Motion, fatigue or wear (resulting from cycling of temperature, flow and/or load, or flow induced vibrations)
	D: Readily	5: Corrosion
		6: Chemical processes
		7: Erosion
		8: Changes of technology
		9: Changes of regulations
		10: Obsolescence of documentation

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