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International Atomic Energy Agency

IAEA SAFETY STANDARDS

No. SSG-94

for protecting people and the environment

# Ageing Management and Maintenance of Packages for the Transport of Radioactive Material

SPECIFIC SAFETY GUIDE

# AGEING MANAGEMENT AND MAINTENANCE OF PACKAGES FOR THE TRANSPORT OF RADIOACTIVE MATERIAL

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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-94

# AGEING MANAGEMENT AND MAINTENANCE OF PACKAGES FOR THE TRANSPORT OF RADIOACTIVE MATERIAL

SPECIFIC SAFETY GUIDE

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# FOREWORD

## by Rafael Mariano Grossi
## Director General

The IAEA's Statute authorizes it to "establish…standards of safety for protection of health and minimization of danger to life and property". These are standards that the IAEA must apply to its own operations, and that States can apply through their national regulations.

The IAEA started its safety standards programme in 1958 and there have been many developments since. As Director General, I am committed to ensuring that the IAEA maintains and improves upon this integrated, comprehensive and consistent set of up to date, user friendly and fit for purpose safety standards of high quality. Their proper application in the use of nuclear science and technology should offer a high level of protection for people and the environment across the world and provide the confidence necessary to allow for the ongoing use of nuclear technology for the benefit of all.

Safety is a national responsibility underpinned by a number of international conventions. The IAEA safety standards form a basis for these legal instruments and serve as a global reference to help parties meet their obligations. While safety standards are not legally binding on Member States, they are widely applied. They have become an indispensable reference point and a common denominator for the vast majority of Member States that have adopted these standards for use in national regulations to enhance safety in nuclear power generation, research reactors and fuel cycle facilities as well as in nuclear applications in medicine, industry, agriculture and research.

The IAEA safety standards are based on the practical experience of its Member States and produced through international consensus. The involvement of the members of the Safety Standards Committees, the Nuclear Security Guidance Committee and the Commission on Safety Standards is particularly important, and I am grateful to all those who contribute their knowledge and expertise to this endeavour.

The IAEA also uses these safety standards when it assists Member States through its review missions and advisory services. This helps Member States in the application of the standards and enables valuable experience and insight to be shared. Feedback from these missions and services, and lessons identified from events and experience in the use and application of the safety standards, are taken into account during their periodic revision.

I believe the IAEA safety standards and their application make an invaluable contribution to ensuring a high level of safety in the use of nuclear technology. I encourage all Member States to promote and apply these standards, and to work with the IAEA to uphold their quality now and in the future.

# 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. The principles are expressed as 'must' statements.

**Safety Requirements**

Safety Requirements are governed by the objective and principles of the Safety Fundamentals. They establish the requirements to be met to ensure the protection of people and the environment, both now and in the future. The format and style of the Safety Requirements facilitate their use for the establishment of a national regulatory framework. Requirements are presented as 'overarching' requirements[2] in bold, followed by a number of associated requirements; all are equally important and are expressed as 'shall' statements.

**Safety Guides**

Safety Guides provide recommendations on how to comply with the Safety Requirements, indicating an international consensus that it is necessary to take the

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

[2] The IAEA Regulations for the Safe Transport of Radioactive Material do not include overarching requirements.

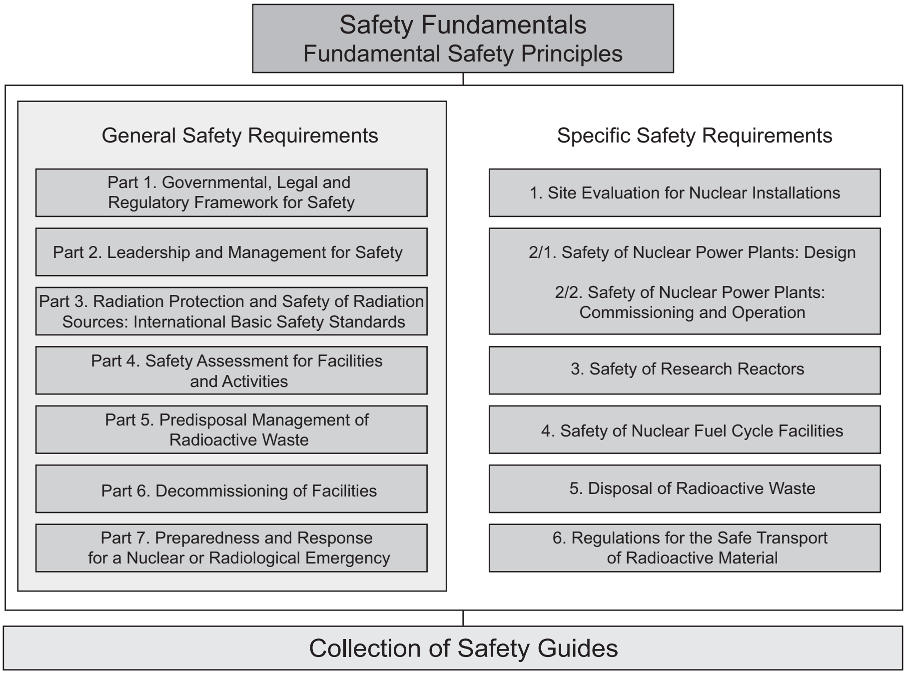


*FIG. 1. The long term structure of the IAEA Safety Standards Series.*

measures recommended (or alternative measures that achieve the same level of protection). Safety Guides present international good practices and, increasingly, best practices. 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 five Safety Standards Committees, for emergency preparedness and response (EPReSC) (as of 2016), 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).

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.

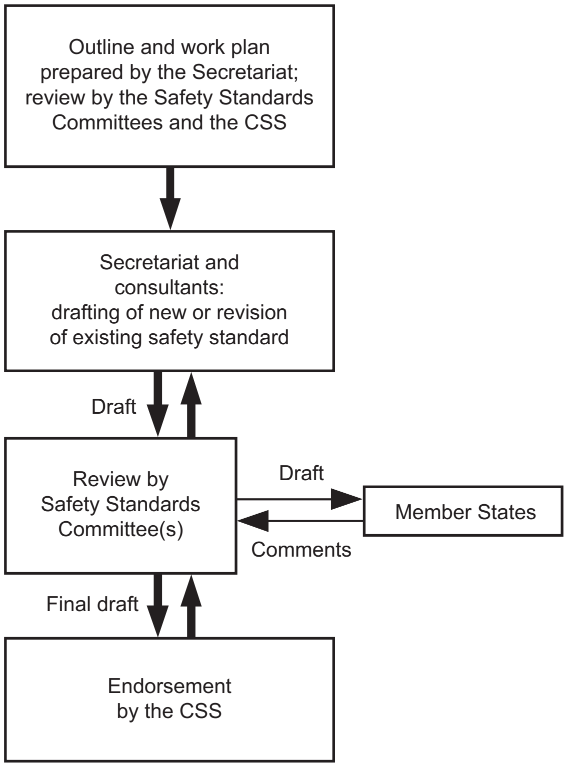


*FIG. 2. The process for developing a new safety standard or revising an existing standard.*

## 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 they appear in the IAEA Nuclear Safety and Security Glossary (see https://www.iaea.org/resources/publications/iaea-nuclear-safety-and-security-glossary). 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. IAEA Safety Standards Series No. SSR-6 (Rev. 2), Regulations for the Safe Transport of Radioactive Material [1] (hereinafter referred to as the 'Transport Regulations'), includes requirements to take into account the ageing[1] of transport packages including, as relevant, their radioactive contents (see paras 613A and 809(f) of the Transport Regulations). Evidence needs to be provided that each package design, including those used for shipment after storage, is in compliance with all the applicable requirements.

1.2. Recommendations on the application of the requirements of the Transport Regulations, including those related to ageing management, are provided in IAEA Safety Standards Series No. SSG-26 (Rev. 1), Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2018 Edition) [3]. Recommendations on the incorporation of ageing considerations and an ageing management programme into the package design safety report[2] are provided in IAEA Safety Standards Series No. SSG-66, Format and Content of the Package Design Safety Report for the Transport of Radioactive Material [4].

1.3. The Transport Regulations also include requirements for the maintenance of transport packages. SSG-66 [4] recommends the inclusion of maintenance specifications in the package design safety report. SSG-26 (Rev. 1) [3] also addresses the maintenance of transport packages with respect to lifting attachments and the ageing management of transport packages.

1.4. Terms used in this publication are to be understood as they appear in the 2022 (Interim) edition of the IAEA Nuclear Safety and Security Glossary [2] unless otherwise specified.

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[1] In the context of this Safety Guide, 'ageing' is intended to mean the physical ageing of package components, including the radioactive content of the package where appropriate (based on Ref. [2]).

[2] In the context of this Safety Guide, 'package design safety report' is intended to mean all documentary evidence of the compliance of a transport package design with the Transport Regulations.

## OBJECTIVE

1.5. The objective of this Safety Guide is to provide recommendations on the ageing management and maintenance[3] of transport packages to ensure compliance with the Transport Regulations.

1.6. The recommendations in this Safety Guide are aimed at package designers; manufacturers and owners of packagings and organizations responsible for packaging maintenance; owners of the radioactive contents of packages; users (consignors) of packages; organizations responsible for the storage of packages before shipment (i.e. shipment after storage); technical support organizations; and competent authorities with responsibility for the safe transport of radioactive material.

## SCOPE

1.7. This Safety Guide covers all packages containing radioactive material (i.e. excepted packages; Type IP-1, Type IP-2 and Type IP-3 packages; Type A packages; Type B(U) and Type B(M) packages; and Type C packages, including packages containing fissile material or uranium hexafluoride ($UF_6$)), as defined in the Transport Regulations.

1.8. This Safety Guide also covers all activities during the service life[4] of transport packages in which ageing management and maintenance are to be considered.

1.9. A graded approach is to be applied to the recommendations provided in this Safety Guide, commensurate with the type of package and its intended use (i.e. single transport, repeated use or shipment after storage).

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[3] In the context of this Safety Guide, ‘maintenance’ is intended to mean the organized activity, both administrative and technical, of keeping package components in good operating condition, including both preventive and corrective (or repair) aspects (based on Ref. [2]).

[4] In the context of this Safety Guide, ‘service life’ is intended to mean the period from the initial operation of a transport package to its final withdrawal from service (based on Ref. [2]).

## STRUCTURE

1.10. This Safety Guide consists of nine sections, three appendices and one annex. Section 2 provides recommendations on applying a graded approach to ageing mechanisms. Section 3 provides recommendations on the relationship between package operating conditions and relevant ageing mechanisms. Section 4 provides recommendations on ageing considerations in package design and management of ageing. Section 5 provides overall recommendations on maintenance activities and considerations in package design, as well as on inspection and testing in the maintenance of transport packages. Section 6 provides recommendations on the maintenance programme for transport packages. Sections 7 and 8 provide recommendations on the role of the competent authority in relation to the ageing management and maintenance of transport packages and related administrative matters. Section 9 provides recommendations on the interfaces between transport and storage and between the countries of origin, storage and use of a package. Appendix I provides additional information on approaches to the consideration of ageing mechanisms in package design. Appendix II provides a structure for an ageing management programme for transport packages. Appendix III describes the roles and responsibilities of some of the relevant interested parties[5] involved in the ageing management and maintenance of transport packages. The Annex provides an example of scope setting for ageing mechanisms.

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[5] In the context of this Safety Guide, 'relevant interested parties' is intended to mean the different entities that may be involved in the ageing management and maintenance operations of a package: the package designer, the manufacturer and the owner of the packaging and the organization responsible for its maintenance, the owner of the radioactive contents of the package, the user (consignor) of the package, and the organization responsible for the storage of packages before shipment (i.e. shipment after storage).

# 2. THE APPLICATION OF A GRADED APPROACH TO THE CONSIDERATION OF AGEING MECHANISMS ON TRANSPORT PACKAGES

2.1. The effects of ageing mechanisms[6] on packaging components, radioactive contents and package safety functions depend on the environmental and operational conditions to which the packages are exposed. A graded approach should be applied when considering the ageing mechanisms on packages, commensurate with the package operational conditions throughout its service life, as described in paras 613A.1–613A.6 of SSG-26 (Rev. 1) [3]. Considerations for ageing management depend on the intended use of the packaging: single transport, repeated use or shipment after storage (see paras 613A.2–613A.4 of SSG-26 (Rev. 1) [3]), as described in paras 2.4–2.10 of this Safety Guide. A graded approach should also be applied when considering the type of package, in accordance with SSG-66 [4]. Ageing considerations might not need to be included in the package design safety report for an excepted package design (see appendix I to SSG-66 [4]).

2.2. For packagings that will be loaded after prolonged storage since their manufacture, the effects of ageing mechanisms should be considered from the completion of manufacture, regardless of whether the packagings are intended for a single transport or for repeated use.

2.3. For package designs requiring competent authority approval, justification of the considerations to ageing mechanisms is required to be included in the package design safety report (see para. 809(f) of the Transport Regulations).

## PACKAGINGS INTENDED TO BE USED FOR A SINGLE TRANSPORT

2.4. Paragraph 613A.2 of SSG-26 (Rev. 1) [3] states:

> "For packagings used once for a single transport and not intended for shipment after storage, inspection prior to use may be sufficient. Such

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[6] In the context of this Safety Guide, 'ageing mechanism' is intended to mean a process that gradually changes the characteristics of a package component over time or with use (e.g. curing, wear, fatigue, creep, erosion, microbiological fouling, corrosion, embrittlement, chemical decomposition) (based on Ref. [2]).

packages may include excepted packages, Type IP-1, Type IP-2, Type IP-3 and Type A packages (e.g. fibreboard boxes, drums).”

2.5. As such, the effects of the ageing mechanisms do not normally need to be considered because the duration of a single transport is relatively short (i.e. one year or less).

## PACKAGINGS INTENDED FOR REPEATED USE

2.6. Paragraph 613A.3 of SSG-26 (Rev. 1) [3] states that “For packagings intended for repeated use, the effects of ageing mechanisms on the package should be evaluated during the design phase in the demonstration of compliance with the Transport Regulations.” The effects of ageing mechanisms on the package’s radioactive contents do not normally need to be considered because the duration of each shipment is relatively short (i.e. one year or less). Based on an evaluation of ageing mechanisms, measures should be defined to monitor and control ageing effects[7] as part of the packaging inspection and maintenance programme to ensure that the safety functions of the packaging do not deteriorate over its service life. Inspection and maintenance could be conducted when the packaging is empty (i.e. without radioactive contents), between shipments of the loaded package (see Section 5).

2.7. Consideration of ageing mechanisms, with appropriate justifications, should be included in the package design safety report.

## PACKAGES INTENDED TO BE USED FOR SHIPMENT AFTER STORAGE

2.8. Paragraph 106.2 of SSG-26 (Rev. 1) [3] states that “Shipment after storage… is a specific shipment operation that requires consideration of ageing of package components”[8]. Shipment after storage includes cases in which packages loaded

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[7] In the context of this Safety Guide, ‘ageing effects’ is intended to mean effects produced by ageing that impair the ability of package components to perform safety functions. If the package’s ability to function within its acceptance criteria is impaired, these effects may be referred to as ‘ageing degradation’.

[8] In the context of this Safety Guide, ‘package component’ is intended to mean any individual part or material of a package (including its radioactive contents) that performs a safety function or another function needed to comply with regulatory requirements.

with their radioactive contents are transported to a facility and then stored for several years or decades until being transported from the facility. In some cases, packages are loaded and stored at the same facility for a long time, then shipped to another storage facility. There might also be cases in which a packaging has been used for repeated transport and is then used for storage.

2.9. The consideration of ageing mechanisms for packages used for shipment after storage should take into account the following issues, as appropriate:

(a) The ageing management programme and the gap analysis programme[9] should ensure that the package complies with the requirements of the Transport Regulations at the time of shipment after storage (i.e. the transportability of the package should be maintained).
(b) The package configuration for transport and the configuration for storage may differ. For instance, dual purpose casks[10] may be stored without shock absorbers.
(c) The impact of ageing effects on the radioactive contents should be considered in the ageing management programme and the gap analysis programme. This should include consideration of whether the characteristics of the radioactive contents might change during storage, affecting the safety functions of the package.
(d) Inspection and maintenance during storage should be such that they can be conducted on the loaded packagings. When it is not possible to directly inspect and maintain the loaded packaging during storage (e.g. if the primary container of the package is enclosed within a shielded overpack or shielded vault during the storage period), alternative means should be used to assess ageing effects. For example, an empty packaging of the same design could be placed in the same storage conditions (e.g. temperature, humidity) at the same starting time as the loaded packaging and periodically retrieved, disassembled and inspected to assess the ageing effects. However, the ageing effects due to phenomena other than the storage conditions (e.g. radiation, heat load) would not be simulated on the empty packaging and would have to be assessed using a different method.

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[9] As stated in para. 809.4 of SSG-26 (Rev. 1) [3], "A gap analysis is a periodic assessment of whether the package design complies with the current Transport Regulations. It should consider changes of the regulations, changes in technical knowledge and changes of the state of the package design during storage, and then identify any gaps. The gap analysis programme should describe the procedure for conducting such a gap analysis."

[10] In the context of this Safety Guide, 'dual purpose cask' is intended to mean the assembly of components (packaging) necessary to fulfil the safety function for both the transport and the storage of radioactive material.

2.10. For the approval of packages intended to be used for shipment after storage, a gap analysis programme is required to be submitted to the competent authority (see para. 809(k) of the Transport Regulations).

# 3. PACKAGE OPERATING CONDITIONS AND RELEVANT AGEING MECHANISMS

3.1. Ageing might be addressed by following the general principles used for nuclear power plant components, taking into account the application of a graded approach to the type of package. Recommendations on ageing management for nuclear power plants are provided in IAEA Safety Standards Series No. SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants [5], and further information is given in Refs [6, 7]. Information on the approach to ageing management in individual States is given in Refs [8–11]. The interim storage of spent fuel and the use of dual purpose casks have strengthened the focus on the consideration of ageing mechanisms for storage packages (e.g. Refs [8, 9, 12–14]).

3.2. Ageing is dependent on time and use and therefore may depend on the service life of the package. The designer should consider the ageing mechanisms that might occur during the service life of the package, both while it is in service (i.e. with the packaging subjected to the loads caused by the radioactive contents and transport operations) and while it is out of service (i.e. subjected to the storage environment).

3.3. For some packages it might be appropriate for the package designer to define an expected service life in terms of number of years of use or number of shipments.

3.4. Additionally, for packagings intended to be used for shipment after storage, the service life includes the storage period of the package and the phases before and after storage, including operations such as loading, handling and transport. The radioactive contents may be stored for a period of time in the packaging; thus, the effects of ageing mechanisms on the radioactive contents should be considered, taking into account any changes that might affect the integrity of the contents, any loads to which the packaging components might be subjected and the retrievability of the contents. The possible effects of irradiation and heat generation due to radioactive decay on package components should also be considered.

## ENVIRONMENTAL AND OPERATIONAL CONDITIONS

3.5. The package designer should define the limitations of the expected environmental and operational conditions to which the packaging might be subjected. These conditions may include the following:

(a) General external and internal conditions:
   (i) General conditions (e.g. humidity, temperature, chemical and biological factors) at the storage location and during loading, shipment and unloading;
   (ii) Specific environmental conditions during the storage of an empty packaging (e.g. outdoors or indoors; uncovered or covered);
   (iii) Internal atmosphere of the package cavity (e.g. air or a filling gas, such as helium or nitrogen) to evaluate the ageing effects on the radioactive contents and internal components of the packaging;
   (iv) Leaktightness criteria;
   (v) Dry storage needs, including specifications for drying;
   (vi) For packagings intended to be used for shipment after storage, the expected environmental conditions during storage, which might be defined in or derived from the storage facility design specifications;
   (vii) Storage configuration (e.g. vertical or horizontal position; on a concrete pad or a floor; storage frame).
(b) Mechanical loading:
   (i) For all transport packages, the mechanical loadings acting on the packaging components during routine conditions of transport (including those caused by acceleration, vibration and resonance);
   (ii) For lifting attachments, such as trunnions, the cumulative number of liftings;
   (iii) For packagings intended to be used for shipment after storage, the mechanical loadings, as defined by the package designer for the conditions of storage.
(c) Thermal loading:
   (i) For packagings intended for repeated use, all thermal loadings that increase the temperature of the package components, including the decay heat of the radioactive contents and the solar insolation data specified in table 12 of the Transport Regulations (taking into account that the daily fluctuation of the insolation might have an effect on the ageing mechanisms);
   (ii) For packagings intended to be used for shipment after storage, the thermal loadings defined by the package designer for the conditions

of storage (i.e. decay heat of the radioactive contents, insolation in the case of outdoor storage, and environmental temperatures).

(d) Irradiation:
   (i) For packagings intended for repeated use, the effects of cumulative irradiation (gamma and neutron) during the packagings' service life;
   (ii) For packagings intended to be used for shipment after storage, the effects of cumulative irradiation (gamma and neutron) and the decay of the radioactive contents during the intended storage period.
(e) Internal pressure: Changes in the internal pressure of the package, if applicable, in accordance with the package design.

## AGEING MECHANISMS RELEVANT TO TRANSPORT PACKAGES

3.6. Ageing mechanisms that might be relevant to transport packages, depending on the package design, are as follows [9]:

(a) Boron depletion: Degradation of the neutron absorbing capacity of the neutron poison and shielding materials when exposed to neutron fluence.
(b) Corrosion: Electrochemical reaction of a metal or a metal alloy in an environment that results in material oxidation or loss. The following are typical forms of corrosion:
   (i) Crevice corrosion: Localized corrosion in joints, connections and other small, close-fitting regions that develops due to local aggressive environments.
   (ii) Galvanic corrosion: Accelerated corrosion of a metal when it is in electrical contact with a more noble metal or a non-metallic conductor in a corrosive electrolyte.
   (iii) General corrosion: Uniform loss of material caused by corrosion that proceeds at approximately the same rate over a metal surface.
   (iv) Microbiologically influenced corrosion: Any form of corrosion influenced by the activity of microorganisms, such as bacteria, fungi and algae, and/or the products of their metabolism. For example, anaerobic bacteria can establish an electrochemical galvanic reaction or disrupt a passive protective film; acid-producing bacteria can produce corrosive metabolites.
   (v) Pitting corrosion: A localized form of corrosion confined to a point or small area of a metal surface in the form of cavities ('pits').
   (vi) Intracrystalline corrosion: Selective attack on the structure of a metal in the grain boundaries or adjacent to them. Examples of materials

susceptible to intracrystalline corrosion include stainless steel, copper–zinc alloys and some aluminium alloys.

(c) Stress corrosion cracking: Metal cracking produced by the combined action of corrosion and tensile stress (applied or residual). Stress corrosion cracking is highly chemically specific; certain alloys are likely to undergo this type of corrosion only when exposed to certain chemical environments.

(d) Stress relaxation: Loss of preload in a heavily loaded bolt. Over time, the clamping force provided by a bolt might decrease.

(e) Wet corrosion and blistering: Degradation mechanism for some types of neutron poison plates with open porosity as a result of water entering the pores of the material during loading, which leads to internal corrosion. Blisters occur from the trapped hydrogen produced by the corrosion reactions. Wet corrosion and blistering can cause dimensional changes affecting the criticality considerations due to moderator displacement and might hinder the retrieval of fuel assemblies.

(f) Creep: Thermally activated and time dependent continuous deformation process for a metallic material under constant stress. It is generally a concern at temperatures greater than 40% of the absolute melting temperature of the material.

(g) Fatigue (also called ‘cyclic loading’ or ‘thermal or mechanical fatigue’): Phenomenon leading to fracture under repeated or fluctuating stresses with a maximum value less than the tensile strength of the material.

(h) Radiation damage: Loss of ductility (embrittlement), loss of fracture toughness, and loss of resistance of a metal or a polymer to cracking, all of which might occur under exposure to radiation.

(i) Radiolysis: A change in the material caused by the breaking of chemical bonds by irradiation. For example, when water is present in a package cavity, hydrogen may be generated by radiolysis, which causes an internal pressure buildup in the package. Polymers might change in composition owing to the decomposition of crosslinks by irradiation.

(j) Thermal ageing: Microstructural or chemical changes to a material exposed continuously to elevated temperatures that affect material or mechanical properties.

(k) Wear: Surface material removal caused by relative motion between two surfaces or under the influence of hard, abrasive particles. Wear can occur because of frequent manipulation.

3.7. Ageing mechanisms that might be relevant to nuclear fuel, especially spent fuel, include the following:

(a) Delayed hydride cracking: Crack propagation in zirconium based cladding materials resulting from hydrogen diffusion to a crack tip, the embrittlement of the near-tip region due to hydride precipitation, and the stress imposed on the cladding.
(b) Hydride reorientation and hydride induced embrittlement: Precipitation of radial hydrides resulting in the embrittlement of zirconium based cladding materials. Hydride reorientation from the circumferential axial direction to the radial axial direction is caused by heating and cooling of the cladding under sufficient cladding hoop tensile stresses and might affect the performance of the cladding under pinch load stress.
(c) Mechanical overload: Overload of fuel cladding caused by fuel pellet swelling. Fuel pellet swelling is the result of the decay gas production in the pellet.
(d) Fatigue: Phenomenon leading to fracture under repeated or fluctuating stresses with a maximum value less than the tensile strength of the material.
(e) Creep: Thermally activated and time dependent continuous deformation process for a metallic material under constant stress. For fuel cladding, creep is caused by internal overpressure. High burnup fuel is more affected because of the higher fission gas release.

See table 3-6 of Ref. [9] for a comprehensive list of nuclear fuel related ageing mechanisms.

## IDENTIFICATION OF THE SAFETY RELEVANT COMPONENTS IN TRANSPORT PACKAGES

3.8. In accordance with para. 104 of the Transport Regulations, the following four safety functions are required to be satisfied during the transport of radioactive material:

(a) Containment of the radioactive contents;
(b) Control of external dose rate;
(c) Prevention of criticality;
(d) Prevention of damage caused by heat.

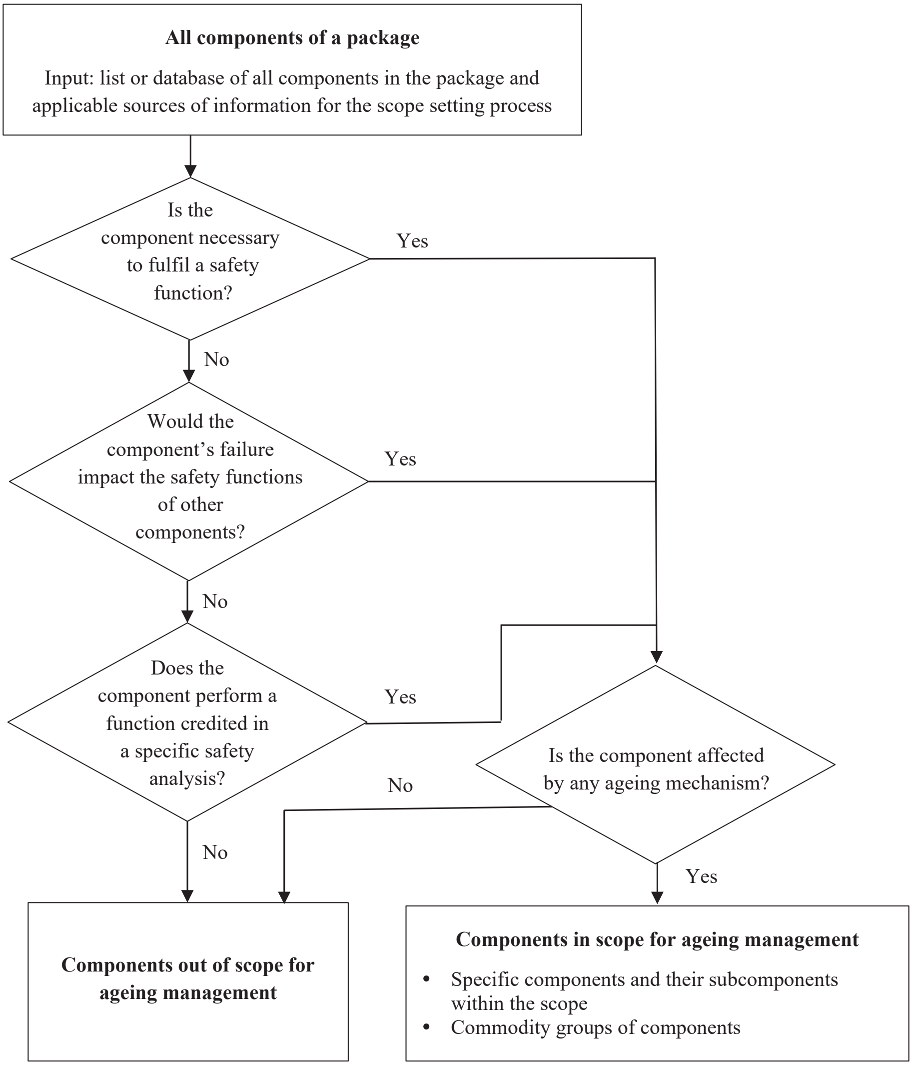


*FIG. 1. Scope setting process for ageing management.*

3.9. A systematic scope setting process (see Fig. 1) should be used to identify components subject to ageing considerations; all package components, including radioactive contents, where relevant, should be listed. The following components should be included by the package designer in the scope of ageing considerations in the package design safety report [5]:

(a) Components relied on for safety and necessary to fulfil one or more of the four safety functions of the package. Examples are containment system components (e.g. shell, bottom plate, lid(s), lid bolts, gasket, orifices, valves), gamma and neutron shielding, fuel baskets, cooling fins, and thermal paths.
(b) Other components whose failure might prevent the components relied on for safety from fulfilling their intended functions. Examples are shock absorbers, rupture discs, trunnions and lifting lugs.
(c) Other components credited in the safety analyses as performing the function of withstanding certain types of event, consistent with the Transport Regulations and national requirements. Examples are protective covers, barriers (e.g. mesh plates), or silicone for the protection of trunnions.

## MATERIALS OF SAFETY RELEVANT COMPONENTS IN TRANSPORT PACKAGES

3.10. The materials of safety relevant components in a transport package should be listed to complete the scope setting process for ageing management described in para. 3.9. Materials used for components of a packaging might include the following [9]:

(a) Aluminium or aluminium alloys: Used as a cladding of metallic gaskets for closure seals or as a structural component or heat conductor (e.g. baskets for positioning spent fuel assemblies).
(b) Borated aluminium: Used as a neutron absorber of a structural or non-structural component of a basket for nuclear fuel.
(c) Borated stainless steel: Used as a neutron absorber of a structural component of a basket for nuclear fuel.
(d) Concrete: Used as a structural material or as a shielding material.
(e) Copper or copper alloys: Used for the rupture disc or as a heat conductor.
(f) Depleted uranium: Used as a shielding material.
(g) Ductile cast iron: Used as a structural material or as a shielding material.
(h) Inorganic material: Ceramic fibres used for thermal insulation; inorganic compounds used for neutron shielding.
(i) Lead: Used as a shielding material.
(j) Nickel or nickel alloys: Used for the closure lid, plate bolt or trunnion bolt, or for the inner cladding and spring of the metallic gasket for the lid seal, or as a cladding material for corrosion protection purposes.

(k) Other neutron absorber and neutron shielding material: Material containing high levels of hydrogen, such as water, polymer or polymer compounds (e.g. resin, polyethylene), used as a shielding material; boron or boron carbide may be used to absorb neutrons and suppress secondary gamma rays and for subcriticality control.
(l) Paint: Used as a surface coating material (e.g. for protection against corrosion, thermal emissivity).
(m) Silicone resin: Used as a filling or sealing material for gaps, notches or holes to prevent the accumulation or ingress of moisture.
(n) Silver: Used as a cladding of the metallic gasket for lid seals.
(o) Stainless steel (austenitic, ferritic, duplex or martensitic): Used as a structural material, shielding material, corrosion-resistant lid gasket seating surface and nuclear fuel cladding tube (older designs).
(p) Steel (i.e. carbon, alloy, high strength and low alloy steels): Used as a structural material or as a shielding material.
(q) Synthetic rubber: Used as an elastomer O-ring for the closure seal.
(r) Tungsten: Used as a shielding material.
(s) Wood or foamed polymer (e.g. polyurethane): Used as a shock absorbing material.
(t) Zirconium based alloys: Used for the cladding tube of nuclear fuel.

# 4. AGEING CONSIDERATIONS IN PACKAGE DESIGN AND AGEING MANAGEMENT

4.1. The package design should be documented by the package designer in accordance with the recommendations provided in SSG-66 [4] to provide evidence of its compliance with the applicable Transport Regulations. For package designs that require approval by a competent authority, the package design safety report should be the basis for the application to the competent authority.

4.2. SSG-66 [4] provides a package design safety report format, including a section for ageing considerations. The ageing effects on packaging and radioactive contents should be considered in the scope setting process for ageing management described in para. 3.9. The tasks that should be completed by the package designer include the following:

(a) Identification of anticipated conditions during service life that might influence ageing: These conditions include environmental and loading conditions during transport and storage (loaded and empty packages).
(b) Identification of potential ageing mechanisms that are relevant to the package design, taking into account the environmental and loading conditions during the service life of the package: The components to be considered and their materials should be listed (i.e. scope setting, see paras 3.9 and 3.10), along with the potential ageing mechanisms, based on the conditions the components might face during their service life. The components that might be subject to ageing effects, together with the ageing mechanisms involved, should then be identified and tabulated. The Annex contains an example of a scope setting table.
(c) Analysis of the influence of ageing on the design assumptions for demonstration of compliance with the Transport Regulations and the preventive measures to be taken: The materials and ageing mechanisms identified in (b) should be evaluated. If the resulting ageing effects have the potential to adversely affect the safety functions of the package (i.e. as assumed in the package design), preventive measures should be incorporated in the design and/or in operation. Appendix I includes typical methods to evaluate ageing effects and measures considered in the design of packages to prevent adverse effects due to ageing.
(d) Compilation of operational measures: The operational measures for detecting ageing effects and preventing adverse effects on the safety of packages (e.g. maintenance, inspections, monitoring, limitations on conditions of use) should be stated (see Sections 5 and 6).

## APPROACHES TO AGEING MANAGEMENT FOR TRANSPORT PACKAGES

4.3. Consideration of ageing mechanisms and their effects on the package should be included in the package design safety report (i.e. in the section entitled 'Ageing considerations') [4]. For each combination of packaging component material and ageing mechanism (see para. 4.2(c)), the package designer should evaluate the effects of ageing on the functions of the component and on the safety functions of the package and should define limitations on the environmental conditions and safety criteria for components, including relevant inspections to control them. The evaluation of ageing should be based on the package design and its operational conditions and service life.

4.4. Based on the results obtained from the initial evaluation (e.g. quantitative changes in material properties and material strength), the consequences of ageing mechanisms on the safety functions of the package should be assessed. If the consequences are negligible or within an allowable range, no measures to control the ageing mechanism need be taken.

4.5. A general approach to ageing management considerations for transport packages is shown in Table 1.

4.6. Some typical items of concern for ageing effects are listed in Appendix I.

## AGEING MANAGEMENT PROGRAMME FOR TRANSPORT PACKAGES

4.7. The ageing mechanisms and effects should be addressed using an ageing management programme. Recommendations relevant to an ageing management programme are provided in SSG-48 [5] and further information is available in Refs [9, 12, 15]. The typical content of an ageing management programme is presented in Appendix II.

4.8. The ageing management programme for dual purpose casks containing spent fuel should be defined by following the approach in Appendix II. Further information is provided in Ref. [12]. An ageing management programme might also be defined for a package containing radioactive material other than spent fuel based on the information included in Refs [8, 9, 12] and in Appendix I and Appendix II. Other components that are not used during storage but are to be used for the shipment after storage (e.g. shock absorbers) should also be included in the ageing management programme.

4.9. The effectiveness of the ageing management programme should be periodically evaluated to take into account new knowledge and feedback from the programme; performance indicators should be updated and adjusted, as appropriate. Relevant knowledge includes information on the operation of the component, surveillance and maintenance histories, information from the results of research and development, and operating experience.

TABLE 1. AGEING MANAGEMENT CONSIDERATIONS FOR TRANSPORT PACKAGES

| | Packagings intended to be used for a single transport | Packagings intended for repeated use | Packages intended for shipment after storage |
|---|---|---|---|
| Management system | Management system of the responsible organization[a], in accordance with para. 306 of the Transport Regulations | Management system of the responsible organization[a], in accordance with para. 306 of the Transport Regulations | Management system of the responsible organization[a], in accordance with para. 306 of the Transport Regulations, or of the organization responsible for storage |
| Package design (package design safety report) | Relevant ageing mechanisms, in accordance with para. 613A of the Transport Regulations, should be considered | Relevant ageing mechanisms, in accordance with para. 613A of the Transport Regulations, should be considered | Relevant ageing mechanisms, in accordance with para. 613A of the Transport Regulations, should be considered for both shipment and storage |
| | Relevant ageing effects should be considered in the design (see paras 2.2 and 2.5) | Relevant ageing effects should be considered in the design | Relevant ageing effects should be considered in the design |
| | Pre-shipment inspection should be conducted | Maintenance programme with periodic and pre-shipment maintenance and inspections should be conducted | Maintenance programme with periodic and pre-shipment maintenance and inspections should be conducted |

TABLE 1. AGEING MANAGEMENT CONSIDERATIONS FOR TRANSPORT PACKAGES (cont.)

| | Packagings intended to be used for a single transport | Packagings intended for repeated use | Packages intended for shipment after storage |
|---|---|---|---|
| Package design (package design safety report) (cont.) | | For packages requiring approval, an ageing management programme should be in place to control and confirm that ageing effects are within an acceptable range, as defined by the package design (see para. 809(f) of the Transport Regulations) | An ageing management programme should be in place to control and confirm that ageing effects are within an acceptable range, as defined by the package design (see para. 809(f) of the Transport Regulations)<br><br>A gap analysis programme should be used for periodic evaluations of changes in regulations, in technical knowledge and in the state of the package design during storage (see para. 809(k) of the Transport Regulations) |
| Package operation | Manufacturing confirmation should be obtained for packaging conformity with the design, in accordance with para. 501 of the Transport Regulations<br><br>Shipment confirmation should be obtained for package content and design, in accordance with paras 502 and 503 of the Transport Regulations | Manufacturing confirmation should be obtained for packaging conformity with the design, in accordance with para. 501 of the Transport Regulations<br><br>Shipment confirmation should be obtained for package content and design, in accordance with paras 502 and 503 of the Transport Regulations | Manufacturing confirmation should be obtained for packaging conformity with the design, in accordance with para. 501 of the Transport Regulations<br><br>Shipment confirmation should be obtained for package content and design, in accordance with paras 502 and 503 of the Transport Regulations |

TABLE 1. AGEING MANAGEMENT CONSIDERATIONS FOR TRANSPORT PACKAGES (cont.)

| | Packagings intended to be used for a single transport | Packagings intended for repeated use | Packages intended for shipment after storage |
|---|---|---|---|
| Package operation (cont.) | Pre-shipment inspection should be conducted | Maintenance should be conducted in accordance with a maintenance programme with periodic and pre-shipment inspections, including periodic monitoring of ageing effects | Periodic maintenance should be conducted during storage, in accordance with a maintenance programme, including periodic monitoring of ageing effects in accordance with the ageing management programme |
| | | | Periodic monitoring of environmental and operational conditions should be conducted in accordance with the ageing management programme |
| | | | Periodic monitoring of gaps should be conducted in terms of compliance with new regulations and technologies, in accordance with a gap analysis programme |

[a] The responsible organization is the entity responsible for the design, manufacture or operation of a package.

### Packagings intended to be used for a single transport

4.10. A wide range of packagings are designed to be used for a single transport. For packagings stored for a prolonged period of time (typically more than a year) before transport, any deformation, rust, corrosion or other defect on the packaging should be detected and assessed prior to shipment. When necessary, the packaging should be repaired or replaced.

### Packagings intended for repeated use

4.11. A wide range of packages are designed for repeated use. For package designs that do not require competent authority approval (i.e. excepted packages, industrial packages and Type A packages), the most common ageing considerations include the following:

(a) The activity of radioactive contents is relatively low, thus the cumulative irradiation of package components and the decay heat from the radioactive contents are not significant, even after repeated use. Provided it is adequately justified in the package design safety report, no ageing effects due to irradiation or thermal loadings need to be considered.
(b) Any deformation, rust, corrosion or other defects in the packaging should be detected by the maintenance programme (see Section 6) and during pre-shipment inspections. If such ageing effects are detected, the packaging should be repaired or replaced.
(c) For an empty packaging that has previously contained radioactive material, ageing effects should have been evaluated in the assessment of the package when it was loaded with radioactive material.
(d) Cyclic mechanical loadings during handling and transport can contribute significantly to the development of ageing effects. These effects should be considered.

4.12. For package designs that require competent authority approval (i.e. Type B(U), Type B(M) and Type C packages, and packages containing $UF_6$ or fissile material), the consideration of ageing effects should take into account the activity of the radioactive contents permitted by the approval. Irradiation and decay heat can potentially cause ageing effects, and the usage of the packagings (e.g. service life, number of shipments) is also a factor. The parameters to be included in the package design safety report should be justified and evaluated on the basis of the specific package design. Ageing management issues that might be relevant to such transport packages, depending on the package design, are as follows:

(a) Embrittlement of stainless steel, carbon steel or low alloy steel should be considered for very high neutron irradiation levels [15].
(b) Changes in the mechanical properties of aluminium and copper alloys should be considered for very high neutron irradiation levels [16, 17].
(c) The ageing effects on lead used as shielding do not need to be considered because no clear change in the properties of lead due to irradiation has been reported.
(d) The radiation resistance of resins (e.g. epoxy, silicone) should only be considered for very high neutron and gamma irradiation levels [18]. The thermal degradation might need to be considered.
(e) In accordance with structural design and construction codes (e.g. Ref. [19]), creep does not need to be considered for carbon steel and low alloy steel for temperatures up to 350°C, or for stainless steel for temperatures up to 425°C. As the temperature of these materials used for a shell, a bottom plate, a lid, lid bolts and trunnions during transport is generally less than 170°C, creep is not expected in these components. As the temperature of the stainless steel basket for spent fuel is generally less than 180°C for a wet type package and less than 390°C for a dry type package, creep and dimensional change in the basket do not need to be considered.
(f) Irradiation and thermal degradation of elastomer O-rings (e.g. for lid seals) should be considered.
(g) Corrosion of the external surfaces of packaging made of carbon steel or low alloy steel should be considered. Contact with sea salt particles and road chemicals during transport or in the storage environment might initiate pitting, crevice corrosion and/or stress corrosion cracking on stainless steel surfaces. For storage indoors, storage conditions might be specified and monitored to exclude all ageing mechanisms that involve electrolytes. For example, the humidity and temperature during storage might be specified and monitored to exclude any condensation on the package surfaces (dew point).
(h) The fatigue of trunnions should be considered, and the trunnions should be replaced when the number of lifting operations exceeds a calculated limit to avoid a fatigue failure. When replacement of the trunnions is not possible because of the design (e.g. when the trunnions are an integrated part of the packaging), other measures should be implemented to take into account their fatigue.
(i) Degradation by bacteria and/or by the humidity of wood used as a shock absorbing material should be considered. Wood degradation might lead

to dry rot or wet rot and result in a loss of strength and/or degradation of mechanical properties. Normally, this does not need to be considered, providing the wood is sealed tightly in a metallic casing that is confirmed to be leaktight during maintenance and/or periodic inspection. The temperature and irradiation of the wood are low enough that such ageing effects (e.g. a change in mechanical properties, decomposition of the adhesive used to form a plywood) do not need to be considered.

(j) Ageing effects on the radioactive contents of these packages do not need to be considered because the duration of a single shipment is relatively short (one year or less).

4.13. For packages containing fissile material, the ageing effects on any components that are intended to maintain subcriticality should also be considered in the package design safety report. Examples of criticality related ageing considerations are as follows:

(a) For transport packages containing fresh (unirradiated) fuel, the effects of irradiation and temperature on the ageing of the packages are almost negligible.
(b) For transport packages containing spent fuel, the effects of high temperature should be considered because possible dimensional changes in the fuel basket might affect criticality safety. The depletion of boron-10 used as the neutron absorber in the basket should be considered in terms of the effects on criticality safety.
(c) For transport packages containing spent fuel, the evaluation of thermal ageing of components made of hardened stainless steels and aluminium alloys should be considered if the components are located inside the package containment, in close proximity to spent fuel.

4.14. Packagings for the transport of $UF_6$ are to be designed, manufactured, inspected, tested and maintained in accordance with international and national standards (e.g. Refs [20, 21]). The maintenance programmes specified in these standards have been established with consideration of the ageing mechanisms; thus, no further consideration of the potential ageing mechanisms is needed when these packages are maintained and inspected in accordance with such standards (see para. 613A.6 of SSG-26 (Rev. 1) [3]).

**Packages intended to be used for shipment after storage**

4.15. Considerations of ageing effects for packages intended to be used for shipment after storage are different from those for packagings intended for repeated use. The major differences are as follows:

(a) The condition of the radioactive contents during storage should be assessed, with due consideration of ageing effects, and this assessment should be reflected in the package design safety report. The decay of the radioactive contents during storage should also be taken into account.
(b) Packages should maintain their safety functions and be able to withstand the conditions of both storage and transport (i.e. shipment after storage).
(c) Transportability after storage should be ensured during the period of storage to ensure compliance with the requirement established in para. 503(e) of the Transport Regulations.

4.16. General ageing management considerations in relation to the storage of spent fuel are as follows (the specific information to be included in the package design safety report should be determined by evaluations of the specific package design):

(a) The containment function of the package during storage needs to be maintained. The metal gasket should be demonstrated (through testing and analysis) to be able to maintain its leak rate within the design limits over a defined storage period. The deterioration of the leaktightness during storage should be monitored, for example by inter-lid pressure monitoring for double lid systems. Corrective actions should be taken in the case of leakage.
(b) For fuel baskets, the ageing effects of an elevated temperature environment for long term storage should be considered. For example, an age-hardened aluminium alloy with a higher mechanical strength might be used as the basket material; however, this alloy can eventually lose its enhanced strength in an elevated temperature environment.
(c) The ageing effects associated with changes in the behaviour of the radioactive contents (e.g. creep, hydride reorientation, embrittlement, reconfiguration of fissile material), especially for spent fuel, should be considered.

# 5. MAINTENANCE OF TRANSPORT PACKAGES

5.1. The maintenance of a packaging involves planned inspections, tests and repairs. The purpose of repairs is to restore the condition in accordance with the package design specifications by replacing and repairing components. Repairs should be planned as part of preventive maintenance and may be made as part of corrective maintenance (i.e. in response to unexpected events during operation). The scope of maintenance operations includes actions to detect and correct ageing effects and other actions necessary to prevent or repair damage incurred during the use of the packaging.

5.2. The maintenance of a packaging should be performed before and/or after each shipment or at planned intervals. Information on when maintenance was previously undertaken or when the next maintenance is due should be readily available. The aim of this, in conjunction with appropriate maintenance records, should be to demonstrate that the packaging continues to comply with the Transport Regulations.

5.3. When planning transport, consignors should take into account the maintenance intervals to ensure that the packaging will be available for its next maintenance.

5.4. Preventive maintenance should be performed with a periodicity established by the designer and stated in the package design safety report and/or specified in the certificate of approval. This maintenance usually consists of:

(a) A series of inspections and tests to demonstrate that the packaging retains the capability specified in the package design safety report for safely transporting the radioactive contents;
(b) The scheduled replacement of components (e.g. gaskets, seals, screws).

5.5. Preventive maintenance might be performed with the following periodicity:

(a) Routine (e.g. before loading of radioactive contents, before and after each shipment);
(b) Short term (e.g. annually);
(c) Medium term (e.g. every 3–5 years);
(d) Long term (e.g. every 10 years);
(e) After a specified number of shipments.

5.6. Corrective maintenance of packaging should be performed when a non-compliance is found during an inspection before or during use or when handling or transport cause the safety performance of the packaging to be impaired. Corrective maintenance could include the replacement of broken thread inserts (e.g. helicoils); the replacement of damaged couplings and valve fittings; or the replacement of a damaged, removable part (e.g. port cover, bolt).

5.7. If a package is not in compliance with the Transport Regulations, it cannot be transported to another location, except when the shipment has been approved under special arrangement, in accordance with para. 310 of the Transport Regulations.

5.8. The owner or user[11] of the packaging should perform or arrange for the maintenance of the packaging. The designer should provide maintenance instructions to the owner or user.

## MAINTENANCE CONSIDERATIONS IN TRANSPORT PACKAGE DESIGN

5.9. The package designer should state the necessary maintenance arrangements within the package design safety report.

5.10. The maintenance needs of package components should be identified during the design process, including which inspections and tests need to be performed, which components need to be replaced, and what the frequency of and schedule for these activities should be.

5.11. When identifying maintenance needs, consideration should be given to regulatory requirements; codes and standards; the conclusions of the package design analysis; the properties and performance of the package materials and components; the usage of the package components; fabrication techniques; and good practices. When a purchased component is used in the package design, the package designer should take into account the recommendations of the vendor with regard to the frequency and type of maintenance and testing.

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[11] In the context of this Safety Guide, 'owner or user' is intended to mean the organization or person responsible for ensuring that transport packagings are maintained throughout their service life. Depending on the specific circumstances, this may be the owner of the packaging or the user (consignor). If packages are in storage (e.g. dual purpose casks), 'owner or user' may also include the operating organization responsible for the storage facility. The roles and responsibilities of owners and users are summarized in Appendix III.

5.12. The package design should facilitate access to components to perform maintenance operations, as far as practicable.

## MAINTENANCE ACTIVITIES ON TRANSPORT PACKAGES

5.13. Maintenance activities should be defined in the operating and maintenance instructions and should also be set out in the package design safety report. Operating and maintenance instructions should be made available to all relevant parties. These instructions should include all activities relevant to the operation, inspection and repair of the packaging, and they should be used by the organizations in charge of operation and maintenance as a basis for establishing their relevant procedures.

5.14. The person or organization performing the maintenance should be qualified, and all maintenance activities should be performed in accordance with an appropriate management system (see paras 6.13–6.16). The latest operating procedures, approved in accordance with the management system, should be made available to all relevant persons.

5.15. During the service life of the packaging, both the owner and the user should maintain sufficient records on the maintenance undertaken to demonstrate that the requirements of the maintenance programme, of the package design safety report and of the Transport Regulations have been met. Documentation on the maintenance undertaken should be retained for the period of time specified by the management system. For multiple packagings of the same design, records should indicate the serial number of each individual packaging.

5.16. Corrective maintenance of packaging could lead to modifications of safety relevant components. These modifications could affect the safety of the package and/or its operating instructions. A package with such modifications might not be covered by the original package design safety report; therefore, potential design modifications should be analysed by the package designer to verify that the design will continue to comply with the Transport Regulations. If the result of the verification is that the modifications are not covered by the original package design safety report, the package design safety report should be updated and, if applicable, an application should be made for approval of the revised package design.

5.17. Where possible, maintenance should be performed using original spare parts and materials. If original components are not available, the use of other components should be analysed as a potential modification of the package design.

5.18. The process of analysing potential design modifications following corrective maintenance should be adequately documented [22]. Both the owner and the user of the packaging should keep records of the modifications made, including the analyses performed. These records should be controlled and maintained in accordance with the management system and be made available to the competent authority on request.

## INSPECTION AND TESTING IN THE MAINTENANCE OF TRANSPORT PACKAGES

5.19. The inspection and testing activities should be defined in the maintenance programme, taking into account the classification of the packaging component, based on its safety relevance (see para. 3.9).

5.20. Inspection and periodic testing should be conducted in accordance with the maintenance instructions provided by the package designer in the package design safety report.

5.21. The packaging may be inspected before and/or after each shipment, as appropriate to the design. In this case, the inspection results should be recorded and may be used as a reference for periodic maintenance. The components to be inspected may include the packaging exterior surface, the cavity, the basket, O-rings and gaskets, seals, nuts and bolts, fasteners and their locking devices, padlocks or other securing devices, trunnions, lifting lugs, shock absorbers, valves, welding seams, coating, paintwork, and permanent markings [22].

5.22. Visual inspection is a common and convenient method that should generally be employed as the first step in the inspection of a packaging. The next step, if appropriate, should be to take measurements to verify that the exterior, dimensions and tolerances of the packaging comply with the design. Typically, these first two steps include checking the following:

(a) The condition of the exterior of the packaging;
(b) The legibility of permanent markings;
(c) The condition of liners, other internal parts, O-rings and gaskets;

(d) The condition of sealing surfaces (e.g. damage, corrosion, residual material such as burrs);
(e) The condition of wooden parts (e.g. drying, shrinkage, deformation, cracks or other damage on the casing of shock absorbers);
(f) The condition and operation of closures, valves, ventilation patches and devices;
(g) The condition and operation of padlocks, lifting attachments and tie-downs;
(h) The condition of nuts, bolts and fasteners;
(i) The condition and operation of other parts or components, as necessary.

5.23. Welds (e.g. on the seams of lifting lugs) may be examined by non-destructive testing, in accordance with the information given by the package designer in the maintenance instructions.

5.24. Components relied on for criticality safety (e.g. neutron absorbers) should be inspected for deformation or displacement if the geometry of those components is relied on for criticality safety.

5.25. Trunnions and lifting lugs should be visually inspected prior to each shipment for permanent deformation, wear, abrasion or cracking. Inspection results should be recorded and evaluated against established acceptance criteria. In addition, trunnions should undergo periodic tests, and key areas should be inspected for defects. When a loading test is performed, the load should be applied for a certain specified period of time; when the load no longer applies, all components should be checked for residual deformation. Inspection methods may include dimensional verification, visual inspection and non-destructive testing of key areas.

5.26. For some package designs — normally those intended for repeated use and requiring competent authority approval — the cask body should be subject to periodic pressure tests. The test media may be gas or liquid. The pressure should be slowly increased and maintained at a fixed value for a specific time in accordance with the design requirements.

5.27. For some package designs, a leaktightness test should be conducted periodically and/or after the replacement of seal parts, both before and after loading of the contents. Gas leakage may be monitored by several methods (e.g. a helium leakage test can be used for greater sensitivity). Additional information is available in Ref. [23].

5.28. For some package designs, a thermal performance assessment should be conducted to verify the heat transfer capability of the packaging over its service life. Thermal performance can be evaluated by using the temperature measurement data obtained during transport or, if applicable, during storage.

5.29. Shielding performance tests should include tests for neutron and gamma radiation shielding, as applicable. Shielding performance can be evaluated by using the dose rate measurement data obtained during transport or, if applicable, during storage, or the test may be conducted during periodic maintenance.

5.30. Periodic tests and replacement schedules for packaging components and materials (e.g. screws, gaskets, valves, rupture discs) should be conducted if indicated in the package design safety report or required by the competent authority.

# 6. MAINTENANCE PROGRAMME FOR TRANSPORT PACKAGES

6.1. The package design safety report should include a description of the maintenance programme for transport packages as part of the maintenance instructions. The maintenance programme should address the following elements:

(a) Package components subject to the maintenance programme;
(b) Type and description of maintenance operations, including inspection methods, scheduled replacement of components (i.e. after a specified amount of time or number of transport operations), tools needed and justification for spot checks;
(c) Frequency of maintenance operations.

6.2. The description of the maintenance programme should also specify the following, as applicable:

(a) Maintenance requirements before and after each shipment;
(b) Maintenance activities that are needed at periodic intervals throughout the service life of the packaging;
(c) Maintenance requirements during periods of non-use.

6.3. The description of the maintenance programme should include a ‘scope’ section that provides basic information on the type and model of packaging, and other general information. The safety relevant packaging components that need to undergo maintenance should also be identified in this section of the maintenance programme.

6.4. The description of the maintenance programme should include a scheme that systematically addresses the content of paras 6.1(b) and (c), for each packaging component that undergoes maintenance and for each activity described in para. 6.2, including a description of planned inspections, the organizational procedures for implementing unplanned inspections and instructions for the maintenance of the packaging.

6.5. The description of the maintenance programme should indicate the process for keeping, archiving and retrieving maintenance records. The aims of these maintenance records should be as follows:

(a) To record that maintenance has been performed in accordance with the package design safety report and certificate of approval, as applicable;
(b) To record the completion of each inspection or test, as well as the result (including any corrective actions taken), to create an audit trail demonstrating satisfactory performance of past maintenance.

6.6. The maintenance records should be in the format defined in the relevant procedure, in accordance with the management system, and should be kept for all the tests and inspections defined in the maintenance programme for transport packages.

6.7. The maintenance records should contain the following information, as appropriate (see Ref. [22]):

(a) Reference to the procedure that specifies the maintenance requirements.
(b) The packaging identification, such as the model or design and a unique identification reference (i.e. a serial number).
(c) Components of the packaging subject to inspection or maintenance.
(d) The inspections and tests performed.
(e) Statement of compliance with the acceptance criteria and associated evidence. In some cases, this may be a simple pass/fail indication for each packaging component. In other cases, practical acceptance criteria should be established in the relevant procedure.
(f) The name and signature of the qualified person who performed the maintenance (if necessary, at each step of the maintenance procedure).
(g) The name and signature of a qualified person responsible for quality control in steps involving instrumentation (e.g. pressure gauges, leak detectors).

(h) The validity period (i.e. the date when the next inspection or test is due).
(i) The serial numbers and calibration dates for the tools, equipment and instrumentation used.
(j) Remarks and other information that needs to be recorded.

6.8. The maintenance procedure should be supported by the training and qualification records of the persons performing the work and by records of calibration, procurement and, if applicable, shelf life (for replacement parts). These records also need to be available for audit.

6.9. In the case of complex designs (e.g. Type B(U), Type B(M) and Type C package designs; packages containing fissile material), or for each package design in use for other cases, in addition to the maintenance records, an individual record (in the form of an electronic log or log book) should be compiled for each packaging. This individual record should provide the following [22]:

(a) Information on any aspects encountered during maintenance activities that could necessitate modifications of the maintenance programme (e.g. an increase or decrease in the frequency of inspections, stricter or more lenient test criteria).
(b) Operating experience from the use of the packagings (i.e. that might result in proposals for design improvements). This operating experience should be shared between the owner or user of the packaging and the designer.

6.10. The individual packaging record should contain the following information, as appropriate:

(a) The packaging identification, such as the model or design and a unique identification reference (i.e. a serial number);
(b) A list of applicable references to the operating quality plans;
(c) Certificate number(s);
(d) Records of inspections and tests performed before first use;
(e) Maintenance records;
(f) Quality control records (e.g. modification certificates, repair certificates);
(g) List of non-compliances and corrective actions taken;
(h) Number of shipments (loaded and empty);
(i) Records of inspections and spot checks performed on packagings of the same design, if available.

6.11. When maintenance operations are to be performed remotely from the location where the maintenance records are stored, the owner or user of the packaging should make the relevant records available at the location of the operation. The owner or user of the packaging should also ensure that the maintenance records are available to the competent authority on request (see also Appendix III).

6.12. In accordance with the management system, procedures for managing the tools, equipment and spare parts used for maintenance, and procedures for keeping the appropriate records, may be established in the maintenance programme.

## MANAGEMENT SYSTEM FOR THE MAINTENANCE PROGRAMME FOR TRANSPORT PACKAGES

6.13. Documentation on the maintenance and repair of packagings should be prepared, reviewed and issued in accordance with the management system.

6.14. If the maintenance programme is changed, including with regard to maintenance operations, instructions and/or technical parameters, the programme documentation should be revised and approved accordingly and reissued to the owners or users of the packaging.

6.15. Maintenance documents should be retained for the period of time specified by the management system, taking into account the type of packaging and its usage.

6.16. Further recommendations are provided in IAEA Safety Standards Series No. TS-G-1.4, The Management System for the Safe Transport of Radioactive Material [24].

## MONITORING, INSPECTION AND MAINTENANCE FOR AGEING MANAGEMENT OF TRANSPORT PACKAGES

6.17. For packagings intended for repeated use or for packages intended to be used for shipment after storage, ageing effects relevant to the safety of the package should be monitored by periodic inspection and pre-shipment inspection.

6.18. For packagings intended for repeated use or for packages intended to be used for shipment after storage, appropriate monitoring should be conducted to ensure that the impacts of ageing effects on the safety of the package are within the acceptance criteria defined in the package design safety report. If the acceptance criteria are exceeded, then corrective maintenance should be undertaken, as defined in the maintenance programme.

6.19. A programme should be prepared at the design stage for systematic integration of monitoring, inspection and maintenance related to ageing management. This programme should be reflected in the package design safety report (i.e. in the sections entitled ‘Package operations’ and ‘Maintenance’; see SSG-66 [4]), as applicable. The programme should then be implemented by the organization in charge of maintenance and/or by the owner or user of the packaging, as relevant.

**Packagings intended for repeated use**

6.20. The maintenance of packagings intended for repeated use should consist of periodic inspections and scheduled replacement of some components (e.g. O-rings, movable components such as valves), which, in conjunction with pre-shipment inspections, should ensure that the safety functions of the package continue to be fulfilled.

*Pre-shipment inspection of packages*

6.21. The pre-shipment inspection should verify that the package is prepared as designed and is ready for shipment in compliance with the Transport Regulations. The pre-shipment inspection should be performed by the consignor of the package (or by another organization on behalf of the consignor).

6.22. The pre-shipment inspection should be defined in the package design safety report (i.e. in the sections entitled ‘Package operations’ and ‘Maintenance’, as applicable; see SSG-66 [4]).

6.23. Pre-shipment inspections may include the following considerations for detecting ageing effects:

(a) Visual inspection: This inspection might detect ageing effects on external surfaces of the package (e.g. corrosion, deterioration of painting, cracks, deformation).
(b) Leaktightness checks: Where appropriate, the containment boundary should be checked, including lid seals and O-rings.
(c) Dose rate measurements: The results may indicate potential ageing effects on the shielding performance.
(d) Checks for subcriticality: For some packages containing fissile material, ageing effects on the components relied on to maintain subcriticality might be detected through a visual check before loading (e.g. deformation, cracks, corrosion, peeling off of neutron absorber).

(e) Temperature measurements: Abnormalities in the package surface temperature and/or surface temperature distribution may indicate deterioration of heat transfer function due to ageing effects (e.g. a loss or a property change of heat conducting medium, a loss or a change of thermal path).
(f) Lifting attachment inspections (e.g. visual inspection, loading test).

*Periodic inspection of packaging*

6.24. Inspections are conducted periodically, either on the empty packaging or on the package containing radioactive contents, depending on the purpose of each item being inspected, to confirm that its safety functions continue to be fulfilled. Depending on the type of package, the inspection activities and inspection intervals may be determined through a systematic analysis, such as a failure modes and effects analysis [25].

6.25. Periodic inspections should be performed by the organization in charge of maintenance, on behalf of the owner or user of the packaging. These inspections should include the items identified in the package design safety report (i.e. in the section entitled ‘Maintenance’; see SSG-66 [4]).

6.26. Depending on the package design, periodic inspections for detecting ageing effects may include the following:

(a) Visual inspection to detect ageing effects on accessible packaging component surfaces (e.g. corrosion, coating defects).
(b) Non-destructive testing (other than visual inspection) to detect the existence, initiation and/or propagation of cracks in packaging components or a reduction in the thickness of components due to ageing.
(c) Leaktightness checks to detect ageing effects on the lid seals and O-rings, where appropriate.
(d) Checks for subcriticality in spent fuel packages to detect ageing effects on the basket structure by dimensional measurements or calibre testing (using gauges), and inspections for cracks and other defects. The neutron absorber depletion can be calculated on the basis of the records of transport operations, and the general condition of neutron absorbers may be monitored by visual inspection.
(e) Operational checks to detect ageing effects of movable components.
(f) Lifting attachment inspection (e.g. visual inspection, loading test, non-destructive testing) to detect ageing effects on the attachments, including weld joints, when necessary.

(g) Thermal performance inspection to detect ageing effects on components due to heat dissipation, by observing trends in the temperature measurement inspections for each shipment or by conducting periodic thermal tests.
(h) Shielding performance measurement to detect ageing effects on shielding components by observing trends in the dose rate inspections for each shipment or by taking periodic direct measurements of the dose rate around the package and comparing them with the expected dose rate considering the loaded radioactive contents.
(i) Pressure tests to detect ageing effects on pressure retaining components.
(j) Inspection and/or destructive testing of analogues. Where it is undesirable or impractical to examine a package component, it may be possible to use an analogue (i.e. an equivalent component) for periodic inspection, non-destructive testing and/or destructive testing. The condition of the analogue should be representative of the condition of the package component because the analogue will be subjected to the same transport conditions (e.g. impacts, vibrations, temperature variations) as the package component during shipments.

**Packages intended to be used for shipment after storage**

6.27. The ageing management programme for packages intended to be used for shipment after storage should be used to determine the associated maintenance programme and the operating and maintenance instructions, which should include the following:

(a) Pre-shipment inspection of the package before loading for storage or before shipment to the storage facility;
(b) Receiving inspection of the package at the storage facility;
(c) Monitoring programme during storage;
(d) Pre-shipment inspection of the package intended for shipment after storage.

These inspections should not be limited to the detection of ageing effects but should also confirm transportability after storage (i.e. compliance with the Transport Regulations should also be assessed to ensure that the safety functions of the package have been maintained without any adverse ageing effects and that the package is ready for shipment).

*Pre-shipment inspection of packages before loading for storage or before shipment to the storage facility*

6.28. This pre-shipment inspection should be in accordance with the provisions described for packages intended for repeated use in paras 6.21 and 6.22.

6.29. Typical pre-shipment inspection activities are listed in para. 6.23. However, for packages intended to be used for shipment after storage, the purpose of the pre-shipment inspection is not to identify ageing effects, but to record the package condition at the time it is shipped for storage.

*Receiving inspection of packages at the storage facility*

6.30. The primary purposes of this inspection are to verify (a) that the package has been transported without being subject to any event that affected its safety functions and (b) that the package complies with the storage specifications. This inspection should provide a record of the initial conditions of the package to be stored. The results should be compared with the results of the pre-shipment inspections (see paras 6.28 and 6.29).

6.31. The receiving inspection at the storage facility should be performed by the organization responsible for the storage, on the basis of the information from the consignor of the shipment before storage, the packaging owner and the owner of the radioactive contents, as appropriate.

6.32. The receiving inspection should be specified in the relevant parts of the package design safety report (i.e. in the sections entitled 'Package operations' and 'Maintenance', as applicable; see SSG-66 [4]).

6.33. The receiving inspection results should be retained throughout the service life of the packaging and retained by the organization responsible for the storage, the packaging owner and the owner of the radioactive contents, in accordance with regulatory requirements and the relevant management systems. The results should be made available to other relevant interested parties and should be used as part of the evaluation of ageing effects.

*Monitoring programme during storage*

6.34. The monitoring of the package during storage might cover the activities described in paras 6.30–6.33 for the receiving inspection of the package at the storage facility; it is not necessary for them to be two completely independent processes. Monitoring during storage may be conducted continuously, or it may be conducted periodically at intervals that are commensurate with the importance to safety. On the basis of an appropriate justification, monitoring may be conducted on a representative sample of packages of the same design. The practicability of monitoring (e.g. in high dose rate areas or areas that are otherwise difficult to access) should also be considered.

6.35. The programme of monitoring during storage should be implemented by the organization responsible for the storage (or by another organization on its behalf), on the basis of the information from the packaging owner and the owner of the radioactive contents, as appropriate.

6.36. The storage facility is expected to be operated in compliance with regulatory requirements and should be subject to the maintenance programme specified in the package design safety report.

6.37. The results of monitoring activities during storage, if applicable, should be retained throughout the service life of the packaging and retained by the organization responsible for storage, the packaging owner and the owner of the radioactive contents, in accordance with regulatory requirements and the relevant management systems. The results should be made available to other relevant interested parties and should be used as a part of the evaluation of ageing effects.

6.38. Depending on the package design, the programme of monitoring during storage may include the following:

(a) Visual inspection to detect ageing effects and evidence of excessive mechanical impact on the accessible packaging component surfaces (e.g. corrosion, coating defects).
(b) Non-destructive testing (other than visual inspection) to detect the existence, initiation or propagation of cracks in packaging components, or a reduction in the thickness of components due to ageing.
(c) Inter-lid or inter-seal pressure monitoring — which may be conducted continuously or intermittently and may substitute the leaktightness inspection of lid seals — to detect ageing effects on the lid seals. If no anomaly is detected, this demonstrates that the leaktightness of the lid seals has been maintained and that, consequently, the atmosphere of the cavity has been maintained. Pressure transducers or pressure switches may be used for monitoring the pressure between the lids or the metal seals. Transducers should be periodically calibrated.

(d) Dose rate measurements on the surface of the package or around the package — which may be performed continuously or intermittently — to detect ageing effects on shielding components.
(e) Checks for subcriticality — normally undertaken through a combination of visual inspections and temperature measurements — to detect ageing effects on components relied on to maintain subcriticality. If no evidence of excessive mechanical impact on the package is identified during the visual inspection, there should be no change in the packaging configuration, including the fuel basket. If there is no abnormal change in package temperature, this indicates that the heat dissipation performance of the package has been maintained as designed and there should be no change in the packaging configuration, including the fuel basket.
(f) Temperature measurement inspection — which may be performed continuously or intermittently — to detect ageing effects on components related to heat dissipation on the basis of the history of temperature change and the decay heat generated by the radioactive contents.

Depending on the type of radioactive contents stored, the monitoring programme could rely on the inspection prior to storage and the use of test or research results and safety analysis to demonstrate that the radioactive contents are maintained during storage. In addition, indirect monitoring from other inspections may be used for early detection of a potential problem with the radioactive contents, whenever possible. If no significant event affecting the package occurs or is detected during storage, changes in the condition of the contents that could affect the safety of the package can be reasonably expected not to arise, on the basis of appropriate justification.

*Pre-shipment inspection of packages intended for shipment after storage*

6.39. The recommendations provided in paras 6.28 and 6.29 on pre-shipment inspection of the package before loading for storage or before shipment to the storage facility should apply for this pre-shipment inspection. Some types of inspection can be conducted directly, while others (e.g. checks of cavity pressure, subcriticality and radioactive contents) should be substituted by records of visual inspection, inter-lid pressure monitoring and temperature measurement during storage. Such substitutions should be justified on the basis of the package design safety report.

6.40. If the following points are confirmed, it can be concluded that there have been no abnormal changes in the condition of the spent fuel [12]:

(a) During preparation of the package at the nuclear power plant, moisture was removed and the package was filled with inert gas in a way that satisfies the design conditions.
(b) The package passed the inspection of contents for shipment from the nuclear power plant to the storage facility, and no abnormal external forces were exerted during transport.
(c) There were no incidents that might have damaged the integrity of the spent fuel during storage.
(d) The inert atmosphere inside the package has been maintained during storage.

Consequently, when the package is shipped from the storage facility, especially if there is no fuel reloading equipment, the inspection of the contents during the pre-shipment inspection can be substituted by the documents that confirm the listed items.

6.41. The results of the pre-shipment inspection of a package intended for shipment after storage are expected to be recorded in accordance with regulatory requirements and the relevant management systems throughout the service life of the packaging and should be retained by the organization responsible for storage, the packaging owner and the owner of the radioactive contents. The results should be made available to other interested parties and should be used as part of the evaluation of ageing effects.

6.42. The pre-shipment inspection of packages intended for shipment after storage should also refer to the results from all the inspections and monitoring described in paras 6.28–6.38.

6.43. If the packages are loaded and stored in the same facility or in separate facilities on the same site — that is, no off-site transport is conducted before storage — the activities described in paras 6.28–6.33 are not necessary. However, in such cases, inspections to confirm the safety of the packages should be conducted (e.g. after loading, before movement). These inspections are similar to those described in paras 6.28 and 6.29 and, as appropriate, paras 6.34–6.38.

# 7. THE ROLE OF THE COMPETENT AUTHORITY IN AGEING MANAGEMENT AND MAINTENANCE OF TRANSPORT PACKAGES

7.1. Both the owner and the user of the packaging should be subject to supervision by the competent authority. When necessary, the competent authority may make specific arrangements for the supervision of ageing management and maintenance programmes for transport packages — in accordance with the characteristics and conditions of use of the packages — and organize compliance inspections accordingly, including on the site.

7.2. A compliance inspection by the competent authority relating to the ageing management and maintenance programmes for transport packages should consider the following:

(a) List of packagings (including model, manufacturer, type and serial numbers);
(b) The requirements of the Transport Regulations, as applicable;
(c) The ageing management programme;
(d) Package operations and their impact on ageing mechanisms;
(e) The maintenance programme and maintenance instructions for packages, with a focus on safety relevant components and the fulfilment of safety functions;
(f) The management system (e.g. personnel training, material and equipment, suppliers, documentation);
(g) Application of the radiation protection programme (see para. 302 of the Transport Regulations) to ageing management and maintenance.

Examples of inspection checklists can be found in IAEA Safety Standards Series No. SSG-78, Compliance Assurance for the Safe Transport of Radioactive Material [26]. These examples can be used as templates to develop specific ageing management and maintenance checklists.

7.3. The manufacture of packagings (including the production of spare parts) should also be subject to surveillance by the competent authority.

7.4. A package design can be used in countries other than the country of origin (i.e. the country of the package designer or the approval authority). Consequently, maintenance operations and ageing management are not necessarily performed in the country of origin. In this case, the relevant competent authorities of each country[12] should coordinate their activities to ensure effective surveillance of the ageing management and maintenance programmes.

# 8. ADMINISTRATIVE MATTERS IN RELATION TO THE AGEING MANAGEMENT AND MAINTENANCE OF TRANSPORT PACKAGES

8.1. Paragraph 802 of the Transport Regulations states that competent authority approval is required for the designs of certain types of package (i.e. Type B(U), Type B(M) and Type C packages and packages containing fissile material or 0.1 kg or more of $UF_6$). This applies regardless of their intended use.

8.2. Paragraph 801 of the Transport Regulations states:

> "For *package designs* where it is not required that a *competent authority* issue a certificate of *approval*, the *consignor* shall, on request, make available for inspection by the relevant *competent authority* documentary evidence of the compliance of the *package design* with all the applicable requirements."

8.3. Paragraph 613A of the Transport Regulations requires the consideration of the ageing mechanisms in the design of a package. These considerations should be included in the package design safety report, as recommended in SSG-66 [4].

8.4. For package designs requiring competent authority approval for Type B(U), Type B(M) and Type C packages, ageing mechanisms are required to be considered in the safety analysis and the operating and maintenance instructions (see para. 809(f) of the Transport Regulations). In addition, if such packages are to be used for shipment after storage, a gap analysis programme is also required (see para. 809(k) of the Transport Regulations).

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[12] A list of competent authorities responsible for approvals and authorizations related to the transport of radioactive material in each country is available at https://gnssn.iaea.org/main/GlobalTransportNetworks/Pages/CompetentAuthorities.aspx

8.5. Paragraph 501 of the Transport Regulations states:

> "Before *packaging* is first used to transport *radioactive material*, it shall be confirmed that it has been manufactured in conformity with the *design* specifications to ensure compliance with the relevant provisions of [the Transport Regulations] and any applicable certificate of *approval*."

The package designer (or the manufacturer, when it is the supplier of the packaging) should supply to the owner of the packaging the manufacturing documentation of the packaging confirming its compliance with the package design. This may include written certification that the packaging complies with all manufacturing and testing requirements, as well as copies of quality records, results of manufacturing inspections, 'as built' drawings and certificates. The owner should forward the documentation confirming the packaging's compliance with the package design to the user of the packaging.

8.6. To fulfil the requirements established in paras 502 and 503 of the Transport Regulations, the applicable pre-shipment inspection (see Section 6 of this Safety Guide) should be conducted to demonstrate compliance with the applicable requirements.

8.7. The results of manufacturing inspections, pre-shipment inspections and inspections during maintenance should be kept, in accordance with the relevant management systems, by the package designer, the owner or user of the packaging, the packaging manufacturer, and the organization in charge of maintenance or storage, as applicable, to demonstrate that the safety functions are maintained.

8.8. In preparation for the pre-shipment inspection after storage, all the results of the previous inspections and monitoring should be maintained by the organization responsible for the storage of the package and delivered to the user of the package responsible for shipment after storage.

8.9. If modifications are made to the package design, a review should be performed by the package designer of possible changes that could affect the consideration of ageing mechanisms. If necessary, an ageing management review should be completed by the package designer for the affected components (see paras 5.16–5.18). Depending on the result of this review, the package design safety report should be updated and, if applicable, an application for revision of the approval of the package design should be considered.

8.10. A transport package design approval is usually renewed by the relevant competent authority on a periodic basis, depending on the period of validity of the certificate of approval. Before each application for renewal, the applicant should evaluate changes in the Transport Regulations, any advances in technical knowledge and feedback from operating experience. Depending on the results of this evaluation, an application for modification of the package design may be needed in addition to the renewal of the certificate of approval.

# 9. INTERFACES IN RELATION TO AGEING MANAGEMENT AND MAINTENANCE OF TRANSPORT PACKAGES

## INTERFACES BETWEEN TRANSPORT AND STORAGE

9.1. The storage of transport packages is often covered by separate regulations (i.e. in addition to the Transport Regulations) in Member States. In the case of shipment after storage, there are important interfaces to be considered between transport and storage that should be addressed to maintain the transportability of the package. In most cases, the approach to ageing management for transport and storage may be the same; however, evaluations of ageing effects may differ because the environment, duration and loading conditions are different.

9.2. When a package is used for storage, the storage facility might be regulated by a regulatory body different from the competent authority for transport. In such a case, cooperation between the involved entities should be encouraged.

9.3. The organization responsible for storage should take into account the ageing management and maintenance programme included in the package design safety report (i.e. in the sections entitled ‘Ageing considerations’ and ‘Maintenance’; see SSG-66 [3]) in the development of its own ageing management programme.

9.4. When a facility is designed for the storage of dual purpose casks, any change in storage conditions that may result from the periodic safety review of the facility (see IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [27]) should be considered in the gap analysis programme of the package designs.

## INTERFACES BETWEEN THE COUNTRY OF ORIGIN, THE COUNTRY OF USE AND THE COUNTRY OF STORAGE

9.5. For shipment after storage of a package subject to unilateral approval, if this approval is withdrawn or not renewed in the country of origin of the package design, the competent authority where the package is stored may consider issuing a new package design approval, as described in para. 840.3 of SSG-26 (Rev. 1) [3].

9.6. The applicant for package design approval in the country of storage should obtain the necessary information from the package designer and/or the competent authority of the country of origin of the package design to help fully understand the contents and background of the original application. This should include information on ageing considerations, maintenance (e.g. monitoring during storage), requirements for shipment after storage, and the gap analysis programme.

9.7. Before issuing the package design approval, the competent authority of the country of storage should obtain information on the safety assessment from the competent authority of the country of origin of the package design.

9.8. Irrespective of the status of the original package design approval, the following should be considered:

(a) The packaging owner, the user of the package and the operator of the storage facility in the country of storage should implement, as relevant, the provisions of the ageing management programme and maintenance programme included in, or based on, the package design safety report that supports the package design approval issued by the competent authority in the country of origin of the package design.
(b) The competent authority of the country of storage should verify the implementation of the ageing management programme and the maintenance programme through inspections.
(c) The owner of the packaging and the owner of the radioactive contents should periodically provide the competent authority of the country of storage with a gap analysis based on the gap analysis programme provided by the package designer in the country of origin. If the periodic gap analysis identifies non-compliances in the safety justifications of the package design approval, the owner of the packaging should ask the package designer in the country of origin for an update of the relevant safety justifications and, if applicable, should request a revision of the design approval.

9.9. For shipment of a package subject to unilateral approval other than shipment after storage, an approach similar to the one described in paras 9.5–9.8, as applicable, should be followed.

## Appendix I

## APPROACHES TO THE CONSIDERATION OF AGEING MECHANISMS IN PACKAGE DESIGN

### IDENTIFICATION OF AGEING EFFECTS

I.1. The potential ageing mechanisms for each packaging component and material should be selected on the basis of the service life of the package and the environmental and loading conditions (see paras 3.2–3.5). The results should be summarized in the package design safety report (i.e. in a table in the section entitled 'Ageing considerations'; see SSG-66 [4]) to show which potential ageing mechanisms are to be considered for each packaging component and material.

I.2. The Annex shows examples of a variety of packages and possible ageing mechanisms.

### EVALUATION OF AGEING EFFECTS

I.3. Typical areas of concern with regard to ageing effects are listed below:

(a) Changes in mechanical strength, such as allowable stress and fracture toughness, caused by irradiation and thermal loading;
(b) Creep due to heat, stress and time;
(c) Number and intensity of cyclic stresses with regard to fatigue assessment;
(d) Initiation of stress corrosion cracking due to stress, environment and material combination;
(e) Reduction in the thickness or localized penetration of components due to corrosion;
(f) Stress relaxation in lid bolts and metal gaskets due to temperature, stress and time;
(g) Reduction in the sealing force in elastomer O-rings due to temperature and irradiation;
(h) Depletion of the hydrogen content of neutron shielding material due to temperature;
(i) Depletion of the boron-10 content of neutron absorbing material due to neutron irradiation;
(j) Initiation of hydride reorientation due to stress and temperature during loading of spent fuel assemblies.

I.4. On the basis of the results obtained from the first step of evaluation (e.g. quantitative changes in material properties or material strength), the consequences for the safety functions of the package due to ageing mechanisms should be assessed by the package designer in the package design safety report (i.e. in the section entitled 'Ageing considerations'; see SSG-66 [4]). If the consequences are negligible (or within an allowable range), no measures to control the ageing mechanism need be taken. The severity of the consequences should be reflected in maintenance programmes, in accordance with a graded approach. Typical examples of consequences of ageing mechanisms on safety functions are as follows:

(a) For structural components, changes in materials caused by high irradiation might lead to embrittlement of the components, which could result in a collapse of the elements that have safety functions, for example as follows:
    (i) The collapse of a component that constitutes a containment boundary (e.g. a shell, a bottom plate, lids, lid bolts and seals), leading to the loss of containment;
    (ii) The collapse or deformation of a fuel basket, affecting criticality safety;
    (iii) The deformation or breakage of a fuel basket plate, disrupting heat conduction through the plate and thereby degrading heat dissipation;
    (iv) The collapse of a trunnion during handling or transport, leading to the package being dropped, resulting in further damage and degradation of the safety functions of the package.
(b) The breakage of a thermal conductor (e.g. copper plates) in the neutron shielding layer might disrupt heat conduction through the plate, thereby degrading heat dissipation and inducing a potential increase in the temperature of the fuel basket and, consequently, a decrease in mechanical properties.
(c) The depletion of boron-10 content in neutron absorber material due to neutron irradiation might affect criticality safety.
(d) The loss of hydrogen and the shrinking and cracking of polymeric material used in neutron shielding due to irradiation and heat might lead to a degradation of the shielding capability and an increase in the external dose rate around the package.
(e) The rupture of spent fuel rod cladding might result in an increase in the internal pressure of the package cavity, a potential change in the physical configuration of the fuel, changes to the cover gas composition and an increase in the radioactive material directly contained in the package containment system.

## DESIGN APPROACHES TO PREVENT ADVERSE AGEING EFFECTS

I.5. There are four typical design approaches to prevent ageing mechanisms from having adverse effects on package performance:

(a) Selecting component materials that do not exceed the ageing effect thresholds;
(b) Replacing or refurbishing components before the ageing effect thresholds are exceeded;
(c) Designing package performance parameters not to exceed the ageing effect thresholds, taking into account environmental and operational conditions;
(d) Ensuring that the package design is based on the properties of aged component materials.

Further details of these approaches are given in paras I.6–I.11. A threshold parameter for preventing adverse ageing effects should be determined for each package component, taking into account the properties of aged material.

### Selecting component materials that do not exceed the ageing effect thresholds

I.6. The most basic approach to prevent adverse effects is to use material within a certain threshold to avoid changes in the material properties. Examples of this approach are as follows:

(a) Selecting a material with a neutron irradiation threshold for changes to mechanical properties that is greater than the cumulative neutron irradiation during operation;
(b) Selecting a material that does not initiate creep deformation under stress and temperature during operation;
(c) Selecting a material that does not initiate stress corrosion cracking under specific stress and environmental conditions during operation.

I.7. The package designer should include restrictions on the selection of components and materials in the package design safety report (i.e. as design requirements in the sections entitled ‘Specification of the packaging’ and ‘Specification of the contents’, with appropriate justification in the section entitled ‘Ageing considerations’; see SSG-66 [4]).

**Replacing or refurbishing components before the ageing effect thresholds are exceeded**

I.8. Components should be replaced, as appropriate, before their performance is degraded to the extent that predetermined ageing thresholds would be reached. This approach is applicable to a component designed to be replaced or refurbished during either operation or maintenance of the empty packaging. The thresholds should be set at levels at which the safety functions of the package might be affected, or else at a detectable value determined by the evaluation of ageing effects. The package designer should provide instructions — reflected in maintenance programmes — for detecting ageing before the thresholds are exceeded and for replacing or repairing components. The following are examples of this approach:

(a) Replacing a component (e.g. an elastomer O-ring for the lid seal) before the acceptance criterion (e.g. leak rate measured during the leaktightness test) or the allowable number of transport operations, as determined by the evaluation of ageing effects, is exceeded;
(b) Replacing a metallic gasket for the second lid of a package intended to be used for transport after storage of spent fuel, after an unacceptable drop of the inter-lid pressure is detected and the integrity of the metallic gasket for the primary lid is proven;
(c) Replacing components (e.g. trunnions) when predetermined criteria are reached (e.g. a cumulative number of lifting operations, as predetermined by the fatigue analysis);
(d) Refurbishing components (e.g. repainting) on the basis of the findings of maintenance activities.

These actions should be included by the package designer in the package design safety report (i.e. as replacement and refurbishing operations in the sections entitled ‘Package operations’ and ‘Maintenance’, as applicable, with the appropriate justification in the section entitled ‘Ageing considerations’; see SSG-66 [4]).

**Designing package performance parameters not to exceed the ageing effect thresholds**

I.9. Performance parameters to limit ageing effects should be set at a level that would avoid serious deterioration of safety functions. Limits can be set in terms of (but not limited to) fatigue, creep, annealing, embrittlement and/or hydride reorientation.

I.10. Typical performance parameters are cyclic stress, temperature and temperature dependent stress. The temperature of the package component depends on the rate of dissipation of decay heat from radioactive contents; hence, such decay heat dissipation can also be set as a parameter. Performance parameters should be monitored by the user of the package, on the basis of instructions provided by the designer, to ensure that they are within an acceptable range. Examples of this approach are as follows:

(a) The cyclic stress that occurs in the component is calculated and should not exceed the fatigue limit of the component material. If the fatigue limit is unlimited, or is so high that it cannot be reasonably exceeded, no further action is necessary. Otherwise, the owner or user of the packaging should, for example, monitor and record the number of transport operations.
(b) In designing the heat dissipation performance of the package, it can be ensured that related parameters (e.g. temperature and stress of the component of concern) do not result in exceeding the predetermined temperature limit of the component material to prevent the initiation of ageing (e.g. annealing of embrittlement and hydride reorientation, creep) during operation. This should be achieved by restrictions on the radioactive contents to ensure that the heat dissipation rate is in accordance with the maximum value stated in the package design safety report (i.e. in the section entitled 'Specification of the contents'; see SSG-66 [4]).

**Package design based on the properties of aged component materials**

I.11. A package design may be based on the properties of aged component materials; however, caution should be taken when considering these properties. Such properties are often estimated by exposing materials to very severe environments to accelerate the ageing mechanisms and shorten the time of the experiment. Hence, the acceleration method and the extrapolation of the obtained data should be fully justified, including uncertainty quantification, to ensure that they are representative of appropriate (and not unduly conservative) properties. Some examples of this approach include the following:

(a) Using the allowable stress of the simulated aged material in structural design;
(b) Using the reduced fracture toughness in the evaluation of fracture mechanics;
(c) Using a depleted hydrogen concentration to represent aged neutron shielding material;
(d) Using a depleted boron-10 concentration to represent aged neutron absorber material in the design for criticality safety.

## Appendix II

## STRUCTURE OF AN AGEING MANAGEMENT PROGRAMME FOR TRANSPORT PACKAGES

II.1. The ageing management programme for transport packages should be developed using a structured methodology to ensure a consistent approach to implementing ageing management. The programme should be developed considering all safety relevant components of the package. In practice, ageing mechanisms and effects are studied and managed at the component level. However, the ageing management programme for individual components may be integrated into an ageing management programme at the package level.

II.2. There are generally four types of activity that should be considered in an ageing management programme:

(a) Prevention activities, which prevent ageing effects from occurring (e.g. coating measures to prevent external corrosion of carbon steel overpack components, adequate drying to prevent hydride reorientation in high burnup cladding alloys);
(b) Condition monitoring activities, which identify the presence and extent of ageing effects (e.g. visual inspection of package surfaces for cracking, sensors to monitor package surface temperatures and inter-lid pressure);
(c) Performance monitoring activities, which verify the ability of the components to perform their intended safety functions (e.g. periodic radiation monitoring, temperature monitoring);
(d) Mitigation activities, which attempt to slow or reduce the effects of ageing.

II.3. Each individual ageing management programme may contain the elements listed in paras II.4–II.16 (adapted from table 2 of SSG-48 [5]). Examples of ageing management programmes and the information needed to develop such programmes are provided in Refs [8–11, 13].

### SCOPE OF THE AGEING MANAGEMENT PROGRAMME

II.4. The scope of the ageing management programme should list the specific package components covered by the programme and the safety functions to be maintained (see paras 3.8 and 3.9). In addition, the environmental and operational conditions (see para. 3.5), ageing mechanisms (see para. 3.6) and specific materials (see para. 3.10) to be managed should be stated.

## PREVENTIVE ACTIONS TO MINIMIZE AND CONTROL AGEING EFFECTS

II.5. Preventive actions, including design or manufacturing procedures, should be used within the ageing management programme to prevent any ageing effects that could affect the safety functions of the package. The preventive actions described should be supported with an analysis and data demonstrating that they will be effective.

## DETECTION OF AGEING EFFECTS

II.6. To detect ageing effects before there is a loss of safety function for any packaging component within the scope of the ageing management programme, the description of inspection and monitoring activities should include the following:

(a) Specification of parameters to be monitored or inspected, taking into account the environmental and operational conditions. The need to monitor each package may be eliminated by monitoring certain facility parameters (e.g. temperature, humidity).
(b) A method (e.g. visual, volumetric or surface inspection) capable of evaluating the conditions of the component for the specific ageing mechanism or effect.
(c) An adequate frequency of inspections to ensure that safety functions will be maintained.
(d) Identification and a justification of the number of components to be evaluated in each inspection, the extent of the inspection of each component and the criteria for selection of the component for inspection. For inaccessible components, alternative measures to assess their condition should be provided.
(e) Documentation of the results, including descriptions of observed ageing effects and supporting diagrams, photographs or videos. Any specific methods to be used for data acquisition and documentation, including any applicable codes and standards, should be referenced. The documentation should be archived in such a way that it is easily retrievable.

## MONITORING AND IDENTIFYING TRENDS IN AGEING EFFECTS ON TRANSPORT PACKAGES

II.7. Parameters related to the condition and safety performance of the package should be identified, providing a clear link to the ageing mechanisms listed in the scope of the ageing management programme and descriptions of the capability and means of identifying ageing effects or potential degradation before a loss of the safety function (see Section 3). The parameters should be used as part of the following:

(a) Monitoring the effectiveness of measures that prevent or mitigate ageing;
(b) Monitoring the performance of components as an indirect indicator of degradation;
(c) Detecting, through direct inspection, the presence and severity of conditions or discontinuities that might have an effect on the function of the components.

II.8. A description of the extent of the effects of ageing should be provided, with an evaluation of the results of examinations and inspections. This should include an evaluation of the results against the acceptance criteria and an analysis of trends in the identified ageing effects. The evaluation should take into account the rate of degradation and any trends identified in the ageing mechanisms and their effects to ensure that the next scheduled inspection is timed to occur before a loss of safety functions.

## MITIGATION OF AGEING EFFECTS

II.9. Mitigating measures, including design and manufacturing procedures, should be used to mitigate the rates of ageing of package components. These measures should be supported by data and an analysis demonstrating that the measures are effective.

II.10. Examples of mitigating measures include maintenance, repair and replacement actions to mitigate detected ageing effects and/or degradation of the components.

## ACCEPTANCE CRITERIA

II.11. The acceptance criteria against which the need for corrective action is evaluated should ensure that the component safety functions are maintained.

The acceptance criteria should be appropriately justified and can be subject to adjustment based on new technical knowledge. The acceptance criteria should be based on the information included in the package design safety report.

## CORRECTIVE ACTIONS

II.12. Corrective actions should include the measures to be taken to address the ageing effects when the acceptance criteria are not met. The corrective actions should also aim to prevent the recurrence of the condition. These actions should be adequately and effectively performed, with care taken to ensure that they do not have an adverse effect on the components.

II.13. The corrective actions should be described in procedures prepared and controlled in accordance with the management system and should be based on the package design safety report.

## OPERATING EXPERIENCE FEEDBACK

II.14. The ageing management programmes for transport packages should be updated and revised to take into account relevant operating experience, including the following:

(a) Technical knowledge and corrective action reports from inside the organization and from similar organizations;
(b) Safety bulletins from suppliers;
(c) Communications from regulatory bodies.

## QUALITY MANAGEMENT

II.15. This part of the ageing management programme is intended to verify that preventive actions are adequate and that appropriate corrective actions have been completed and are effective. The verification process should describe or reference the following:

(a) A process to verify that preventive actions are adequate and appropriate;
(b) A process to verify the effective implementation of corrective actions;

(c) Indicators to facilitate evaluation and improvement of the ageing management programme;
(d) Monitoring for adverse trends identified through recurring or repetitive findings or observations.

II.16. The ageing management programme should include administrative controls in respect of the following:

(a) Instrument calibration and maintenance;
(b) Qualification of staff performing inspections (e.g. organization, training, certificates of competence);
(c) Retention of records and document control, in accordance with the management system.

## Appendix III

## ROLES AND RESPONSIBILITIES OF RELEVANT INTERESTED PARTIES IN RELATION TO AGEING MANAGEMENT AND MAINTENANCE OF TRANSPORT PACKAGES

III.1. The purpose of this appendix is to summarize the roles and responsibilities of some of the relevant interested parties involved in the ageing management and maintenance of transport packages. The list of relevant interested parties is provided in para. 1.5 and footnote 5.

### PACKAGE DESIGNER

III.2. The package designer is the person who or organization that should take responsibility for the complete package design. For each package design there should be only one package designer, who should issue the package design safety report as described in SSG-66 [4].

III.3. Before the first use of packages that require competent authority approval, the package design has to be approved. The package designer is usually the applicant for the approval of the package design.

III.4. When issuing the package design safety report (see SSG-66 [4]), the sections entitled ‘Ageing considerations’ and ‘Gap analysis programme’ should be based on the specification of the package (defined in the sections entitled ‘Specification of the contents’ and ‘Specification of the packaging’) and on the maintenance programme (defined in the sections entitled ‘Package operations’ and ‘Maintenance’).

III.5. The package designer should interact with the relevant interested parties regarding manufacture, use and maintenance and with the organization responsible for storage, if applicable, to gather feedback. For transport packages containing spent fuel, the package designer should also interact with fuel vendors and reactor operating organizations to gather the necessary information regarding changes in the behaviour of the spent fuel assemblies.

III.6. The package designer should update the package design safety report as necessary. This update may include the ageing management programme, the maintenance programme and the gap analysis programme, as applicable.

## MANUFACTURER OF THE PACKAGING

III.7. The manufacturer of the packaging should be responsible for compliance with the provisions defined by the package designer in the package design safety report regarding the use of materials, technology and processes.

III.8. Before starting manufacture, the manufacturer should ensure that the procedures to be applied are qualified to meet the provisions of the package designer and are conducted in accordance with the management systems of both the manufacturer and the designer.

III.9. In the case of non-compliance with the applicable design documents and design modifications, the role of the manufacturer is even more relevant. The manufacturer should collaborate with the package designer to assess the impact of any such variations.

## OWNER OF THE PACKAGING

III.10. The owner of the packaging should implement the actions that are necessary to ensure compliance of the packaging with the provisions in the package design safety report, and in the package design approval, if applicable. For that purpose, the owner of the packaging should:

(a) Liaise with the organization in charge of maintenance;
(b) Maintain the records from inspections and maintenance operations;
(c) Conduct the necessary preventive actions and corrective actions in the ageing management programme and the gap analysis programme, as applicable.

III.11. The owner of the packaging should evaluate the results of the maintenance programme. If non-compliances with the safety justifications in the package design safety report are identified, the owner of the packaging should inform the package designer to review the package design and notify the competent authority, if applicable.

III.12. If the owner of the packaging is not the same as the user of the packaging, the owner should be responsible for supplying the necessary information from the package design safety report to the user.

## USER OF THE PACKAGING

III.13. The user of the packaging is usually the consignor of the package. The consignor prepares the shipment of the package in accordance with the requirements of the Transport Regulations. Therefore, the user of the packaging should be responsible for ensuring that the packaging is in a serviceable condition prior to shipment.

III.14. Generally, the user of the packaging is the owner of the packaging (see footnote 11) and should therefore assume the responsibilities of the owner described in paras III.10–III.12.

III.15. When the user of the packaging is not the owner of the packaging, and the owner is responsible for the implementation of the maintenance programme, the user should request from the owner all relevant records from the ageing management and maintenance programmes.

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## Annex

## EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS

A–1. Table A–1 shows examples of a variety of packages and possible ageing mechanisms, in which the letter ‘Y’ (i.e. yes) indicates that the mechanism should be considered. In all cases, an evaluation of the specific package design should be performed by the package designer, taking into account the environmental and operational conditions.

A–2. Additional points to be noted when setting the scope are:

(a) ‘Y’ indicates all ageing mechanisms that are possible. If a mechanism can be excluded through subsequent evaluation, the reason for its exclusion needs to be stated in the package design safety report (i.e. in the section entitled ‘Ageing considerations’).[1] The excluded mechanisms have been left blank in Table A–1.
(b) As ageing mechanisms are time and stressor dependent phenomena, the operation duration and loading conditions are essential elements to be considered in addition to the type of package, component and material, as presented in Table A–1. For packagings intended for repeated use, the cyclic loadings induced from the maximum radioactive contents and number of cycles also need to be considered.

[1] See INTERNATIONAL ATOMIC ENERGY AGENCY, Format and Content of the Package Design Safety Report for the Transport of Radioactive Material, IAEA Safety Standards Series No. SSG-66, IAEA, Vienna (2022).

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS

| Type of package | Component | Material | Ageing mechanism: General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Excepted Type A | Outer shell | Cardboard | | | | | | | | | | | | | | |
| | Inner shell | Steel (can) | Y | | | | | | | | | | | | | |
| | Buffer cushion | Urethane foam | | | | | | | | | | | | | | |
| Type IP Type A (Steel drum) | Can body and bottom plate | Carbon steel | Y | Y | Y | | | | | | | | | | | |
| | Lid | Carbon steel | Y | Y | Y | | | | | | | | | | | |
| | Lid band | Zinc plated steel | Y | Y | | | | | | | | | | | | |
| | Lid band clamping screw | Carbon steel | Y | Y | Y | | | | | | | | | | | |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | Ageing mechanism: General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type IP Type A (Metal container) | Outer panel | Stainless steel | | Y | Y | Y | | | | | | | | | | |
| | Inner container | Stainless steel | | Y | Y | Y | | | | | | | | | | |
| | Shielding | Lead | | | | | | | | | | | | | | |
| | Damping system | Urethane foam | | | | | | | | | | | | | | |
| | Screw | Carbon steel | Y | | Y | | | | | | | | | | | |
| | Lid | Carbon steel | Y | Y | Y | | | | | | | | | | | |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | Ageing mechanism: General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type B(U)<br>Type B(M)<br>Type C | Outer shell | Stainless steel | | Y | Y | Y | | | | | | | | | | |
| | Inner shell | Low alloy steel | Y | Y | Y | | | | | | | | Y | | | |
| | Lid | Stainless steel | | Y | Y | Y | | | | | | | | | | |
| | Lid bolt | Low alloy steel | Y | Y | Y | Y | | | | | | | | | Y | |
| | Screw | Carbon steel | Y | | Y | | | | | | | | | | | |
| | Lid seal | Elastomeric polymer | | | | | | | | | | | Y | Y | Y | |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type B(U) Type B(M) Type C (cont.) | Gamma shielding | Lead | | | | | | | | | | | | | | |
| | Thermal conductor | Copper | | | | | | Y | Y | | | | | | Y | Y |
| | Trunnion | Stainless steel | | Y | Y | Y | | | Y | | | | | | | |
| | Shock absorber | Plywood | | | | | Y | | | | | | | Y | | Y |
| | Casing of shock absorber | Stainless steel | | Y | Y | Y | | | | | | | | | | |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | Ageing mechanism: General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Uranium hexafluoride ($UF_6$) | Overpack | Stainless steel | | Y | Y | Y | | | | | | | | | | |
| | Screw | Carbon steel | Y | | Y | | | | | | | | | | | |
| | Thermal insulator | Urethane form | | | | | | | | | | | | | | Y |
| | Valve and plug | Alloy | Y | Y | | Y | | | Y | | | | | | | |
| | Cylinder shell | Carbon steel | Y | Y | Y | Y | | | | | | | | | | |
| | Skirt | Carbon steel | Y | Y | Y | | | | | | | | | | | |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | Ageing mechanism: General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Uranium dioxide ($UO_2$) (Type AF, Type IF) | Overpack | Stainless steel | | Y | Y | Y | | | | | | | | | | |
| | Lid | Stainless steel | | Y | | | | | | | | | | | | |
| | Screw | Carbon steel | Y | | Y | | | | | | | | | | | |
| | Lid seal | Elastomeric polymer | | | | | | | | | | | | | | |
| | Outer shield | Lead | | | | | | | | | | | | | | |
| | Inner can | Stainless steel | | Y | Y | Y | | | | | | | | | | |
| | Thermal insulator | Foam | | | | | | | | | | | | | | |
| | Neutron absorber | Boron–aluminium or boron stainless steel | | | | | | | | | | | | | | |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | Ageing mechanism | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
| Fresh fuel (Type AF, Type IF, B(U)F) | Outer shell | Stainless steel | | Y | Y | Y | | | | | | | | | | |
| | Inner shell | Low alloy steel | Y | Y | Y | | | | | | | | | | | |
| | Lid | Stainless steel | | Y | Y | | | | | | | | | | | |
| | Screw | Carbon steel | Y | | Y | | | | | | | | | | | |
| | Lid bolt | Low alloy steel | Y | Y | Y | | | | | | | | | | Y | |
| | Lid seal | Aluminium/ Inconel | Y | Y | Y | | | | | | | | | | Y | |
| | Fuel cladding | Zircaloy | | | | | | | | | | | | | | |
| | Thermal insulator | Foam | | | | | | | | | | | | | | |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | Ageing mechanism: General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fresh fuel (Type AF, Type IF, B(U)F) (cont.) | Neutron absorber | Boron–aluminium or boron–stainless steel | | | | | | | | | | | | | | |
| | Trunnion | Stainless steel | | Y | Y | Y | | | Y | | | | | | | |
| | Shock absorber | Plywood | | | | | Y | | | | | | | | | |
| | Casing of shock absorber | Stainless steel | | Y | Y | Y | | | | | | | | | | |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | Ageing mechanism | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
| Dual purpose cask Spent fuel (Type B(U)F, Type B(M)F, Type CF) | Outer shell | Stainless steel | | Y | Y | Y | Y | | | | | | Y | | | |
| | Inner shell | Low alloy steel | Y | Y | Y | | | | | | | | Y | | | Y |
| | Lid | Stainless steel | | Y | Y | Y | Y | | | | | | Y | | | |
| | Screw | Carbon steel | Y | Y | Y | | | | Y | | | | Y | | Y | |
| | Lid bolt | Low alloy steel | Y | Y | Y | | | | Y | | | | Y | | Y | |
| | Lid seal | Aluminium alloy | Y | Y | Y | | | Y | | | | | Y | | Y | Y |
| | Additional lid seal | Elastomeric polymer | | | | | | | | | | | Y | Y | | Y |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ageing mechanism | | | | | | | | | | | | | |
| Dual purpose cask Spent fuel (Type B(U)F, Type B(M)F, Type CF) (cont.) | Gamma shielding | Lead | Y | | | | | Y | | | | | | | | |
| | Neutron shielding | Resin | | | | | | | | | | | Y | Y | | Y |
| | Thermal path basket | Copper | | | | | | Y | Y | | | | | | Y | Y |
| | Fuel basket | Borated aluminium | | | | | | Y | | | | | Y | Y | | Y |
| | Spent fuel cladding | Zircaloy | Y | | | | | Y | | Y | Y | Y | Y | | | Y |
| | Trunnion | Stainless steel | | Y | Y | Y | | | Y | | | | | | | |

TABLE A–1. EXAMPLE SCOPE SETTING TABLE FOR AGEING MECHANISMS (cont.)

| Type of package | Component | Material | Ageing mechanism: General corrosion | Crevice corrosion | Pitting corrosion | Stress corrosion cracking | Microbiologically influenced corrosion | Creep | Fatigue | Hydride reorientation | Delayed hydride cracking | Mechanical overload | Radiation embrittlement | Radiolysis | Stress relaxation | Thermal ageing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dual purpose cask | Shock absorber | Plywood | | | | | Y | | | | | | | Y | | |
| Spent fuel (Type B(U)F, Type B(M)F, Type CF) (cont.) | Casing of shock absorber | Stainless steel | | Y | Y | Y | | | | | | | | | | |

## CONTRIBUTORS TO DRAFTING AND REVIEW

| | |
|---|---|
| Bujnova, A. | International Atomic Energy Agency |
| Chrupek, T. | Authority for Nuclear Safety and Radiation Protection, France |
| Davis, M. | Nuclear Regulatory Commission, United States of America |
| Ejaz, M.U. | International Atomic Energy Agency |
| Fayyaz, S. | International Atomic Energy Agency |
| Fukuda, T. | Nuclear Regulation Authority, Japan |
| Huang, J. | Nuclear Regulatory Commission, United States of America |
| Jones, C. | Office for Nuclear Regulation, United Kingdom |
| Komann, S. | Federal Institute for Materials Research and Testing, Germany |
| Li, G.Q. | China Institute for Radiation Protection, China |
| Malesys, P. | World Nuclear Transport Institute |
| Meng, D.Y. | China Institute for Radiation Protection, China |
| Reichardt, A. | Federal Institute for Materials Research and Testing, Germany |
| Shaw, P. | International Atomic Energy Agency |
| Wright, R. | International Atomic Energy Agency |
| Zamora Martin, F. | Consultant, Spain |
| Zhan, Y.L. | Nuclear Industry Management College, China |

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