Ageing Guide for Transport Packages Containing Radioactive Material

DRAFT

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by Nuclear Regulation Authority, Japan

TRANSSC TECHNICAL EXPERT GROUP
ON PACKAGE PERFORMANCE AND ASSESSMENT
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1. INTRODUCTION

1.1 Background

The International Atomic Energy Agency (IAEA) Safety Standards Series No. SSR-6 (Rev.1), Regulations for the Safe Transport of Radioactive Material 2018 Edition [1], which is hereinafter referred to as “the Regulations”\(^1\) introduced important requirements and a concept related to the ageing of transport packages, including their radioactive contents when relevant.

The first requirement is specified in para. 613A, which considers ageing mechanisms in the package design. The second requirement is the applicants for the design approval of the package to be used for shipment after storage, which is a new concept introduced as a transport-related activity as found in para. 106, to submit the consideration of ageing mechanisms and a gap analysis programme as stipulated in paras 809(f) and 809(k). For such packages, the transportability after storage has to be ensured during storage as specified in para. 503(e). Some of guidelines for these requirements and concept are provided in the IAEA Safety Standards Series No. SSG-26 (Rev.1), Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2018 Edition) [2], which is hereinafter referred to as “the Advisory”\(^2\).

Guidelines on the placement of the abovementioned considerations and programme in the package design safety report (PDSR) are given in IAEA Safety Standards Series No. SSG-XX, Format and Content of the Package Design Safety Report (PDSR) for the Transport of Radioactive Material [3].

The TRANSSC Technical Expert Group "Package Performance and Assessment" (TTEG PPA) was founded during the TRANSSC 36 Meeting in June 2018. As a result of a questionnaire, a significant number of member states and observer organizations expressed the need for an additional and comprehensive guidance for ageing of transport packages to support the Member States in implementing the new requirements stipulated in the Regulations. Hence, the TTEG PPA agreed to the production of an ageing guide under the leadership of the Working Group Ageing (WG-AG) established for this purpose.

1.2 Objective

This guide is aims to provide guidance for the implementation of ageing-related requirements in the Regulations. It also aims to assist package designers, vendors, operators, applicants, licensees, regulators, technical support organization, and others in the Member States in developing documentary evidence to justify the considerations to ageing mechanisms in the package design, establish the ageing management and the gap analysis programme when related, and ensure proper application of these programmes.

1.3 Scope

This guide covers all packages that need to be considered in the ageing mechanism, irrespective to their classification (i.e. Type IPs, Type A, Type B(U) or B(M), Type C or packages containing fissile material or uranium hexafluoride). This guide also covers all activities that

\(^1\) Throughout this guide, reference to ‘the Regulations’ always refers to the 2018 Edition unless otherwise stated.

\(^2\) Throughout this guide, reference to ‘the Advisory’ always refers to the 2018 Edition unless otherwise stated.
need to be considered in the ageing mechanisms, such as design, manufacture, maintenance and repair of packaging, and the preparation, consigning, loading, carriage that includes in-transit storage, shipment after storage, unloading and receipt at the final destination of loads of radioactive material and packages. A graded approach is applied commensurate with the aspects in package use (i.e. once-through, repeated, or intended use for shipment after storage).

1.4 Structure

This section provides a general envelope of the guide. Section 2 defines the terms required for the purpose of this guide. Section 3 explains the graded approach applied to the ageing mechanism considerations. Section 4 defines the conditions of packages relevant to the ageing mechanism. Section 5 addresses the technical aspects of the ageing mechanism applicable to packages based on the defined conditions. Sections 6 to 8 provide guidance applicable to the ageing mechanism considerations in the package design, operation and administrative control, respectively. Section 9 presents the conclusions.
2. DEFINITIONS

2.1 Transport and Storage

The definitions stated in the Regulations and the terms, including those related to the storage of nuclear and radioactive material, defined and explained in the IAEA Safety Glossary [4] apply throughout this Guide. Additionally, the following terms are defined to be used in this Guide:

(a) Package design safety report (PDSR): a set of documentary evidence of compliance of the transport package design with all applicable requirements stipulated in the Regulations. For package designs that require approval by a competent authority, the PDSR is the basis for the application to the competent authority for design approval. For package designs where competent authority approval is not required, it is advised to prepare the PDSR for the purpose of maintaining evidence of self-certificate by the operator or the consignor [3].

(b) Dual-purpose cask (DPC): the assembly of components (packaging) necessary to fulfill the safety functions for transport and storage of radioactive contents [5].

- ‘Dual purpose’ refers to the purposes for transport and storage, but not for disposal (i.e. ‘multipurpose’ is out of the scope of this definition).

- The DPC configuration for transport and storage may differ. For example, a DPC for transport may be fitted with shock absorbers, while a DPC for storage may be fitted with an additional lid or a monitoring system.

- ‘DPC package’ refers to the DPC with radioactive contents.

- The radioactive contents of the DPC are not limited to spent nuclear fuel, but also refer to other radioactive material such radioactive waste.

(c) Ageing management programme (AMP): a programme conducted by appropriate organizations, such as the packaging owner, operator or consignor of the package, to address the ageing effects that may include prevention, mitigation, condition monitoring, and performance monitoring [5].

(d) Gap analysis programme (GAP): a programme conducted by appropriate organizations such as the packaging owner, operator or consignor of the package to assess the state of technical knowledge, standards and regulations regarding the safety function of the package. A gap analysis i) lists characteristic factors, such as the state of technical knowledge, regulations and standards of the PDSR, ii) evaluates the effect of changes of technical knowledge, standards and regulations on the PDSR, and iii) highlights the existing gaps that need to be filled [5].

2.2 Ageing

The terms related to ageing listed below are specifically defined for use in this guide.

[to be listed]
3. GRADED APPROACH

The effects of ageing mechanisms on packaging components, radioactive contents and package safety functions depend on their operational conditions. A graded approach can be applied to the considerations of the ageing mechanisms to packages commensurate to the package operational conditions throughout its service life as described in paras 613A.1 – 613A.6 of the Advisory. Consideration to the ageing mechanisms are divided into three grades depending on the aspects of package use and as defined in Subsections 3.1 to 3.3 (i.e. Packages for Once-through Use, Packages for Repeated Use, and Packages Intended to be used for Shipment after Storage, respectively).

3.1 Packages Intended for Once-through Use

No ageing mechanism that occurs in the packaging components is considered for the packaging used only once for a single transport because the effects of ageing on the safety functions of the package during a single transport with a maximum duration of transport of less than one year are hardly credible. Excepted packages are generally categorized under this grade. Part of Type IP-1, IP-2 and IP-3 and Type A packages made of fibreboard boxes or drums for single use are examples of this grade. A Type B(U) or B(M) package designed for one-time transport of a very specific radioactive content is also another example. If such packages are intended to be used for shipment after storage, they should be addressed under Subsection 3.3.

3.2 Packages Intended for Repeated Use

For packaging intended for repeated use, the effects of ageing mechanisms on the packaging components during its service life should be evaluated. No effect of the ageing mechanisms on its radioactive contents is considered because the duration of a single transport is relatively short (i.e. less than one year). Based on this evaluation, an inspection and maintenance programme on the packaging should be developed and implemented to monitor and control the ageing effects so as not to deteriorate the safety functions of the package during transport over its service life. The inspection and maintenance can be conducted when the packaging is empty (i.e. without radioactive contents) in between carriages of the loaded package.

Documentary evidence to justify the considerations to the ageing mechanism should be included in the PDSR [3]. The outcome of the inspection and maintenance programme, including inspection results and maintenance records should be maintained all throughout the packaging service life by an appropriate organization (e.g. packaging owner or consignor) under its management system to demonstrate the integrity of the safety functions of the packaging and should be submitted to the competent authority when required.

3.3 Packages Intended to be Used for Shipment after Storage

As stated in para. 106.2 of the Advisory, the shipment after storage is a specific shipment operation that requires considering the ageing of package components. Thus, the following elements should be considered to address the ageing mechanisms;

1. Packages loaded with radioactive contents are stored for a duration of several decades to 100 years after the first shipment to the storage facility until the second shipment from the storage facility has commenced.
During storage, the transportability after storage should be maintained. In other words, the packages should comply with the requirements of the transport regulations at the time of shipment after storage, including those for accident conditions of transport.

The package configuration for transport and storage may differ.

The impact of ageing effects on the radioactive contents should be considered, because the characteristics of the radioactive contents, which may change during storage, may affect the safety functions of the package.

Inspection and maintenance during storage should be conducted on the loaded packages.

The storage of packages is out of the scope of the transport regulations and often regulated by storage-specific regulations of the State.

The transport and storage regulations may change during the storage period. Technical knowledge may also change.

Similar to Subsection 3.2, documentary evidence to justify the considerations to the ageing mechanism should be included in the PDSR [3]. In addition, the applicant of the package design approval has to submit an AMP and a GAP to the competent authority following paras 809(f) and 809(k) of the Regulations. Monitoring and inspection results and maintenance records have to be maintained all throughout the storage period by the appropriate organization such as the packaging owner, storage facility operator or consignor, under its management system as part of the evidence that would ensure the transportability of the package during and after the storage. The same should be submitted to the competent authority when required.
4. DEFINING CONDITIONS FOR EVALUATING EFFECTS OF AGEING MECHANISMS

4.1 General

As a nuclear component, the same ageing management approach for nuclear power plant components can be applied to the consideration of ageing mechanisms of transport packages. Guidance to the ageing management of nuclear power plants are available from the IAEA Safety Standards Series No. SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants [6], or from the Member States, where nuclear power generation has developed. With reference to these guidance terms, the ageing mechanisms in repeated-use packaging have been well considered in the design or maintenance programme, but not explicitly stated in the PDSR.

The wide spread of the interim storage of spent nuclear fuel and the use of DPC has strengthened the focus on the consideration to the ageing mechanisms for storage packages. Thus, several guidance terms for addressing the ageing management of transport packages during storage are available, such as IAEA technical documents on the DPC [5 and 7] and guide from a Member State [8]. A report from the United States [9] has provided comprehensive and detailed information for managing the ageing process of dry storage systems based on competent authority experience to review related applications. Furthermore, efforts to construct an international database of ageing mechanisms of the storage system are ongoing [10]. This pool of information is rather dedicated to storage packages, but the basic concept is common and the approach employed is applicable to packages designed for repeated use and those to be used for shipment after storage.

4.2 Definition of the Operational Duration of Package

Ageing is a time-dependent phenomenon; hence, the operational duration of a package should be first defined for further consideration to the ageing mechanism. Packages used for once-through transport need not define such a duration because their operational duration is short (less than one year) thus no consideration to ageing mechanisms is required basically. An exception to such packages is those subjected to transport after storage, in which a long duration after radioactive contents loading to the packaging before the shipment is expected. For other packages the operational duration should be defined through manner (a) or (b) below.

(a) Packages intended for repeated use

Packages in this category are intermittently subjected to transport operations; therefore, the operational duration is defined as a sum of the durations in transport (cumulative period in the transport operation) and those out of transport (cumulative period out of service, that is, storage as an empty packaging). It may be expressed as the service life (in years) or the limitation on the number of transport (times). However, to consider the ageing mechanisms, both the in-service duration subjected to the loads caused by the radioactive contents and transport operations and the out-of-service duration subjected to the storage environment should be defined. An infinite duration (i.e. no limit on service) can be defined if the required performance of the packaging could be maintained eternally through the packaging maintenance programme.

The single-transport period is short (less than one year); hence, no consideration to the ageing mechanisms on the radioactive contents is required.
Packages intended to be used for shipment after storage

The operational duration for this type of packages coincides with the storage period of the package. From the viewpoint of ageing, the transport periods before and after the storage are negligible.

They are loaded for long time in the package; thus the ageing mechanism in the radioactive contents should be considered taking into account that the changes in the configuration and characteristics of the radioactive contents may affect the integrity of the contents themselves, loads to packaging components and content retrievability. The decay of radioactive contents in heat generation and radiation emittance should definitely be considered. The decay histories (time-dependent change in amount) of heat the flux and the photon and the neutron fluxes during the storage period have to be prepared for the evaluation of the ageing effects.

4.3 Identification of the Relevant Components of a Package

Paragraph 104 of the Regulations exhibits the following four functions as safety functions have to be maintained during transport. These functions are also required to the safety of package storage [5].

— Containment\(^3\) (of the radioactive contents);
— Shielding (to control of the external dose rate);
— Subcriticality (to prevent criticality);
— Heat dissipation (to prevent damage caused by heat).

As a systematic scope setting process (scoping) for identifying components\(^4\) subject to the ageing consideration, all package components, including radioactive contents when relevant, should be listed. The following components should be included in the scope of consideration (Fig. 1).

(a) Level 1: components important to the safety necessary to fulfill one or more safety functions of the package;
(b) Level 2: other components whose failure may prevent the components important to safety from fulfilling their intended functions;
(c) Level 3: other components credited in the safety analyses as performing the function of coping with certain types of events, which are consistent with the Regulations and national requirements.

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\(^3\) In the area of nuclear facilities the function for preventing the release of radioactive material is called “confinement”. In this Guide, this is called “containment” to be consistent with the Regulations.

\(^4\) A storage package may be classified as a component because of the complexity in constitution of structures, systems and components. This document addresses only transport/storage packages; hence, sub-components or parts (e.g. shell, lid, basket, seal, and shieldings) are called “components” (of the packaging).
All components of a package
(including radioactive contents)
Input: list or database of all components in the package and applicable sources of information for the scope setting process

Is the component necessary to fulfil a safety function?
Yes
No

Would the component’s failure impact the safety functions of other components?
Yes
No

Dose the component perform a function credited in a specific safety analysis?
Yes
No

Is the component subject to periodic replacement or to a scheduled refurbishment plan, and is not required by national regulatory requirements to be included in the scope?
Yes
No

Components out of the scope for ageing management

Components in the scope of ageing management
- Specific components and their subcomponents within the scope
- Commodity groups of components

FIG. 1. Scope setting process for ageing consideration
The components subject to a periodic replacement or a scheduled refurbishment plan on the basis of predetermined rules (i.e. based on a manufacturer’s recommendation or other bases and not on an assessment of the condition of the component, which would comprise implementation of maintenance or AMP for the package) can be excluded from the scope of ageing consideration.

The radioactive contents of packages intended to be used for shipment after storage should be included. The typical examples are spent nuclear fuel and radioactive waste (e.g. vitrified high level waste (HAW)), including canisters containing them if applicable. The ageing effects on spent nuclear fuel, radioactive waste and canisters during storage should be considered.

4.4 Material

The list of material constituting these components should be presented to complete identification of the relevant components of the package described in Subsection 4.3. The typical material used for packaging and radioactive contents are listed below [9].

(a) Aluminum: used as a cladding of metallic gaskets for closure seals mainly for storage packages, or as a structural member (e.g. basket for allocating spent fuel assemblies).

(b) Borated aluminum: used as a neutron absorber of a structural or non-structural member of the basket for spent nuclear fuel.

(c) Borated stainless steel: used as a neutron absorber of a structural member of the basket for spent nuclear fuel.

(d) Copper or copper alloys: used as a rupture disk or a heat conductor.

(e) Ductile cast iron: used as a structural member.

(f) Nickel alloys: used as a closure lid/plate bolt or a trunnion bolt, or as an inner cladding and spring of the metallic gasket for the lid seal of storage packages.

(g) Neutron absorber material: high-hydrogen-containing material such as water or polymer compounds (resin), used as shieldings; boron or B₄C may be contained to suppress the secondary gamma ray.

(h) Paint: used as a surface coating material.

(i) Silver: used as a cladding of the metallic gasket for lid seal mainly for storage packages.

(j) Stainless steel (austenitic, ferritic, or martensitic): used as a structural member.

(k) Steel (i.e. carbon, alloy, and high-strength, low-alloy steels): used as structural member.

(l) Synthetic rubber: used as an elastomer O-ring for the closure seal mainly for transport.

(m) Woods or foamed polymer (e.g. urethane): used as a shock absorbing material.

(n) Zirconium-based alloys: used as a cladding tube of nuclear fuel.

4.5 Environment and Loading Conditions

Ageing is a process of material change induced by time and stressors from the operational environment; thus defining environment loading conditions to the material is an essential step for evaluating the ageing effects.
(a) Atmosphere
For repeated-use transport packages general weather conditions during transport and specific ambient conditions during empty packaging storage (e.g. outdoor, in a building, or when being covered by a sheet) should be considered.
For packages intended to be used for shipment after storage, the detailed ambient conditions during storage, which are defined in the storage facility design specifications, should be considered. The storage configuration (i.e. vertical or horizontal on a concrete pad or floor, storage frame, outdoors, and in a building) may also be considered. The atmosphere of the package cavity (i.e. cover gas, such as helium and nitrogen) should be defined to evaluate the ageing effects on the radioactive contents.

(b) Mechanical loadings
For repeated-use transport packages mechanical loadings acting on the packaging components during routine conditions of transport, including those caused by acceleration, vibration and vibration resonance, should be considered. For lifting components (e.g. trunnions) the cumulative number of lifting may also be considered.
For packages intended to be used for shipment after storage mechanical loadings under the normal conditions of storage should be considered. The cyclic loadings caused by natural phenomena (e.g. earthquakes) may also be considered.

(c) Thermal loadings
For repeated-use transport packages, the thermal loadings that increase temperature of the packaging components should be considered. These loadings are the decay heat of the radioactive contents and the insolation specified in the Regulations. The daily fluctuation of the insolation seems to have a negligible effect on the ageing mechanisms.
For packages intended to be used for shipment after storage, the thermal loadings under normal conditions of storage should be considered. These loadings are the decay heat of the radioactive contents and, in the case of outdoor storage, storage site specific insolation. The decay in heat generation from the radioactive contents during storage can be considered.

(d) Irradiation
For repeated-use transport packages, the cumulative irradiation (gamma and neutron) during whole numbers of transport in their service life should be considered.
For packages intended to be used for shipment after storage, the cumulative irradiation during the intended storage period should be considered. The decay in the radiation source of the radioactive contents during storage can also be considered.

4.6 Ageing Mechanisms
Among a wide range of ageing mechanisms, the candidate mechanisms specific to the transport and/or storage packages are listed and explained below [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, which results in material oxidation or wastage.

(c) Creep: for a metallic material, creep refers to a time-dependent continuous deformation process under constant stress. It is a thermally activated process and generally a concern at temperatures greater than 40% of the material’s absolute melting temperature. However, a low-temperature creep is a thermal process considered as a potential degradation mechanism for some alloys, including zirconium-based alloys.

(d) Crevice corrosion: a localized corrosion in joints, connections, and other small, close-fitting regions that develop local aggressive environments.

(e) Delayed hydride cracking: the crack propagation in zirconium-based cladding materials as a result of hydrogen diffusion to a crack tip and embrittlement of the near-tip region due to hydride precipitation. The operability of the delayed hydride cracking mechanism in fuel cladding depends on the stress imposed on the cladding.

(f) Erosion: soil erosion, or removal, is primarily caused by rainfall and surface runoff, floods, or wind. Soil erosion can affect the stability of concrete structures, thereby resulting in scouring defined as the localized loss of soil, often around a foundation element. The factors affecting the erosion rates include soil structure and composition, climate, topography, and vegetation cover.

(g) Fatigue: also termed “cyclic loading” or “thermal/mechanical fatigue.” Fatigue is a phenomenon leading to fracture under repeated or fluctuating stresses with a maximum value less than the tensile strength of the material.

(h) Galvanic corrosion: accelerated corrosion of a metal when in an electrical contact with a more noble metal or a non-metallic conductor in a corrosive electrolyte.

(i) General corrosion: uniform loss of material caused by corrosion, which proceeds at approximately the same rate over a metal surface.

(j) Hydride reorientation and hydride-induced embrittlement: the precipitation of radial hydrides results in the embrittlement of zirconium-based cladding materials under pincho-load stresses at low-to-moderate temperatures. The hydride reorientation from the circumferential-axial to the radial-axial direction is caused by heating and cooling of the cladding under sufficient cladding hoop tensile stresses.

(k) Mechanical overload: the overload of fuel cladding caused by fuel pellet swelling. The fuel pellet swelling is the result of the decay gas production in the pellet. Pellet swelling can increase stresses on the cladding.

(l) Microbiologically influenced corrosion: any of the various forms of corrosion influenced by the activity of such microorganisms 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, while acid-producing bacteria can produce corrosive metabolites. The wood corrosion bacteria may degrade the wood used as a shock absorber.

(m) Oxidation: a corrosion reaction that is also a defined as the ageing mechanism describing the reaction of the zirconium alloy fuel rod cladding with water to form zirconium oxide.
(n) Pitting corrosion: a localized form of corrosion confined to a point or small area of a metal surface and takes the form of cavities, called pits.

(o) Radiation damage and radiation embrittlement: the loss of ductility, fracture toughness, and resistance to metal cracking that may occur under exposure to neutron radiation.

(p) Radiolysis: in broad meaning, this refers to the material change caused by irradiation. For example, when water exists in the package cavity, hydrogen is generated by radiolysis, which causes an internal pressure buildup in the package. Polymer changes its composition, thereby decomposing crosslinks by radiation.

(q) Stress corrosion cracking (SCC): the metal cracking produced by the combined action of corrosion and tensile stress (applied or residual). SCC is highly chemically specific, in that, certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments.

(r) Stress relaxation: a loss of preload in a heavily loaded bolt. Over time, the clamping force provided by a bolt may decrease because of the atomic movement within the stressed bolt material (analogous to the metallic creep mechanism at elevated temperatures).

(s) Thermal aging: many materials are intentionally thermally aged during manufacture to achieve the desired mechanical properties. Continued exposure to elevated temperatures during operation can sometimes result to undesirable properties. For example, at operating temperatures of 300°C to 400°C [572 to 752 °F], austenitic stainless steel welds containing ferrite exhibit a spinodal decomposition of the ferrite phase into ferrite and chromium-rich phases. This may lead to embrittlement (reduction in the fracture toughness) depending on the amount, morphology, and distribution of the ferrite phase and the stainless steel composition. These phenomena is called “thermal aging embrittlement” or “thermal embrittlement”. On the contrary, in the case of some alloys, where the material strength is increased by adding specific elements and heat treated when needed, a long thermal history may cancel the enhanced mechanisms and reduce the strength.

(t) Wear: surface material removal caused by relative motion between two surfaces or under the influence of hard, abrasive particles. Wear occurs in parts that experience intermittent relative motion or frequent manipulation.

(u) Wet corrosion and blistering: a degradation mechanism for 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 may hinder the retrieval of fuel assemblies.
5. TECHNICAL AGEING EFFECTS

5.1 Identification of Ageing Effects

Based on the operation duration of the package defined in Subsection 4.1 and the environment and loading conditions defined in Subsection 4.5, the potential ageing mechanisms should be selected from the candidate mechanisms in Subsection 4.6 on each material of the components identified in Subsection 4.3. The selection results should be summarized in a table to exhibit the relations between the material and the potential ageing mechanisms to be considered. Table 1 shows a simple example of a package intended to be used for shipment after storage, in which yes (Y) or no (N) is given to determine whether that mechanism needs consideration for the material.

This table is specific to the package design of concern. Some points to be noted are:

(a) “Yes” should be given to all the ageing mechanisms that can affect the material even the slightest. If a mechanism can be excluded through evaluation in the following sections, the reason and/or evidence of the exclusion should be stated in the section titled “Ageing considerations” in the PDSR. The mechanisms apparently excluded for the material can be marked as “No”.

(b) Ageing mechanisms are time and stressor (loadings act on material)-dependent phenomena; hence the operation duration and loading conditions are essential elements to be considered in scoping. For packages intended for repeated use, the cyclic loadings induced from the maximum radioactive contents and number of cycles should be considered. Meanwhile, for packages intended to be used for shipment after storage, the long duration of static storage and the decay of radioactive contents should be considered.

(c) For packages intended for repeated use, the ageing mechanism of the radioactive contents need not be considered. For packages intended to be used for shipment after storage, the ageing mechanisms of the radioactive contents is within the scope of consideration.

(d) The table is for scoping of possible ageing mechanisms; hence, some mechanisms may be excluded through the evaluation of the ageing effects in later sections. Even so, “Yes” should be kept in this table. The reasons of exclusion (i.e. evaluation results) should be documented in a form, such as “ageing considerations”, in the PDSR.
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<th>Ageing mechanisms</th>
<th>Components</th>
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<tr>
<td>Stress corrosion cracking</td>
<td>Y N N N N N N N N Y N</td>
</tr>
<tr>
<td>Microbiologically influenced corrosion</td>
<td>N N N N N N N N N Y Y</td>
</tr>
<tr>
<td>Creep</td>
<td>N N N N Y Y N N N N</td>
</tr>
<tr>
<td>Fatigue</td>
<td>N N N N N N N Y N N Y N</td>
</tr>
<tr>
<td>Hydride reorientation</td>
<td>N N N N N N N N N N Y N N</td>
</tr>
<tr>
<td>Radiation embrittlement</td>
<td>Y Y Y Y Y Y N Y N N N N</td>
</tr>
<tr>
<td>Radiolysis</td>
<td>N N N N N Y Y N N Y N</td>
</tr>
<tr>
<td>Stress relaxation</td>
<td>N N N Y Y N N Y N N N N</td>
</tr>
<tr>
<td>Thermal ageing</td>
<td>N N N N N Y Y N Y N N Y</td>
</tr>
</tbody>
</table>

Remarks: Y – ageing mechanism with potential effects on the material. N – ageing mechanism that needs no consideration for the material.
5.2 Evaluation of Ageing Effects

The effect of each combination of ageing mechanism and the material selected as potential on the functions of components and safety functions of the package should be evaluated. As the first step, the quantitative change in material composition or properties or the possibility to initiate material degradation should be evaluated based on the package design and its operational conditions and operational duration. The typical items of concern are listed below:

(a) Changes in mechanical strength such as allowable stress, fracture toughness caused by irradiation, and thermal history
(b) Creep rate/quantity by heat, stress and time
(c) Number and intensity of cyclic stress with regard to fatigue assessment
(d) Initiation of stress corrosion cracking due to stress, environment and material combination
(e) Reduction in the thickness of the member due to corrosion
(f) Extent of stress relaxation in the lid bolt and metal gasket due to temperature, stress and time
(g) Reduction in the sealing force in the elastomer O-ring due to temperature and irradiation
(h) Depletion of the hydrogen content of the neutron shielding material due to temperature
(i) Depletion of the $^{10}$B content of the neutron shielding/absorbing material due to neutron irradiation
(j) Initiation of the hydride reorientation due to stress and temperature history

The effects on the safety functions of the package should then be assessed using the results obtained from the first step of evaluation. The severity of the consequences is to be reflected in planning surveillance and maintenance programmes.

(a) For the structural components, the changes in material property caused by irradiation lead to a decrease in the allowable stress or embrittlement of the structural members of the component, which results in a collapse of the members sharing safety functions under severe loading at the accident conditions of transport.
   - The collapse of components consisting a containment boundary (e.g. a shell, a bottom plate, lid(s), lid bolts and seal(s)) leads to the loss of the containment function.
   - The collapse or deformation of the basket affects the criticality prevention function.
   - The basket plate breakage disrupts the heat conduction through the plate, which degrades the heat dissipation function.
   - The collapse of the trunnion during handling or transport leads to a drop of the package, which results to further damage on the safety functions of the package.
(b) The breakage of the thermal pass (copper plates) in the neutron shielding layer disrupts the heat conduction through the plate, thereby degrading the heat dissipation function.
(c) The depletion of $^{10}$B contained in the basket material due to neutron irradiation affects the criticality prevention function.
(d) The loss of hydrogen contained in the neutron shieldings due to heat the increases external dose rate of the package to degrade the shielding function.
The breakage of the thermal pass disrupts the heat dissipation function.

The rapture of the spent nuclear fuel cladding results in increases in the internal pressure of the package cavity, change of the cover gas composition and increase of the radioactive source directly contained in the package containment system. The increase of the internal pressure and the radioactive source result in the increase of the radioactive material released from the package. The change of cover gas composition results in the degradation of the heat dissipation capability.

5.3 Control of Ageing Effects

When the package uses any material with a potential ageing mechanism, the ageing effects should be evaluated and controlled to avoid adverse effects on its safety functions. This control should be achieved by a design including the planning of surveillance and maintenance programmes. The four typical approaches below can be applied to the package design.

5.3.1 Design Component for Usage of Material below the Ageing Effect Threshold

This is the most basic approach for using the material within the range to avoid inducing material property change. Examples of this approach are as follows;

(a) Selecting a material with the neutron irradiation threshold of the mechanical property change 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 without initiation of stress corrosion cracking under stress and environment during operation.

5.3.2 Design Component for Replacement when Parameter Reaches the Ageing Effect Threshold

Components are designed to be replaced when their performance is degraded to the predetermined threshold. This approach is applicable to a component designed to be replaceable during operation or maintenance of empty packaging. The threshold is set as the performance level of the component that affects its safety function or a detectable value determined by the ageing effect evaluation. A surveillance and maintenance programme for detecting the threshold exceedance and replacing or repairing the component should be established. Examples of this approach are as follows;

(a) Replacing a component (e.g. elastomer O-ring for the lid seal) when the acceptance criterion (e.g. leak rate measured at the leak-tightness test) or the allowable number of transport set through the ageing effect evaluation is exceeded (note: the periodic replacement of the seal based on a manufacturer’s recommendation is out of the scope of the ageing management of the package).
(b) Replacing the metallic gasket for the second lid of a package intended to be used for transport after storage when a drop of the inter-lid pressure is detected, and the integrity of metallic gasket for the primary lid is proven (if such operation is allowed under national regulations for storage).
(c) Replacing components (e.g. lifting attachments) when a criterion is exceeded (e.g. the cumulative number of lifting exceeds the number predetermined by the fatigue analysis is exceeded), in which case, the numbers of lifting should be monitored.

(d) Repainting.

5.3.3 Design Package Performance Parameter for not to Exceeding the Ageing Effect Threshold

First, the limit of the ageing effect is set to a level that would avoid seriously deteriorating the component function. The package performance is then designed not to exceed that limit. Typical limits can be set on fatigue, creep, annealing of embrittlement, or hydride reorientation. The typical controllable parameters are cyclic stress, temperature and temperature-dependent stress. The temperature of the package component depends on the heat dissipation rate of radioactive contents; hence, its decay can be considered. These parameters should be somehow monitored to be within a designed range. The examples of this approach are enumerated below:

(a) The cyclic stress that occurs in the component is designed. The occurrence number should not exceed the fatigue limit of the component material.

(b) By designing the heat dissipation performance of the package, the related parameters (e.g. temperature and stress of the component of concern) do not result to an excess of the predetermined cumulative creep limit of the component material during operation.

(c) By designing the heat dissipation performance of the package, the related parameters (e.g. temperature of the component of concern) do not result to an excess of the predetermined temperature limit of the component material, which prevents the initiation of ageing (e.g. annealing of embrittlement and hydride reorientation) during operation.

5.3.4 Design Component Using Aged Material Properties

A package can be designed using the obtained properties of aged material. However, caution should be taken when obtaining these properties. The acceleration of time by the parameter, which enhances the ageing mechanism, is usually is used. Hence, the acceleration method and the extrapolation of the obtained data should be fully justified to represent appropriate aged properties. The examples of this approach are as follows;

(a) Using the allowable stress of the simulated aged material in structural design.

(b) Using the reduced fracture toughness in the fracture mechanics evaluation.

(c) Using the increased leak rate of the aged metallic gasket in the radioactive material release evaluation.

(d) Using the depleted hydrogen concentration to represent the aged neutron shielding material in the shielding design.

(e) Using the depleted $^{10}$B concentration to represent the aged neutron absorber material in the criticality design.
5.4 Definition of Ageing Surveillance Programmes

The package performance throughout the operational duration should be maintained and ensured by establishing and implementing an ageing surveillance programme, by which the ageing effects are controlled within a range defined in the package design process. The ageing surveillance programme is reflected in, or is part of a maintenance programme for the package intended for repeated use. For the package intended to be used for shipment after storage, the ageing surveillance programme is reflected in a maintenance programme and part of an AMP.

The ageing effects are directly or indirectly monitored in a time-dependent manner as defined in an ageing surveillance programme. “Indirectly” means the package performance parameters are monitored to ensure that the ageing effects are within the designed range (i.e. no clear adverse effect of ageing is found on the specific safety function of the package).

5.4.1 Packages Intended for Repeated Use

A surveillance programme intended for package for repeated use consists of sets of inspections during the packaging manufacture, pre-shipment inspections of package and periodical inspections of packaging. The purpose of these inspections is not limited to detecting the ageing effects, but extended to the confirmation that the total safety functions of the package are intact when subjected to transport. Depending on the package design, not all inspections are applicable.

(a) Manufacturing inspection of packaging: A set of inspection results during the manufacture of packaging should be maintained as a record of the initial packaging condition.

(b) Pre-shipment inspection of package: This inspection aims to verify that the package is prepared as designed and ready for shipment in compliance with the applicable requirements of transport regulations. Some records of this inspections can be used to evaluate the ageing effects. The typical inspection items are as follows:

- Visual inspection: The ageing effects on the package surfaces can be detected.
- Leak-tightness inspection: The lid seal (O-ring) is replaced when the specified leak rate is not achieved.
- Cavity pressure inspection: Not related to ageing effects
- Dose rate inspection: No ageing effects on the shielding performance can be confirmed.
- Sub-criticality inspection: No ageing effects on the basket structure can be confirmed.
- Temperature measurement inspection: No ageing effects on the heat dissipation performance can be confirmed.
- Lifting inspection: Not related to ageing mechanism in initial shipments. After repeated use, no ageing effects on lifting attachments can be confirmed.
- Weight inspection: Not related to ageing effects
- Radioactive contents inspection: Not related to ageing effects
- Surface contamination inspection: Not related to ageing effects.
- Marking and labeling inspection: Not related to ageing effects.
Periodical inspection of packaging: This inspection is periodically conducted to the empty packaging, or the package containing radioactive contents depending the purpose of each inspection item (annual, every 3 – 5 years, or every 10 years depending on the inspection items) to confirm that it maintains its performance as designed. The inspection items and intervals are programmed through a systematic analysis such as failure modes and effects analysis (FEMA). The typical inspection items are as follows:

- Transport record: History of transport including transport numbers, radioactive contents specifications, and pre-shipment inspection results for each transport that should be maintained, and used in the package performance evaluation.

- Visual inspection: The ageing effects on the accessible packaging component surfaces can be detected. Additionally, a die-penetrant test on the component surfaces can be applied to detect the surface defects when required.

- Leak-tightness inspection: The ageing effects on the lid seal part configurations and lid seal (O-ring) can be confirmed.

- Sub-criticality inspection: No ageing effects on the basket structure can be confirmed more closely such as by a dimensional measurement or gage. The neutron absorber depletion can be calculated based on the transport record.

- Operation inspection: The ageing effects on movable parts such as valves can be confirmed.

- Lifting inspection: The ageing effects on the lifting attachments can be confirmed. A die penetrant test may be applied on the attachments when required.

- Thermal performance inspection: The ageing effects on components related to heat dissipation can be confirmed from the tendency of the temperature measurement inspections for each transport, or direct measurements by using radioactive contents at the first shipment after the periodical inspection.

- Shielding performance inspection: The ageing effects on shieldings can be confirmed from the tendency of the dose rate inspections for each transport, or direct measurements by using radioactive contents at the first shipment after the periodical inspection.

- Pressure test: The ageing effects on the pressure retaining components can be confirmed.

5.4.2 Packages Intended to be Used for Shipment after Storage

A surveillance programme on packages intended to be used for shipment after storage consists of sets of inspections during packaging manufacture, pre-shipment inspections of package for the first shipment, reception inspection at the storage facility, a monitoring programme during storage and pre-shipment inspections of the package for the shipment after storage. These inspections are not limited to the detection of the ageing effects, but extends to confirming transportability after storage (i.e. total safety functions of the package), including the integrity of the radioactive contents, which are maintained throughout the storage duration. Depending on the package design, not all inspections are applicable.

(a) Manufacturing inspection of packaging: A set of inspection results during packaging manufacture should be maintained as a record of the initial packaging condition.
(b) Pre-shipment inspection of package for the first shipment: This inspection aims to verify that the package is prepared as designed and ready for shipment in compliance with the applicable requirements of transport regulations. The typical inspection items are identical to those in Subsection 5.4.1 (b), but no ageing effect need to be considered. The inspection results should be maintained as a record of the initial package condition, including radioactive contents.

(c) Receipt inspection of package at the storage facility: This inspection aims to verify that the package has been transported without any incident to affect its safety functions and that it complies with the storage specifications. This also aims to maintain a record of the initial conditions of the package to be stored. The items should be confirmed to have no adverse effect on the safety functions of the package by comparing the results of pre-shipment inspections.

(d) Monitoring programme during storage: The monitoring programme aims to ensure transportability after storage, as required in para. 503 (e) of the Regulations. The items to be monitored are planned to cover those in (b) above. The monitoring should be conducted on the package loaded with radioactive contents. Monitoring can be conducted continuously or periodically (daily, weekly, monthly, annually or in other intervals depending on the safety importance of the monitored functions and practicability). A monitoring programme is generally part of the safe operation programme for the storage facility required by the national storage regulations. Monitoring the integrity of radioactive contents should be included, from viewpoint of the transport components not used for storage but for transport (e.g. shock absorbers). The typical monitoring items are as follows:

- Visual inspection: The ageing effects on the package surfaces can be detected. Defects found should be repaired under the maintenance programme.

- Inter-lid pressure monitoring: This monitoring, which is conducted continuously or intermittently, substitutes the leak-tightness inspection of lid seals. The decrease of the inter-lid pressure indicates a degradation of the metallic seal of the primary or the secondary lid. When a pressure decrease is detected, countermeasures under the maintenance programme should be taken based on the leak rate measurement of the secondary lid seal.

- Cavity pressure inspection: This inspection is not related to ageing effects and is substituted by the inter-lid pressure monitoring.

- Dose rate inspection: The dose rate on the surface of the package or around the package is continuously or intermittently measured. The ageing effects on the shieldings can be confirmed based on the history of the dose rate change and the considerations to the decay of the radioactive source.

- Sub-criticality inspection: This inspection is substituted by a set of visual inspections, inter-lid pressure monitoring, and temperature measurement inspections. The absence of an anomaly in these inspection results indirectly confirms that the ageing effects on the basket structure and the neutron absorber are within the designed range.

- Temperature measurement inspection: The temperature at the package surface is measured continuously or intermittently. The ageing effects on components related to heat dissipation can be can be confirmed based on a history of the temperature change and considerations to the decay of heat generation from the radioactive contents.
- Lifting inspection: This inspection is substituted by a visual inspection of the lifting attachments. No ageing effects on the lifting capability can be confirmed when no anomaly is observed in the visual inspection.

- Weight inspection: This inspection is not related to the ageing effects and is substituted by visual inspection.

- Radioactive contents inspection: This inspection is substituted by a set of visual inspections, inter-lid pressure monitoring and temperature measurement inspections. The absence of an anomaly in these inspection results confirms that the ageing effects on the radioactive contents are within the designed range.

(e) Pre-shipment inspection of package intended for the shipment after storage: The same items in (b) above are conducted. Some inspection items can be conducted as they are, while others (e.g. cavity pressure inspection, sub-criticality inspection and radioactive contents inspection) should be substituted by a set of records of visual inspection, inter-lid pressure monitoring, and temperature measurement inspection during storage. The logic for substitution should be carefully structured.

5.5 Definition of Ageing Management and Gap Analysis Programmes

For the package intended to be used for shipment after storage, an ageing management programme (AMP) for any material with a potential ageing mechanism should be established and submitted to the competent authority, as required in para. 809 (f) of the Regulations. A gap analysis programme (GAP) should also be established as per para. 809 (k).

Section 1.7 “AGEING CONSIDERATIONS” in Ref. [5] provides a detailed information on the ageing consideration for the DPCs containing spent nuclear fuel. A concept of the AMP and information to be included are presented under Section 1.11 “MANAGEMENT SYSTEMS”. The AMP for DPCs containing spent nuclear fuel can be defined, by referring to these sections. Based on these sections, defining an AMP for the package containing radioactive contents other than spent nuclear fuel is not difficult. An AMP should be supplemented in the case of the components not included in the abovementioned considerations, but are to be used for the shipment after storage (e.g. shock absorbers).

An AMP is generally prepared for the storage facility operation to be licensed under the national storage regulations. Thus, in applying for the package design approval, the AMP for the storage facility can be duplicated (with supplements, when needed) or a summary of the programme with reference to the programme for the storage facility can be placed.

A GAP aims to conduct a periodic assessment of whether the package design complies with the current national and/or international transport regulations, as explained in paras 613A.5 and 809.4 of the Advisory. The programme addresses changes in technical knowledge; hence, the state of the package design requirements of the transport and storage regulations, consideration to changes in knowledge on the ageing mechanisms (e.g. new demonstration data become available, when a new ageing mechanism is revealed), or ageing-related requirements (e.g. fatigue limit and creep limit) should be stated with reference to the AMP.
### 6. CONSIDERATIONS FOR PACKAGE DESIGN

The outcome of the package design should be documented to maintain evidence of the package design compliance with the applicable transport regulations. For package designs that require approval by a competent authority, the PDSR is prepared for application to the competent authority. For package designs where a competent authority approval is not required, such documentary evidence should be prepared in the PDSR format.

SSG-XX [3] provides the PDSR format, in which a section for ageing considerations is included. Thus, evidence to consider the ageing mechanisms in the package design should be placed in that section as described below for the types of packages. The recommended items to be addressed are:

(a) Intended conditions of use: The conditions of using the package, such as the operational duration with its mode (i.e. transport, empty packaging or storage), environmental and loading conditions, are defined.

(b) Potential ageing mechanisms: First, the components to be considered and their material are listed. The potential ageing mechanisms are then listed for scoping, based on the intended conditions of use. The combinations between the ageing mechanism and the material that may have ageing effects are to be selected and tabulated (see Table 1 for an example).

(c) Analysis of the influence of ageing and measures to be taken: The ageing effects for each combination are evaluated. Countermeasures taken by design and/or operation are defined if adverse effects on the component or safety functions of the package are foreseen.

(d) Operational measures: The operational measures for detecting the ageing effects and preventing the adverse ageing effects (e.g. inspections, monitoring and limits on operation) are stated.

These items are not applicable to packages for once-through use.

### 6.1 Packages Intended for Once-through Use

No ageing effect needs to be considered for packages intended for once-through use because the operating duration is less than one year. The section of ageing considerations in the PDSR presents the following relevant guidelines: “not applicable” or “no ageing mechanism needs to be considered in the design, because the transport duration is less than one year”.

### 6.2 Packages Intended for Repeated Use

A wide range of packages is designed for repeated use. The typical considerations are listed below:

(a) Excepted packages

Five kinds of excepted package are defined in the Regulations:

(i) Empty packaging (UN 2908)

(ii) Containing articles manufactured of natural uranium, depleted uranium or natural thorium (UN 2909)
(iii) Containing limited quantity of material with activity not exceeding the limits specified in the Regulations (UN 2910)

(iv) Containing instruments or articles not exceeding the activity limits specified in the Regulations (UN 2911)

(v) Containing uranium hexafluoride less than 0.1 kg (UN 3507)

The activities of the radioactive contents for these packages are limited and very small; hence, the following considerations can be given;

- The activity of radioactive contents is limited to small; thus, cumulative irradiation to package components is negligible even after repeated use. No ageing effect due to irradiation needs to be considered.

- The activity of radioactive contents is limited to small; thus, heat dissipation from the contents is negligible. No ageing effect due to thermal loadings needs to be considered.

- The packaging (e.g. cardboard box and steel can) is designed and manufactured on the basis of ordinary industry standards. Hence, no ageing effects due to mechanical loading or the environment are expected when subjected to routine conditions of transport repeatedly. Any deformation, rust, corrosion or other defect occurrence in the packaging will be detected by the pre-shipment inspections (e.g. visual and dose rate inspections). The packaging will then be repaired or replaced.

- For an empty packaging, the consideration of the ageing effects is excluded because no irradiation nor thermal loadings from the radioactive contents to progress ageing effects exist. Only in the case that cyclic mechanical loadings during handling and transport are critical to develop the ageing effects, these effects should be considered.

(b) Type IP and Type A packages

The aspects of considerations on the ageing effects for Type IP and Type A packages are similar to those for except packages because the activity of the radioactive contents is limited. In the case of frequently used packaging, the effects of cyclic mechanical loadings should be considered. These types of packagings are usually designed, manufactured and maintained on the basis of industrial common sense (i.e. using common design techniques, common material, common manufacturing procedures, and common maintenance programmes) or in accordance with the industrial standards or codes); thus, their integrity can be assured unless the designer’s instructions have been followed. Any anomaly is designed to be detected during maintenance or pre-commencement inspections for each operation. Meanwhile, when new material, design or manufacturing techniques (e.g. polymer material, joints by specific welding or by adhesive) are introduced, care should be taken to the potential adverse effects including those caused by ageing. The examples of ageing considerations are presented below:

- The activity of radioactive contents is limited to small; thus cumulative irradiation to package components is negligible even after repeated use. No ageing effect due to irradiation needs to be considered.

- The activity of radioactive contents is limited to small; thus, heat dissipation from the contents is negligible. No ageing effect due to thermal loadings needs to be considered.

- The packaging (e.g. cardboard box and steel can) is designed and manufactured on the basis of ordinary industry standards. Hence, no ageing effects due to mechanical loadings or the environment are expected when the package is repeatedly subjected to routine conditions of transport. Any deformation, rust, corrosion, or other defect
 occurrence in the packaging will be detected by the pre-shipment inspections (e.g., visual and dose rate inspections). The packaging will then be repaired or replaced.

- The freight container-type packaging is designed, manufactured, and tested on the basis of voluntary, national, or international standard (e.g. ISO 1496/1 [11]). Hence, no ageing effects due to mechanical loadings or the environment is expected when it is repeatedly subjected to routine conditions of transport. Any deformation, rust, corrosion, or other defect occurrence in the packaging, it will be detected by the pre-shipment inspections (e.g. visual and dose rate inspections), or by the periodical inspection and testing. The packaging will then be repaired or replaced. This consideration can be applicable to UN packages, portable and other tanks, and metal IBCs, which follow Ref. [12].

(c) Type B(U), Type B(M) and Type C packages

The considerations to the ageing effects caused by irradiation and heat should be taken commensurate to the activity of radioactive contents. The examples of these considerations on a typical material are as presented below, in which documentary evidence for demonstration data and design calculations to prove the range of parameters should be referred to. The parameters of irradiation, temperature, and numbers and duration of operation are assumed as values that indicate magnitudes. These values for the PDSR should be determined by evaluations on the specific package designed.

- Embrittlement of stainless steel, carbon steel or low-alloy steel by neutron irradiation occurs at an irradiation level over $10^{17}$ to $10^{18}$ cm$^{-2}$. The maximum cumulative neutron irradiation of these materials used for a shell, a bottom plate, a lid, lid bolts, and trunnions during design transport duration is a level of $10^{15}$ cm$^{-2}$; thus, the embrittlement due to neutron irradiation in these materials can be excluded. The same consideration can be applied because the maximum cumulative neutron irradiation on the stainless steel used for basket plates is at level $10^{15}$ cm$^{-2}$.

- Changes in the mechanical properties of aluminum alloys occur at a neutron irradiation level over $10^{21}$ cm$^{-2}$. The maximum cumulative neutron irradiation on aluminum alloy used as basket plates is at level $10^{15}$; therefore, the mechanical property changes due to neutron irradiation can be excluded.

- Changes in the mechanical properties of copper occur at a neutron irradiation level over $10^{20}$ cm$^{-2}$. The maximum cumulative neutron irradiation on copper plates used as thermal paths is at level $10^{15}$; thus the embrittlement due to neutron irradiation can be excluded.

- The ageing effects on lead used as gamma shieldings are excluded because no clear change in the properties of lead due to irradiation has been reported.

- The radiation resistance of resin (epoxy, silicone) is $10^6$ to $10^8$ Gy, while the cumulative irradiation of resin used as neutron shieldings is at level $10^3$ Gy. Thus, no ageing effects on resin need to be considered.

- In the structural design and construction code (e.g. Boiler and Pressure Vessel Code issued by the American Society of Mechanical Engineers [13]), mechanical properties up to $350^\circ$C are given for carbon steel and low alloy steel and up to $425^\circ$C for stainless steel. The temperature of these material used for a shell, a bottom plate, a lid, lid bolts, and trunnions during transport is less than $170^\circ$C; thus, no creep occurs in these components. The temperature of the basket made of stainless steel is less than $180^\circ$C.
for a wet type package and less than 390°C for a dry type one; thus, no creep nor dimensional change occurs in the basket.

- Based on the results of the thermal decomposition tests, the thermally accelerated, long-term service temperature for resin (epoxy, silicone) used for neutron shieldings is evaluated by extrapolation as 170°C with the maximum loss of mass of less than 5%. The maximum temperature of resin is designed less than 170°C. A 10% loss in mass is conservatively assumed in dose rate analysis (shielding analysis). Hence, the ageing effects on the shielding performance of the package is taken into the package design. In the case of borated resin, although the $^{10}$B depletion due to irradiation is negligible, the same rate as that of resin mass is considered in the shielding analysis.

- Based on the test data on irradiation and thermal degradation, the elastomer O-rings for the lid seal are determined to be replaced at the number of transports, including transport as an empty package, for less than six times to avoid the ageing affecting its leak-tightness. In addition, the O-ring that failed to satisfy the designed leak rate in the pre-shipment inspection of the package or the periodical inspection of the packaging will be replaced. The elastomer O-rings used for the fusible plugs on the outer shell surface or on the shock absorber casing surface (designed to release excessive gas pressure generated during the fire test) are replaced every 5 years during the periodic maintenance.

- The external surfaces of the packaging made of carbon steel or low ally steel are covered by plating or painting to avoid corrosion. The defects on the covering can be detected by the pre-shipment inspection of the package or the periodical inspection of the packaging. Sea salt particles in the package transport or packaging storage environment may cause the initiation of the stress corrosion cracking (SCC) on stainless steel surfaces. Accordingly, surfaces with a potential stress corrosion cracking environment (e.g. stress and temperature) are protected by paint or coating. The small gaps or clevis that may cause a clevis corrosion are filled with sealant (e.g. attachment point of a trunnion) or covered with a sealing material (e.g. plastic sheets and adhesive tapes) during the radioactive contents loading/unloading in a wet pool to prevent water intrusion. The initiation of corrosion can be detected by the pre-shipment inspection of the package or the periodical inspection of the packaging, then repaired.

- Based on the fatigue analysis, trunnions are determined to be replaced when the number of lifting operations exceeds 10,000 times to avoid a fatigue failure.

- The wood used as a shock absorbing material is sealed tightly in a metallic casing; thus, the ageing effects (e.g. corrosion by wood corrosion bacteria, change in water concentration) are excluded. The temperature of and irradiation to the wood is low enough to exclude ageing effects such as change of its mechanical property or decomposition of adhesive to form a plywood.

- No ageing effects on the radioactive contents need to be considered because the single-transport duration is short (less than one year).

(d) Packages containing fissile material

In the PDSR, for packages containing fissile material, the considerations to the ageing effects on criticality-related components should be added to the considerations given to the design for the package type designated by radiological characteristics. The examples of criticality related ageing considerations are as follows:

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- The temperature of the basket made of stainless steel is less than 180°C for a wet-type package and less than 390°C for a dry-type one; thus, no creep nor dimensional change in the basket that affects the criticality analysis occurs.

- The depletion of $^{10}\text{B}$ contained as the neutron absorber in the basket is at level $10^{11}$; therefore, the ageing effects on criticality prevention are negligible. In addition, the conservative boron content (e.g. 80%) is used in the criticality analysis for conservativeness.

- The neutron poison plate is sealed in stainless steel sheath and attached to the basket plate. Thus, the ageing effects caused by wet corrosion or blistering such as depletion of the neutron-absorbing performance, or moderator displacement affecting the criticality analysis, or dimensional change that may hinder the radioactive contents retrieval, can be excluded.

(e) Packages containing uranium hexafluoride

Packagings to contain uranium hexafluoride, usually called as ‘cylinders’, are designed, manufactured, inspected and tested, and maintained in accordance with the internationally standards, i.e. ISO 7195 [14] or ANSI N14.1 [15]. The maintenance programmes specified in these standards has been established with considerations to the ageing mechanisms; thus, no further consideration of the potential ageing mechanism is needed when these cylinders are maintained and inspected to follow these standards. See para. 613A.6 of the Advisory.

6.3 Packages Intended to be Used for Shipment after Storage

The basic concept of considerations on the ageing effects for packages intended to be used for shipment after storage is somewhat different from that for packages intended for repeated use. The major differences for this are as follows:

(a) The package is subjected to transport twice (i.e. before and after storage) and subjected to static storage for several decades to 100 years, with its radioactive contents loaded.

(b) The integrity of the radioactive contents should be maintained, including its retrievability. The decay of the radioactive contents activity during storage can be considered.

(c) Transportability after storage should be ensured during storage. To do so, the maintenance of the safety functions for the transport and integrity of radioactive contents should be monitored throughout the storage.

(d) Regarding ageing, packages should maintain their safety functions and withstand storage and transport conditions, including accident conditions of storage and transport after storage with an aged material.

Documentary evidence of consideration to the ageing mechanism during storage may be included in the safety case for storage package under national storage requirements. If applicable, such evidence can be referred to in the PDSR. The considerations to the package components not used during storage but for shipment after storage should be included in the PDSR as well.

Examples of storage specific considerations are given below:
- Through demonstration test and analysis, the metal gasket (aluminum clad) is proven to maintain its leak-tightness below the designed leak rate over 100 years at 150°C. The temperature of the seal region of the package is below 150°C during storage; hence, the containment function of the package during storage can be maintained. In addition, the deterioration of the leak-tightness during storage can be detected by the inter-lid pressure monitoring for the double-lid system. The proper countermeasures will be taken in such a case.

- Meanwhile, the leak-tightness of the aged metal gasket under transport conditions after storage, including accident conditions, has not been demonstrated. Thus, for transport after storage, an additional lid (third lid) with an elastomer O-ring will be used as a containment boundary for transport.

- An age-hardening aluminum alloy with a higher mechanical strength is used as the basket material. Such an aluminum alloy will lose its enhanced strength under an elevated temperature environment for a long time. Hence, the mechanical properties obtained from the test specimen annealed with the thermally accelerated process to simulate the state of the alloy after 60 years of service are used in the structural analysis of the basket to include the ageing effects on the material.

- The cumulative creep is limited to less than 1%, and the cladding temperature at the beginning of storage is designed not to exceed the cumulative creep limit using the creep configuration equation to prevent creep rupture in the zircaloy cladding tube. Assuming a storage duration of 60 years and the decay of heat dissipating from the spent fuel, the allowable initial temperatures of cladding are calculated as 380°C and 360°C for the BWR and PWR spent fuel, respectively. Thus, the heat dissipation performance of the package is designed to achieve an initial cladding temperature below these allowable temperatures. In addition, the operation procedure is controlled, such that the cladding temperatures do not exceed these limiting temperatures during the vacuum drying process.

- The hydride reorientation in zircaloy cladding tube from the circumferential-axial to radial-axial direction is caused by the heating and cooling of the cladding under sufficient cladding hoop tensile stresses and the resulting change of the mechanical properties of the cladding material. The test data show that no change in the mechanical properties were observed in cooling from 300°C with a hoop stress of 100 MPa for the zircaloy-2 material or from 350°C with a hoop stress of 135 MPa for the zircaloy-4 material. Thus, the cladding temperature is designed not to exceed these temperatures during the vacuum drying process and storage.

- The embrittlement of the zircaloy material used as a nuclear fuel cladding tube due to the irradiation in the reactor results to a higher material strength. This embrittlement can be annealed by the cooling process in the package, which increases the ductility but decreases mechanical strength. The occurrence of annealing should be avoided when the mechanical strength of the embrittled material is used in a structural analysis of cladding tube under the accident conditions of transport after storage. The test data show that annealing occurs in the cooling from over 305°C; thus, the cladding temperature is designed not to exceed this temperature during the vacuum drying process and storage.

- The residual water in the cavity gas of the package at the completion of the vacuum drying process is controlled to be less than 10 mass%. Assuming that the cladding material reacts to all the residual water and absorbs the hydrogen generated in the reaction, the thickness of the oxidation layer at the cladding surface is evaluated to be
less than 1 µm, and the hydrogen concentration in the cladding is approximately 6 ppm. The ageing effect caused by the reaction is negligible.
7. OPERATIONAL ASPECTS

7.1 Surveillance of Package Functions

A surveillance programme on package functions including ageing management is developed in the package design phase as stated in Subsection 5.4. This program is then established and implemented by the related organization responsible for the maintenance of package functions (e.g. packaging owner, transport operator including consignor, radioactive contents owner or storage facility owner or a storage facility operator). The programme consists of several steps and includes in the PDSR as a pre-shipment inspection in 1.7 “PACKAGE OPERATIONS” and a periodical inspection in 1.8 “MAINTENANCE”. A systematic surveillance programme for the packages intended to be used for shipment after storage is included in 1.4 “AGEING CONSIDERATIONS” in the PDSR.

7.1.1 Packages Intended for Repeated Use

A surveillance programme on packages intended for repeated use consists of the following procedures, whose details are found in Subsection 5.4.1.

(a) Manufacturing inspection for the packaging
(b) Pre-shipment inspection of the package
(c) Periodical inspection of the packaging, which may be conducted in conjunction with the maintenance programme.

7.1.2 Packages Intended to be Used for Shipment after Storage

A surveillance programme for package intended to be used for shipment after storage consists of the following procedures, whose details are found in Subsection 5.4.2.

(a) Manufacturing inspection of the packaging
(b) Pre-shipment inspection of the package for the first shipment
(c) Receipt inspection of the package at the storage facility
(d) Monitoring programme during storage, which may be conducted in conjunction with the maintenance programme
(e) Pre-shipment inspection of the package for the shipment after storage.

Note that the pre-shipment inspection of the package for the shipment after storage is completed with the results from all the inspections and monitoring (a) to (d).

7.2 Controls before Shipment

A pre-shipment inspection should be conducted and complied with for packages intended for repeated use. In contrast, all manufacturing inspection procedures, the pre-shipment inspection for the first shipment, receipt inspection at the storage facility, monitoring during storage and pre-shipment inspection of the package for the shipment after storage should be conducted and complied with for packages intended to be used for shipment after storage. In preparation for
the latter inspection, all results of the previous inspections and monitoring should be maintained by the inspection conductor.
8. ADMINISTRATIVE ISSUES

8.1 Package Design Approval

Paragraph 802 of the Regulations states that the package design approval by a competent authority is required for certain types of packages (i.e. Type B(U), Type B(M), Type C packages and packages containing fissile material or 0.1 kg or more uranium hexafluoride), regardless of whether they are intended to be used repeatedly for shipment after storage or not. In applying for the package design approval for Type B(U), Type B(M) and Type C packages, the considerations to the ageing mechanisms in the safety analysis and within the proposed operating and maintenance instructions as per para. 809(f) of the Regulations and a GAP as per para. 809(k) are required for packages intended to be used for shipment after storage.

Nevertheless, although not mandatory, designers are advised to prepare ageing considerations as a documentary evidence of compliance to para. 613A of the Regulations for packages intended for repeated use, packages other than Type B(U), Type B(M) and Type C, and packages that are not required design approval by a competent authority, commensurate to the operating conditions and the package design, as stated in SSG-XX [3].

8.1.1 Duration

The typical operational durations of packages intended for repeated use, including Type IP and Type A packages, are 30 to 40 years based on industrial common sense; otherwise, a shorter duration is specifically defined. Thus, the ageing considerations should be taken as stated in this guide. If the intended use of the packaging is limited to several times of transport or a duration of a few to several years, the ageing considerations may be excluded on the basis of the scoping described in Subsection 5.1. At present, package design approvals are issued by the competent authorities of the Member States with a validation period of 3 to 5 years. These periods are extended another 3 to 5 years by revalidation when the package design complies with the latest transport regulations. Some competent authorities of the Member States consider an extension of the validity period for packages intended to be used for shipment after storage based on the proper implementation of the ageing management programme and gap analysis programme.

The operational durations of packages intended to be used for shipment after storage (i.e. storage periods) are defined in the storage facility specifications or by the national requirements of the Member States as 20 to 40 years or more. An extension of the storage period that was initially intended may be achieved by a proper implementation of the ageing management and gap analysis programme. Although this guide concentrates on single storage, multiple storages for one package (e.g. first storage at a nuclear power plant, then to a central storage outside the power plant) can be considered. In such a case, the ageing consideration, including the AMP, should be revised for the second storage on the basis of newly defined conditions such as storage facility specifications and additional storage period.

8.1.2 Ageing Aspects

[What is expected to be placed here?]
8.1.3 Interface for Storage Approvals/Licenses

As regards packages intended to be used for shipment after storage, a documentation on ageing considerations, including an AMP, is required for the transport license, and most probably, also for the operational license of the storage facility under the national requirements for storage. References between both documents are possible on the extent, in which the same considerations and evaluations are applicable. In most cases, approach to ageing considerations may be common; however, evaluations may differ between transport and storage, because the environment and loading conditions (i.e. routine, normal and accident conditions of transport versus normal, anticipated occurrences and accident conditions of storage) are different. Meanwhile, the surveillance programme during storage should be well structured to support the transport license to be applied to the shipment after storage.

8.1.4 Interface for Country of Origin/Storage Country

In the case of a Type B(U) package intended to be used for shipment after storage, the transport license is issued by the competent authority of the country of origin of the design only, as defined in para. 205 of the Regulations. Thus, the Type B(U) package design approval is valid in countries other than that in the country of origin of the design, where storage occurs, except for a part of the license that addresses fissile material if contained. A problem arises when the Type B(U) license is lost in the country of origin of the design for some reason or because of withdrawal or non-renewed, which results in the unavailability of the transport license in the country where storage occurs. A solution to this problem is advised in para. 840.3 of the Advisory. The solution involves the issuance and maintenance of a new transport license (i.e. Type B(U) or Type B(M)) by the competent authority of the country where storage happens. To do this, the applicant of the new license should fully understand the contents and the background of the original application not limited to the package design but also involving other supporting documents that address ageing considerations, AMP, GAP, surveillance during storage and requirements for shipment after storage. The competent authority of the country, where storage occurs, with preferably share information on the original review with the competent authority of the country of the origin of the design. Such an arrangement may be established before the commencement of storage.

8.2 Periodical Review of Packages to Ensure Transportability

For packages intended for repeated use a transport license is renewed every 3 to 5 years depending on the validity period determined by the competent authority. Before application for renewal an applicant conducts gap analyses to the current regulations. If applicable, new technical knowledge is used to fill the gaps. The application is then submitted to the competent authority. A validation period of the transport license practically results a periodical review of the package design. Some competent authorities of the Member States may require “packaging approval” or “packaging confirmation” to ensure that the packaging is manufactured and maintained as designed based on the applicable package design approval. In such case, the packaging performance can be periodically reviewed by considering periodical inspection and maintenance results.

The periodical review of packages is part of a GAP for packages intended to be used for shipment after storage. A gap analysis programme systematically reviews current technologies and requirements to find the gaps to be filled in the package design and related programmes.
Reviews are conducted, and transportability after storage will be ensured when the gaps are filled.

8.2.1 Integration of Surveillance Results into the Review

As stated in Subsection 5.4.2, a surveillance program for packages intended to be used for shipment after storage is structured to ensure transportability after storage in step by step manner. The outputs from the monitoring programme during storage can be translated into compliance to pre-shipment inspection after storage at any time. Thus, transportability after storage is ensured when surveillance results are integrated in any periodical review during storage.

8.2.2 Providing Feedback to the Package Design Approval Procedure

One important purpose of the periodical review is to provide feedback to package designs and related programmes, including the surveillance, maintenance, ageing management, and gap analysis programmes. Feedback to the package design approval procedure, especially in conjunction with the licensing procedure for storage, is highly welcomed because the package design approval procedure for packages intended to be used for shipment after storage is a new procedure for the Member States and may contain much to be improved.

9. CONCLUSIONS

[To be prepared.]
REFERENCES


