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IAEA-TECDOC-1938

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Methodology for a Safety Case of a Dual Purpose Cask for Storage and Transport of Spent Fuel

Report of a WASSC/TRANSSC Joint Working Group

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METHODOLOGY FOR A SAFETY CASE OF A DUAL PURPOSE CASK FOR STORAGE AND TRANSPORT OF SPENT FUEL

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INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

Spent nuclear fuel generated in the operation of nuclear reactors needs to be safely managed following its removal from the reactor core. Reactor storage pools were designed based on the assumption that, after a short period of time, spent nuclear fuel would be removed for reprocessing, disposal or storage elsewhere. Owing to delays in making decisions on the disposition of spent fuel and in putting decisions into effect, the volume of highly radioactive spent fuel that needs to be stored is growing and additional storage capacity is required.

One widely used option for additional storage capacity is the use of dry spent fuel storage casks. Of the various existing dry storage concepts, several Member States are using the dual purpose cask. There are obvious benefits to storing spent fuel in a container that can be safely handled and stored, and that provides levels of radiation shielding, heat dissipation, criticality safety and containment making it acceptable for transport in the public domain. However, these benefits come with inherent strategic risks that need to be managed over the entire storage timescale.

In April 2011, the IAEA initiated a working group to develop guidance for Member States on an integrated safety case for dual purpose casks for the transport and storage of spent fuel, with the support of both the Transport Safety Standards Committee (TRANSSC) and the Waste Safety Standards Committee (WASSC). This publication is based on discussions within the TRANSSC/WASSC Working Group during its activities from 2011 to 2013. It provides information on the structure and contents of an integrated safety case for a dual purpose cask. The publication is expected to be of interest to designers, vendors, operators, licensees, regulators, technical support organization and others involved in the development and review of the safety case and supporting safety assessment.

The IAEA appreciates the contributions of various experts to this publication. The IAEA officers responsible for this publication were Y. Kumano, A. Guskov and S. Whittingham of the Division of Radiation, Transport and Waste Safety.

CONTENTS

INTRODUCTION

This introduction provides the background and history of the Working Group activities as well as general discussion to consider for subsequent parts of this report (PART 1 and PART 2).

1. BACKGROUND

Operating nuclear reactors generate spent fuel, which needs to be safely managed following its removal from reactor cores. The reactor on site pool-type storage capacities were designed based on the assumption that fuel would be removed after a certain period of time either for reprocessing, disposal, or further storage. However, as a result of storing higher burn-up fuel, significantly increased timeframe till disposal solutions are prepared, and delays in decisions on strategies for spent fuel management, the volume of spent fuel discharged from reactors which needs to be managed and stored is on the increase. Consequently, additional storage capacity may be needed following the initial storage in reactor pools.

In some countries, a concept of dual purpose cask (DPC) is considered as an option for further storage. This is because of that the concept increases flexibility for storage capacity, as well as its economic efficiency that can reduce the complexity of handling highly radioactive spent fuels.

The primary safety objectives of a DPC design relate to national storage regulations and compliance with the transport regulations extant at the time of transport. DPCs are generally designed with a dual containment boundary and are designed and maintained so the primary lid need not be opened for inspection or maintenance during storage or before transport after storage to avoid unnecessary degradation, incidental risks, and radiological exposures. Storage based on this concept basically does not require additional equipment (such as hot cells).

If a DPC is designed based on a single-containment boundary concept, it is necessary to provide appropriate maintenance facilities that can be used to maintain the cask in the event of failure of primary containment boundary.

Managing spent fuel using a DPC involves storage and on-site and off-site transport of the spent fuel before and after storage. Many countries require licenses for storage of the spent fuel in the DPC or for storage facilities containing DPC packages. Most countries also require package design approval for the DPC package to be transported.

Safety assessment and approval or licensing procedures have to consider the differences between the two DPC configurations (i.e. the DPC transport package design and the DPC storage package design). A DPC provided for transport is usually equipped with impact limiters and often has a one-lid closure system. The acceptance criteria for this DPC transport package are defined in Ref [1]. The DPC transport package also needs to be designed so that it can be used in an operational mode that is different from usual transport packages. More specifically, the DPC transport package needs to be transported after several decades of storage and, therefore, needs to use long term resistant packaging components that require ageing considerations.

A DPC package provided for storage is usually not equipped with transport impact limiters, but often has a closure system with additional lids, including lid interspace pressure monitoring. The acceptance criteria for this DPC storage package are specific for the regulations for on-site activities, including storage and on-site transport, and they are very often different from SSR-6 (Rev. 1) requirements. Nevertheless, most of the safety relevant DPC components are the same for both purposes.

Therefore, demonstration of compliance of the DPC package with national and international transport regulations, as well as with the storage requirements in an integrated manner is recommended.

2. WORKING GROUP ACTIVITIES

The International Conference on Management of Spent Fuel from Nuclear Power Reactors, which was hosted by the IAEA in June 2010, recommended establishing a joint international working group to provide guidance to Member States for integrating the safety cases for storage and transport of spent fuel in a DPC in a holistic manner. A consultancy meeting (CS-130) was convened to “Establish a Working Group on an Integrated Safety Demonstration for the Dual Use Cask for Spent Nuclear Fuel” at the IAEA in November 2010. The meeting also developed the terms of reference for that working group.

The objectives of the working group were:

(1) To prepare an IAEA guidance document (TECDOC or Safety Report) containing guidance for the structure and contents of a DPC integrated safety case (DPCSC) (as a supporting document to Refs [2-5]);

(2) To provide recommendations to the Transport Safety Standards Committee (TRANSSC), Waste Safety Standards Committee (WASSC), Radiation Safety Standards Committee (RASSC), and Nuclear Safety Standards Committee (NUSSC), as appropriate, for changes to be made to existing IAEA requirements and guidance relevant to the licensing and use of transport and storage casks for spent fuel.

Plenary meeting for the working group meetings were held at the IAEA Headquarters in April 2011 (TM-40975), April 2012 (TM-42920), and April 2013 (TM-44985).

The working group took Ref. [6] as an initial model regarding structuring of the guidance. The work was distributed into 4 sub-groups.

3. OBJECTIVE AND SCOPE

This TECDOC contains guidelines for the structure and contents of a DPCSC. The scope is only for dual-purpose metal storage and transport casks for short- and long-term dry storage (as defined in Ref. [4], Appendix I). This publication does not cover requirements for a safety case of a DPC storage facility. A canister is considered a DPC component when it is contained within a DPC as a part of its internals.

This TECDOC aims to assist designers, vendors, operators, licensees, regulators, technical support organizations, and others in developing and reviewing the safety case and supporting safety assessment. This TECDOC contains guidance that can be used, irrespective of how the safety case and safety assessment process is addressed within individual national regulatory frameworks.

Reference [2] (see also Ref. [7]) introduces the concept of safety case as follows:

> *The safety case is a collection of arguments and evidence in support of the safety of a facility or activity. The safety case will normally include the findings of a safety assessment, and will typically include information (including supporting evidence and reasoning) on the robustness and reliability of the safety assessment and the assumptions made therein.*

An integrated safety case for transport and storage aims to support the application for the package design approval for transport and the application for the licensing of the storage cask (as part of the safety case for the storage facility). The DPCSC may be a collection of scientific and technical arguments including safety assessments in support of:

(1) The demonstration of compliance with Ref. [1] for off-site transport, including transport after storage;

(2) The demonstration of compliance with the international standards and national requirements for dry storage of spent fuel as they apply to the DPC package during its storage period.

This TECDOC is based on the concept of an integrated DPCSC. This concept assumes that the DPCSC is in line with Ref. [4] and linked to the transport and storage approvals as described in subsequent paragraphs (see also Figure 1).

The basic information for the DPCSC is the description of the DPC and its contents, the impact conditions and acceptance criteria. The term ‘impact conditions’ means all basic data for the safety assessment arising from normal, off-normal, and accident conditions of storage and routine, normal, and accident conditions of transport (RCT, NCT, and ACT). Transport regulations provide impact conditions for off-site transport. The impact conditions for storage need to be specified based on national regulations and an assessment of the operational conditions at the storage facility. ‘Acceptance criteria’ are based on regulatory limits that the DPC package and the storage facility are required to meet (e.g. dose rates). The acceptance criteria for off-site transport are given in the transport regulations. The acceptance criteria for storage (to be applied to each DPC package/storage facility combination) need to be specified based on national regulations and an assessment of the operational conditions of the storage facility. This basic information is complemented by instructions for operation and maintenance. The DPCSC needs then to demonstrate that a DPC of the specified design loaded with the specified contents and being exposed to the defined impact conditions, operations, and maintenance meets the specified acceptance criteria. A regulatory body could assess this demonstration leading to an approval of the DPC package design. Assuming approval will be given only if compliance with the transport regulations has been demonstrated in the DPCSC, the design can be approved as a transport package. Regarding storage, the DPCSC could qualify the DPC package for storage in a specific facility.

This concept leaves some freedom to the DPC designer in defining impact conditions and acceptance criteria. In either case, the transport requirements are not so flexible and need to be met. An incorrect choice of storage impact conditions or acceptance criteria could lead to problems in obtaining a license for the storage facility, if the DPC package as defined in the DPCSC does not meet the regulatory requirements and operational limits of the storage facility. Therefore, impact conditions and acceptance criteria have to be selected based on a careful review of the regulatory requirements and operational limits and conditions of the storage facility. Of course, acceptance criteria can also be set in a more restrictive manner, which should provide some additional margin in assessing current and future storage facilities.

4. DEFINITIONS

The definitions included in Refs [1, 7] apply throughout this publication. The definitions section toward the end of this publication provides additional publication-specific definitions.

5. STRUCTURE OF THIS PUBLICATION

Part 1 provides a generic consideration of the organization and contents of a DPCSC. It also provides information on administrative matters; specification of contents; DPC specifications, DPC performance criteria; and compliance with regulatory requirements, operation, maintenance, and management systems as a part of the DPCSC.

Part 2 provides generic and specific considerations for technical assessments of the safety case.

Figure 1 shows the structure of the DPCSC.

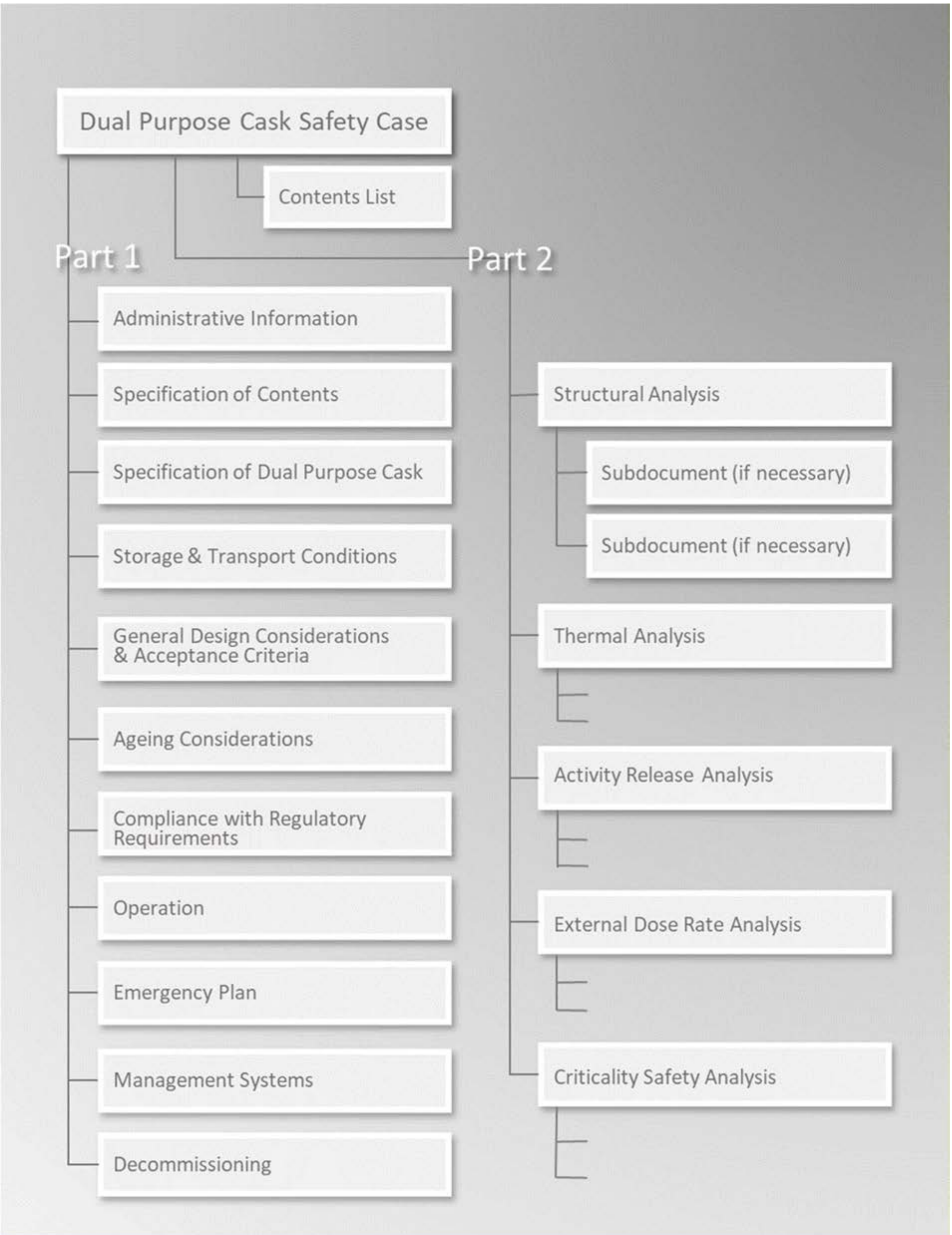

FIG. 1. Integrated process for the dual purpose cask safety case.

PART 1: GENERAL PRINCIPLES AND TECHNICAL INFORMATION

Part 1 of the DPCSC needs to include the following information.

1.1. TRACKING THE HISTORY OF DPCSC

As soon as a DPC has its own life cycle starting from design and ending with decommissioning, a DPCSC is a ‘rolling process’ and is updated periodically, or when incorporating new findings. Therefore, it is important to clearly identify exact stage of the life cycle and the issue version of each DPCSC document or subdocument and keep updated a list of DPCSC documents, including a description of each document version.

1.2. BASIC ADMINISTRATIVE AND TECHNICAL INFORMATION

The DPCSC include the following basic administrative and technical information:

(1) Designer-specific model identification of the DPC.

(2) Identification of DPC designer (name, address, contact details).

(3) Type of transport package.

(4) Transport-specific limitations of operational conditions after short- or long-term storage, e.g.:

- (a) Modes of transport for which approval is requested;
- (b) Any special instructions to the carrier such as required special transport configurations (e.g. transport frame, canopy).

(5) Storage specific limitations of operational conditions for generic DPC package licenses, e.g.:

- (a) Need for storage building;
- (b) Environmental conditions (temperature, wind, snow, etc.);
- (c) Storage orientation (vertical, horizontal);
- (d) Handling capacity (weight, dimensional limits);
- (e) Fuel retrievability (hot cell, etc.);
- (f) Maintenance/repair capability;
- (g) Inspection and maintenance frequency;
- (h) Storage pitch (minimum distance between DPC packages);
- (i) Accident conditions (drop height/orientation, tip over, tornado, missile, flooding. etc.);

(j) Siting requirements, including seismic, tsunami, and volcano;

(k) Monitoring requirements.

(6) Reference to applicable transport regulations and/or storage requirements, including the edition of IAEA Regulations for the Safe Transport of Radioactive Material and other relevant IAEA Safety Standards to which the DPC design refers.

(7) List of laws, regulations, guidelines, codes, standards, and licenses applicable to the design, fabrication, quality assurance programme, transport, and storage of the DPC package based on the defined operational scenarios, as well as the related nuclear facilities and modes of transport to be used. From these laws, regulations, and guidelines, the regulatory requirements (technical, operational, and other) that control the design, analysis, and operation of the DPC package need to be determined and included in the DPCSC. These regulatory requirements have to be tabulated and presented in Section 1.8 with a description of the design, safety analysis results, and references to DPCSC sections.

(8) Reproducible conceptual drawings need to be provided. The conceptual drawings may include bird's eye views and three dimensional illustrations showing the configuration of the DPC in each transport and storage modes indicating the major components of the DPC, such as packaging, impact limiters, devices for thermal insulation, and packaging inserts, if applicable. The illustrations need to indicate at least the overall outside dimensions, the masses of the main components of the packaging, and the gross mass for empty and loaded conditions.

1.3. SPECIFICATION OF CONTENTS

A detailed description of the permitted radioactive contents of the DPC needs to include, but is not limited to, the following information, as applicable:

(1) Radionuclides / radionuclide composition; progeny, if applicable.

(2) Activity, mass and concentrations, and heterogeneities, if applicable.

(3) Physical and chemical state, geometric shape, arrangement, loading restrictions, irradiation parameters, moisture content, and material specifications (particularly, information on spent fuel degradation during storage).

(4) Fuel condition (e.g. damaged, non-damaged, intact, or consolidated fuel rods; fuel assemblies with missing rods,). Fuel integrity may be defined in the national regulations or guidelines (e.g. Ref. [8]) or based on international technical reports (e.g. Ref. [9]).

(5) Nature and characteristics of the radiation emitter.

(6) Thresholds of heat generation rate for contents.

(7) Mass of fissile material or fissile nuclides.

(8) Other contents such as canisters and non-fuel hardware (e.g. control rods, sources, thimble plugs, burnable poison rods, moisture absorbers, etc.).

(9) Typical parameters of spent fuel which provide the basis for the derivation of some of above descriptions, such as fuel design type, initial enrichment, burnup and cooling period.

(10) The acceptable parameters of the history of the spent fuel before loading. Before it is loaded in the DPC, the fuel will have been subjected to a number of processes, including irradiation in the reactor, handling operations and pool storage, all of which can influence the physical integrity of the fuel rods and the structural components. The history of the spent fuel before loading is, therefore, an important input into the safety case.

1.4. SPECIFICATION OF THE DPC

The DPC design has to be defined by including the following information, as applicable:

(1) A list of all DPC components, monitoring systems, and complete design drawings for transport and storage configurations;

(2) A parts list of all safety related components including bolts and seals;

(3) Material specifications of all DPC components and standard items and methods of their manufacture including requirements for material procurement, welding, other special processes, non-destructive evaluation, and testing;

(4) Information on material degradation during storage and transport;

(5) A description of:

   (a) The DPC body, lid (closure mechanism) and inserts;

   (b) The DPC components of the containment system;

   (c) The DPC components required for shielding;

   (d) The DPC components for criticality control;

   (e) The DPC components for thermal protection;

   (f) The DPC components for heat dissipation;

   (g) The protection against corrosion;

   (h) The protection against contamination;

   (i) The transport configuration, including any devices required for the transport including impact-limiting components, canopies and tie-downs, which may have an effect on the safety of the package;

(j) The storage configuration, including any devices required for the safe handling and storage that may have an effect on the safety of the package in storage operations.

1.5. STORAGE AND TRANSPORT CONDITIONS

This section needs to describe the performance criteria that allow the DPC design to meet applicable transport regulations and the storage safety requirements such as summarized here:

(1) Radioactive material containment;

(2) Shielding (control of external radiation levels);

(3) Criticality prevention;

(4) Heat removal (prevention of damage caused by heat);

(5) Stored spent fuel retrievability;

(6) Structural integrity;

(7) Ageing.

For this purpose, the DPC designer has to first consider DPC package operational scenarios, and has to identify the regulatory and licensing requirements. The designer has to then develop operational procedures for each operational step included in the scenarios, and identify conditions to which the DPC package could be subjected considering the operational limits. Furthermore, the designer needs to describe analysis assumptions and data used for the safety case and how they are derived from the design and the behaviour of the package under routine, normal, and accident conditions of transport (RCT, NCT, and ACT) and normal, off-normal and accident conditions of storage. This is especially true regarding the release of radioactive material, radiation levels, criticality safety, heat removal, structural integrity of the DPC, and integrity of contained spent fuel.

This section needs to include items to be considered in developing the DPCSC, from the determining the operational scenario to interpreting the safety analysis basis.

1.5.1. Basic concept

When developing the DPCSC, the DPC designer first determines the DPC package operational scenarios by considering:

(1) Operational scenarios

The DPC designer has to consider DPC package operational scenarios, including those in the DPCSC, together with the nuclear facilities (either actual or postulated) related to each scenario. The DPC designer also needs to justify each operational scenario (e.g. country specific requirements, regulatory situation, siting, technical feasibility, safety philosophy) selection in the DPCSC.

(2) Safety case for DPC package storage system

A complete safety case for the DPC package storage system will be achieved by integrating the DPCSC and related nuclear facilities safety cases. Thus, the DPC designer and nuclear facility operator responsibilities need to be agreed upon before developing the safety case. Therefore:

(a) In general, safety cases related to DPC package operations in a given nuclear facility have to be included in the nuclear facility safety case, as the safety analysis or assessment and the associated acceptance criteria depend on the environmental conditions unique to that facility.

(b) In some cases, normal operations (e.g. loading, unloading and handling of DPC packages) and off-normal operations (e.g. operations during loss of power, loss of crane operation) in nuclear facilities are specific to the DPC design. In such cases, the safety cases related to the operations involving the DPC package at the storage facility may also be included in the DPCSC.

(c) Nuclear facilities accidents, except those incidents that are considered and for which acceptance criteria are defined, are to be considered by the nuclear facilities.

(3) Environmental conditions

Some Member States provide a regulatory framework of regulations or guidelines that stipulates environmental conditions to be considered at the storage facility for the DPC package storage design. This allows approval of the DPC package design independently of the storage site. Storage facility operators may select a DPC design that fits their site conditions from approved designs or design a storage facility to meet selected DPC design specifications. In the latter case, the DPCSC can include the safety assessment of the DPC package in the specified storage environment.

(4) Time spans

The DPC designer has to consider the intended storage and transport time span.

(5) Operational procedures and environmental conditions of operation.

The DPC designer has to develop procedures for each step in the considered operational scenarios and include them in the DPCSC. At the same time, environmental conditions of the DPC package operations have to be clearly defined and included in the DPCSC. The developed operational procedures have to be presented in Section 1.9, “Operation” in the DPCSC.

(6) Retrievability

Retrievability of the DPC content is required under Ref. [2], requirement 11, and specifically addressed in Ref. [4], paras 6.133 and 6.134.

In this publication, retrievability is the ability to recover DPC contents. Some states may define the condition at retrieval.

(7) Retrieval Facility

The storage safety may not rely as heavily on the previous operational steps if a retrieval facility has the necessary infrastructure to enable opening a DPC for inspection of the internals and the spent fuel in the DPC. The same is true if the storage facility allows for the opening of the lid for DPC maintenance and repair work.

Inspection of spent fuel and DPC internals demonstrates the storage safety at the storage facility and ensures the safety of transport after storage and safety of spent fuel retrieval at the next destination facility.

1.5.2. Operational scenarios

1.5.2.1. Operational steps that constitute the operational scenario

The DPC operational scenario consists of various steps addressed in the DPCSC. The DPC designer has to select and organize them sequentially from the following list of steps.

(1) DPC package preparation (for transport and storage, including spent fuel loading and inspections);

(2) On-site transport (before storage and/or after storage);

(3) Off-site transport (before storage and/or after storage);

(4) Handling at storage facility (before and after storage);

(5) Storage (on-site or off-site);

(6) DPC package unloading (at the destination of transport after storage).

Figure 2 illustrates DPC operational steps, including some of their required elements; Figures 2a-2d shows typical operational scenarios.

The DPCSC will be clear about which of the possible various operational scenarios need to be included and, in addition to transport, the approval being sought. The operator is responsible to ensure operations that are carried out, but not within the scope of the DPCSC, are adequately covered elsewhere (e.g. within the storage and/or retrieval facility safety case).

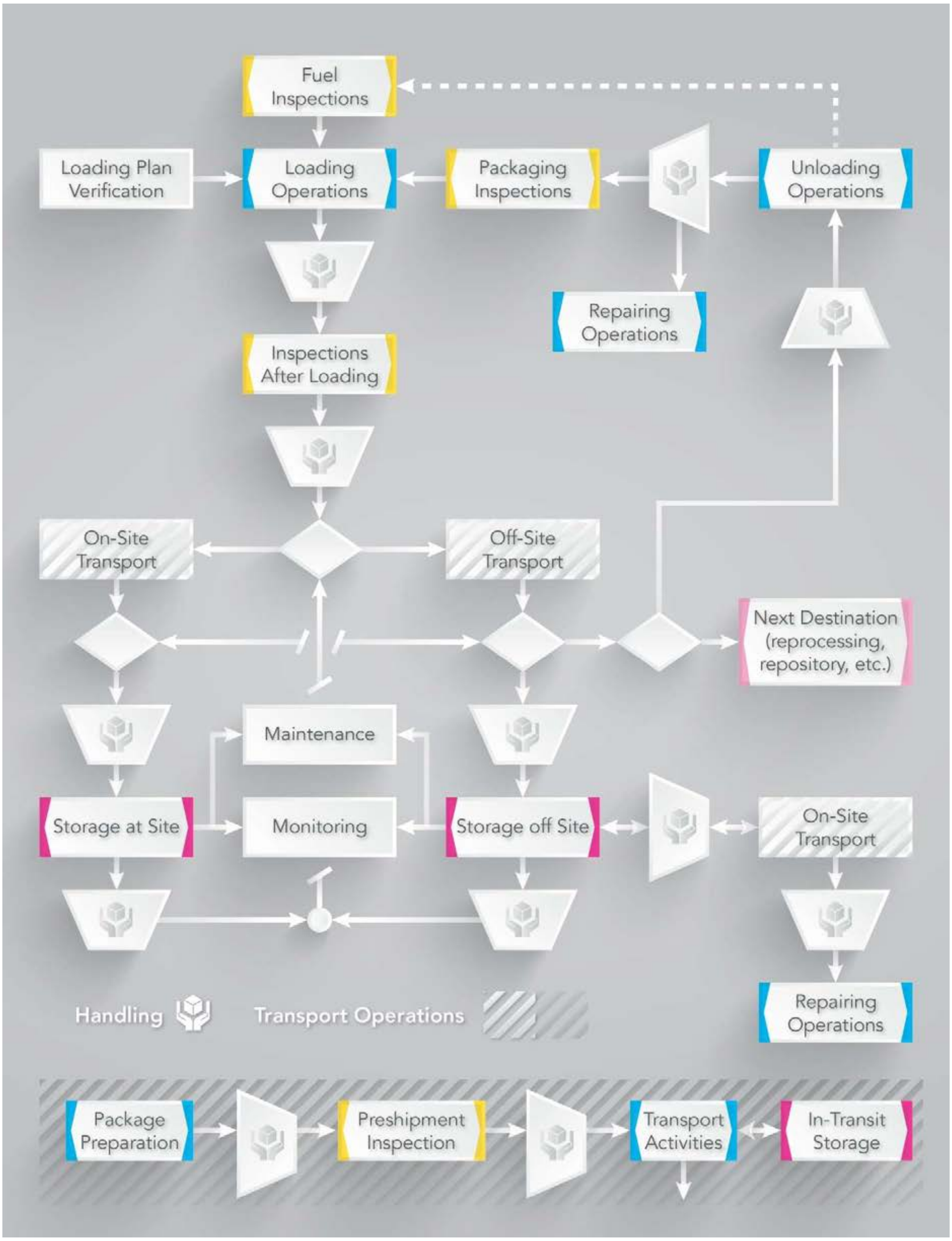

FIG. 2. Transport/ storage operational steps.
(Note: Handling and transport are distinguished in this figure,
since they deal with different configurations of package).

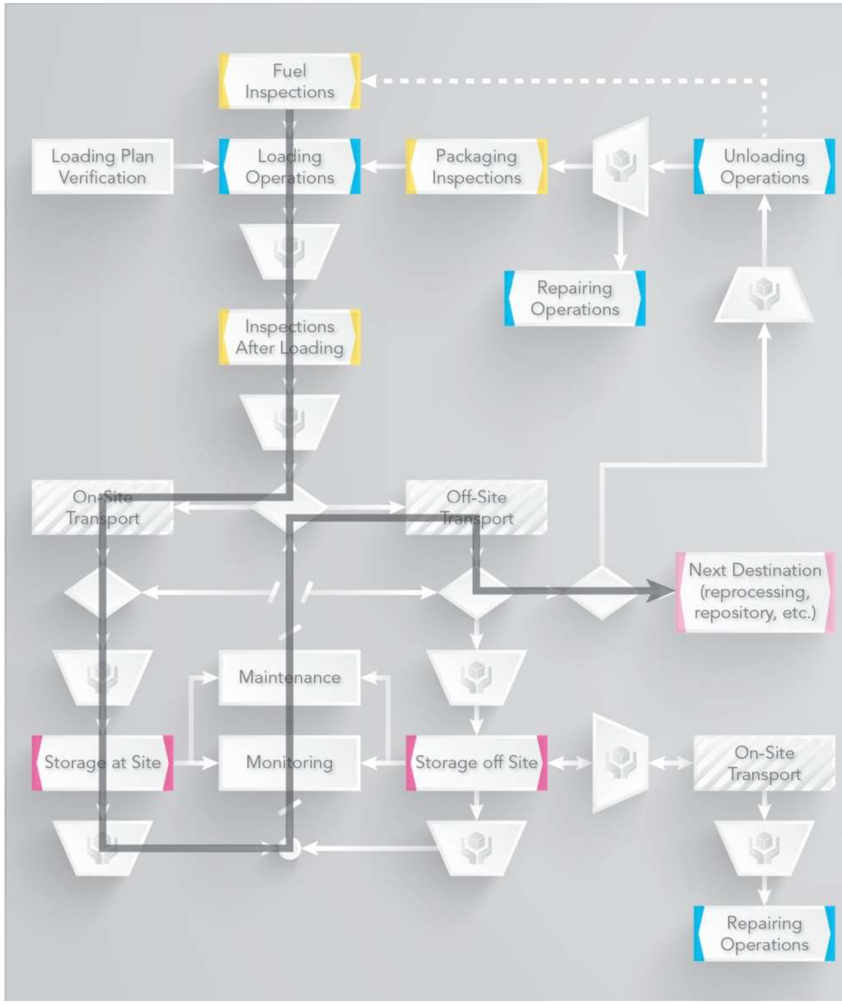

FIG. 2a. Scenario for on-site storage operational steps.

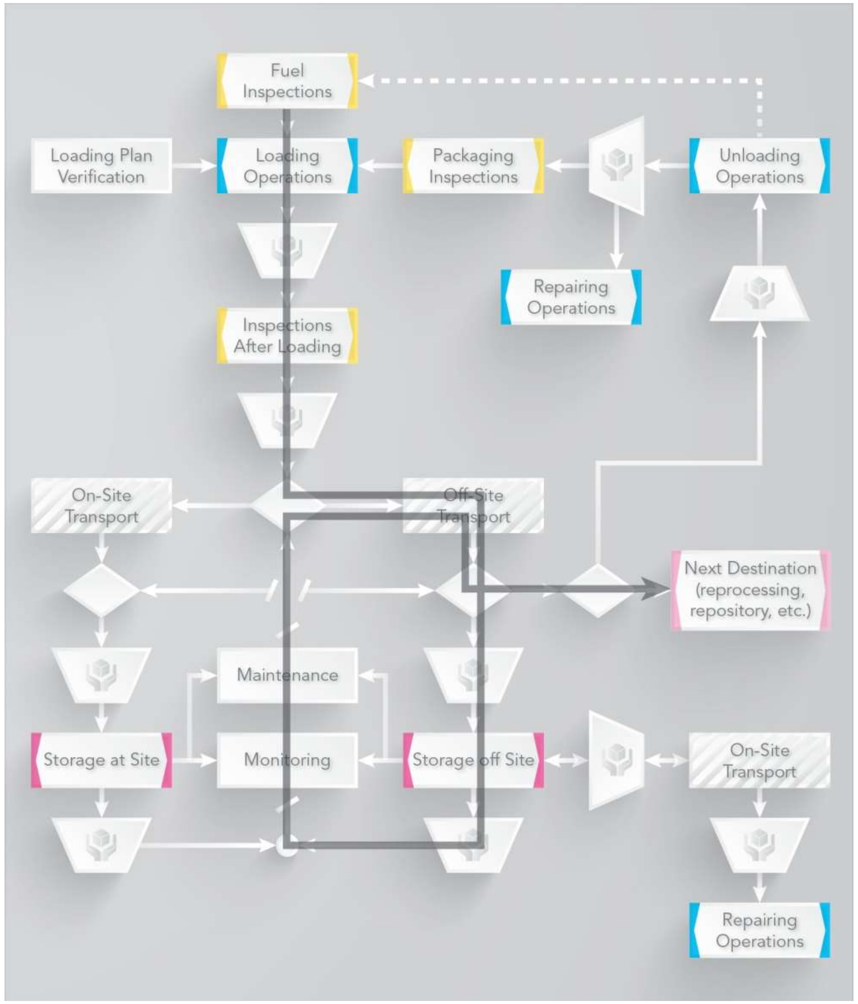

FIG. 2b. Scenario for off-site storage operational steps.

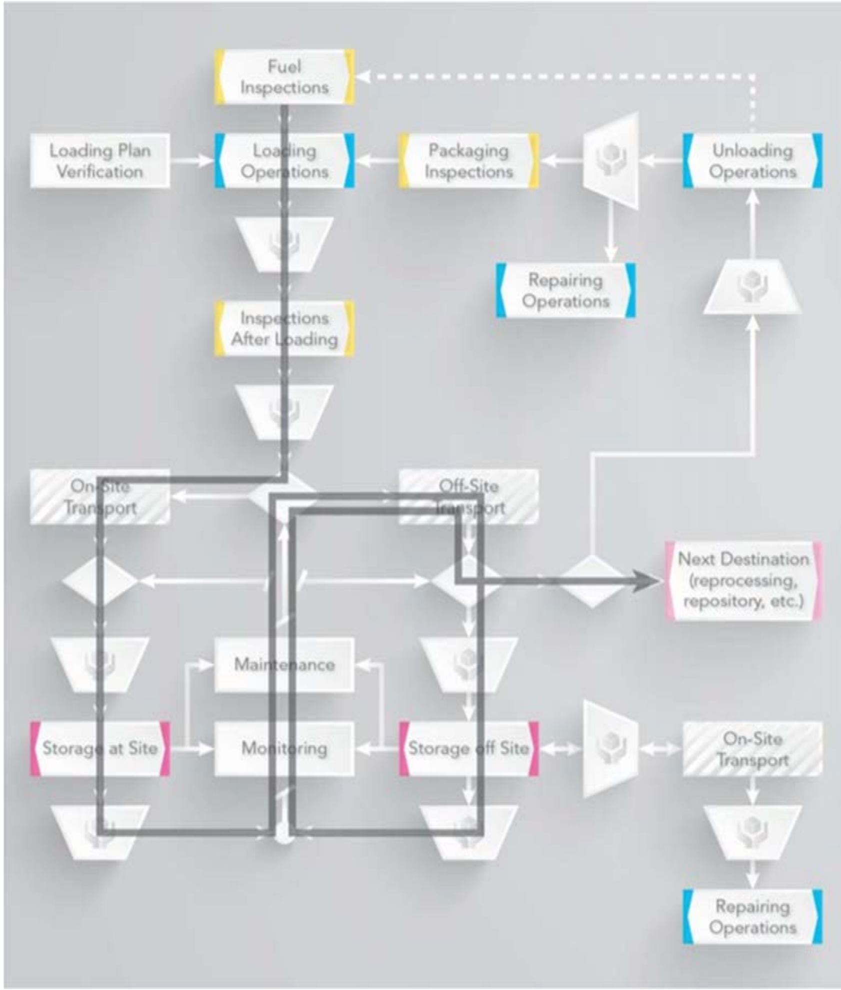

FIG. 2c. Scenario for on-site and off-site storage operational steps.

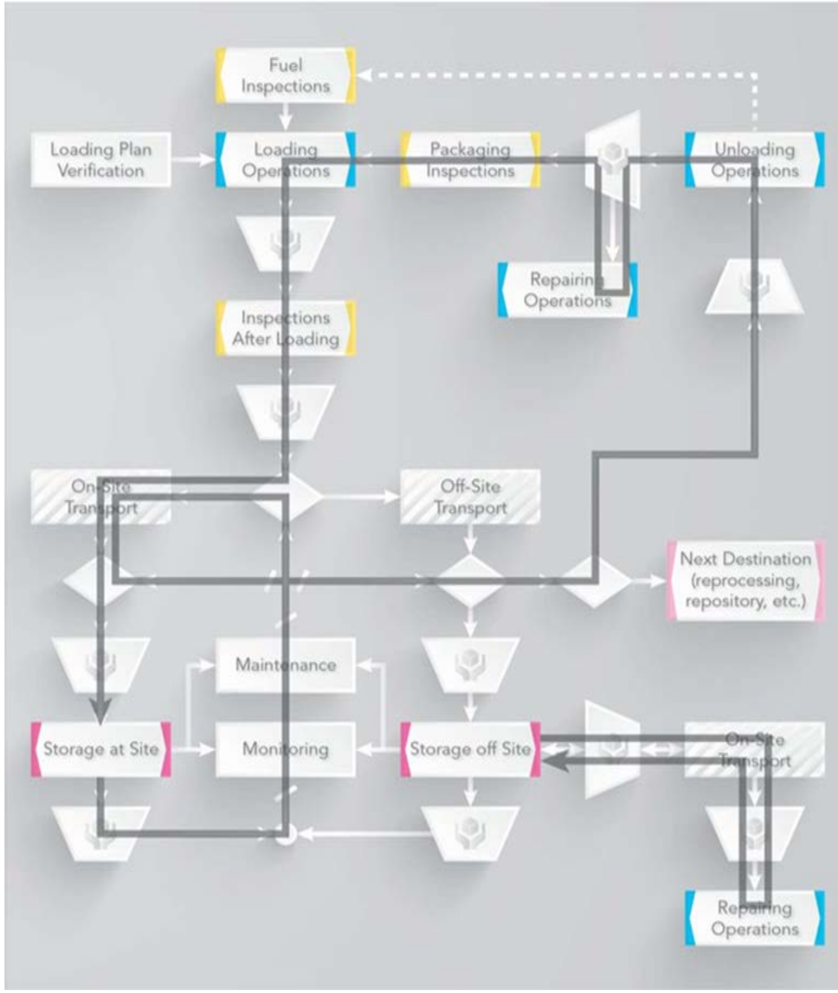

FIG. 2d. Scenarios for on-site and off-site repair routines.

1.5.2.2. Notes on each operational step

Section 1.5.2.1 states that the DPC designer has to develop operational procedures and include the environmental conditions of operations in the DPCSC. Some guidance for developing the operational procedures is addressed as follows:

(1) DPC package preparation:

(a) This step is in principle conducted at the spent fuel storage pool at nuclear power stations.

(b) To initiate this step, the DPC has to be fabricated as designed and the spent fuel to be loaded complies with the DPC spent fuel specifications. It needs to be ensured that the operator of this step confirms the former by the record of fabrication inspections supplied by the DPC vendor and the latter by the record of nuclear plant fuel inspections.

- Under the operational scenario where there is no inspection of DPC internals by removal of the DPC lid(s) (such as after storage in preparation for shipment), the condition of the spent fuel and the DPC package preparation confirmed in this step provide initial conditions for the safety assessment in all of the following operational steps. The spent fuel and the DPC, therefore, need to be properly inspected, recorded, and referenced in the following steps.

- This step includes preparing the DPC for spent fuel loading, lid(s) closure, internal water drainage, drying, inert gas filling, preparation for transport, and preshipment inspections. Detailed preparation and inspection procedures may differ for on-site or off-site transport of the DPC package.

(2) On-site transport:

(a) On-site transport is necessary at all facilities involved in the scenario.

(b) On-site transport may consist of any movement of the DPC package at nuclear facilities where the off-site transport regulations usually do not apply. Such on-site transport may include transfer between different nuclear facilities/buildings as long as public roads or railways transport are not involved.

(c) On-site transport begins when the DPC package is ready for on-site transport in the nuclear facility dispatching the DPC package, and ends when the DPC package is unloaded in nuclear facility receiving the DPC package.

(d) Generally, environmental conditions and the configurations of the DPC package between on-site and off-site transport will differ.

- Compared with off-site transport, on-site transport environmental conditions tend to be less onerous due to a smaller range of ambient conditions (temperature, pressure, etc.) and limited consequences from incidents and/or accidents under controlled operations. It may not be the case, however, that off-site transport environmental conditions bound those of on-site transport.

- While during off-site transport a DPC package is generally secured horizontally in or on a conveyance with impact limiters attached, on-site transport may be conducted without impact limiters, or vertically.

(3) Off-site transport:

Off-site transport of the DPC package is conducted in compliance with Ref. [1] or similar national regulations. Environmental conditions of off-site transport are prescribed in the transport regulations, and the safety assessment of the DPC package under those conditions has to be included in the DPCSC. The DPC package condition prior to transport after storage relies on safe storage at the facility.

(4) Storage facility handling:

(a) There are generally two steps to handling of the DPC package at a storage facility: i) handling in preparation for storage and ii) handling in preparation for transport after storage. For installations equipped for fuel retrieval, additional handling steps to prepare transfer of the DPC package between the storage position and the retrieval installation needs to be considered.

(b) While preparing for storage, a receipt inspection needs to confirm whether the DPC package complies with storage limits and conditions of the facility. Then operations of configuration changes from transport to storage (i.e. removal of impact limiters), and DPC package transfer to and storage at the storage location are conducted.

(c) Though preparation for shipment is the reverse of preparation for storage, a preshipment inspection to confirm whether the DPC package complies with the transport regulations after the storage period, instead of the receipt inspection that is completed prior to storage, will be conducted.

(d) Consideration needs to be given to all situations in which handling mechanisms could malfunction.

(e) Consideration has to be given to the possibility of DPC package becoming wedged and immovable within the spent fuel storage facility. In addition to the issue of shielding in such circumstances, consideration needs to be given to whether handling equipment and systems are able to recover from such situations or could be damaged by the application of excessive stresses.

(5) Storage:

(a) The safety of storage relies on the proper preparation of the DPC package for storage, its safe transport to the storage facility, and maintaining specified environmental conditions while in storage.

(b) There are generally two options for storage: i) on-site storage and ii) off-site storage. For an on-site storage facility located inside the boundary of a nuclear power station site, the DPC package would be shipped to the next destination (e.g. a spent fuel handling facility for unloading) by off-site transport after storage at the facility. For the off-site storage option, a DPC package is first transported from a nuclear power plant to an off-site storage facility, and may be transported again to a subsequent destination (perhaps for reprocessing or disposal) after storage.

(c) A design option for some storage facilities is to construct a storage building, which mitigates impacts from natural phenomena to the DPC package and reduces the radiation level at the site boundary by the shielding provided by the building structure. Incidents such as building collapse or a cooling air inlet blockage need to be considered.

(d) Providing a fuel retrieval capability is another option for a storage facility design. When fuel retrieval capability is available, spent fuel can be unloaded from a damaged or otherwise compromised DPC to repair it, or fuel could be moved to another DPC. This capability allows for contingencies in the case of incidents and/or accidents. Furthermore, to confirm post-storage shipment requirements compliance, spent fuel and DPC internals can be inspected by opening the DPC package. This reduces the reliance on fuel records management from previous steps, including storage.

(e) A hot cell is typical of a fuel retrieval installation. For on-site storage facilities, it may be possible to use the spent fuel storage pool at a nuclear power plant on-site as a retrieval installation. However, in the case of long-term storage for a period such as 50 to 100 years, the guaranteed period of availability of the pool has to be identified in the operational scenario. Alternative measures need to be provided if this guaranteed period is not possible. Alternative measures to control undue leakage of the first lid include DPC design features such as providing for a second lid qualified for off-site transport, or attaching a third lid (welded or bolted) to re-establish a double-barrier storage closure system, or to transport the DPC to another facility with a pool or a hot cell.

(f) When no spent fuel retrieval capability is available at the storage facility, there is no chance to directly confirm the state of the DPC internals or the spent fuel contained in the DPC after loading until the DPC package is unloaded at the destination facility. As confirming the DPC maintains its safety functions and verifying the status of the spent fuel at each operational step is essential, alternative inspection or assessment confirmation methods need to be established and described.

(6) DPC package unloading:

(a) DPC package unloading will be conducted at a reprocessing facility, nuclear power plant, another spent fuel storage facility, or the disposal facility. As this DPCSC concerns dual purpose casks (i.e. transport and storage), and not multi-purpose casks (i.e. transport, storage, and disposal), the DPC package has to be unloaded at the disposal facility. The feasibility of disposal of the DPC and contents is outside of the scope of this DPCSC.

(b) Spent fuel retrieval safety at subsequent facilities relies on safe storage in the original storage facility and safe transport to the destination facility.

(c) The operational steps for DPC package unloading are the reverse of the DPC loading. Two optional methods to unload spent fuel from DPC include wet unloading in a pool and dry unloading within a hot cell. The latter eliminates processes such as water injection into DPC package, spent fuel reflooding, and placement of DPC package into water.

1.5.3. Operational scenarios impact

1.5.3.1. Incidents considered for each operational scenario

To establish conditions with which to design the DPC and to assess its safety, the DPC designer needs to postulate conditions that the DPC package may encounter at each operational step in the operational scenarios defined in Sections 1.5.1 and 1.5.2, and identify every loading (mechanical, thermal, radiological, chemical, electrical, etc.) that could have an adverse effect on the DPC and its contents as impact conditions. The DPCSC needs to identify and justify reasons for selecting operational situations and related impact conditions .

Safety arguments concerning outside the regulatory environment of transport or storage facility or a storage site design basis accident are out of the scope of the DPCSC. However, when it is a matter of public or competent authority's concern, such arguments may be included.

(1) DPC package preparation

Designed DPC package preparation operations including handling inside the loading facility (nuclear power plant) are considered normal conditions. Incidents caused by a credible single failure of equipment or a credible single human error are considered to be off-normal conditions. Accidents in the facility, such as a DPC package drop inside/outside the reactor building, are out of the scope of the DPCSC (but in the scope of the facility safety case).

(2) On-site transport

Transport regulations cover situations to be considered during on-site transport. When on-site transport is conducted under conditions not covered by the off-site transport regulations, or if the DPC configuration is different than for off-site transport (e.g. without impact limiters or transport in vertical orientation of the DPC), normal, off-normal, and accident conditions of on-site transport have to be defined commensurate to frequencies of occurence and consequences of the credible incidents/accidets.

(3) Off-site transport

Reference [1] prescribe three conditions for classifying off-site transport situations: i) RCT (incident free), ii) NCT (minor mishaps), and iii) ACT (credible accidents).

(4) Storage facility handling

Planned DPC package handling operations for storage preparation, shipment preparation and inspection, or DPC maintenance if applicable during storage are considered normal conditions. Incidents caused by minor mishaps, a credible single equipment failure or a credible single human error are considered to be off-normal conditions. Incidents such as a tip over or drop of the DPC package, or a fall of an overhead crane onto the DPC package can be classified as accident conditions.

(5) Storage

The facility operator needs to identify situations or incidents during storage to be evaluated, as they are specific to the facility siting and design and to DPC package operation in the facility. Reference [4], Annexes V and VI provide comprehensive examples of anticipated incidents in spent fuel storage facilities. For some Member States, national spent fuel storage regulations or guidelines, such as Refs [10–12], define incidents and accidents to be considered in the design of the storage facility.

As a DPC is a static component stationary during storage with its safety functions maintained statically, nothing would happen under normal conditions of storage, except a self-induced phenomenon (i.e. ageing). DPC package environmental conditions, including effects of natural events, will differ depending on storage location (indoors or outdoors).

Incidents caused by minor mishaps, a credible single failure of equipment, or a credible single human error are considered to be off-normal storage conditions. Situations caused by postulated initiating events, such as credible equipment failure, operator or human induced error, or natural events have to be identified and classified with careful consideration to their occurrence frequencies and consequences as either off-normal or accident conditions during storage. In some Member States, an aircraft crash and consequent building collapse and fire has to be considered as an example of human induced accident. In other States, less frequent but extreme natural events such as tsunami or volcanic eruption may have to be considered. Even a hypothetical radioactive material release from the loss of containment of a single DPC package due to non-mechanistic reasons can be considered accident conditions to demonstrate safety of storage.

(6) DPC package unloading

Planned DPC package unloading operations, including handling inside the unloading facility, are considered normal conditions. Incidents caused by minor mishaps, a credible single failure of equipment, or a credible single human error are considered off-normal conditions.

1.5.3.2. Loading factors impacting the DPC

Any loading impacting the DPC in each operational step including the most severe natural loadings at the storage facility need to be considered with reference to historical records and siting investigations of the storage facility site and its surrounding area. Seismic loading needs to be established according to the approach discussed earlier.

Examples of conditions to be considered are:

(1) Mechanical loadings:

  (a) Internal and external pressure;

  (b) Dead load, compressive load by stacking;

  (c) Bolt tightening load, reaction load from seals;

  (d) Thermal stress by expansion or contraction;

  (e) Transport acceleration, vibration, handling acceleration (lifting, rotating);

  (f) Impact load due to drop or collision; local load at collision area;

  (g) Impact load by a heavy item dropped onto the DPC; or by collision of a wind driven missile, a turbine missile, or an aircraft crash; local load at the point of impact;

  (h) Seismic load, tsunami load, wind load, snow load.

(2) Thermal loadings:

  (a) Ambient temperature, solar insolation;

  (b) Deformation or dimensional change caused by thermal expansion or contraction;

  (c) Thermal load by fire;

  (d) Thermal load from peripheral DPC packages;

  (e) Temperature rise by vacuum drying or blockage of cooling air inlet;

  (f) Thermal shock by reflooding of DPC internal;

  (g) Material structure change, decomposition by heat, and thermolysis gas;

  (h) Ageing, including creep, stress relaxation, and overageing.

(3) Radiological impacts:

  (a) Hardening or embrittlement of metal or polymers by radiation;

  (b) Material structure change, decomposition by radiation, radiolysis gas;

  (c) Loss in efficiency of built-in neutron absorbers.

(4) Electrochemical or chemical reactions:

(a) Electrochemical or chemical reactions between different materials, reaction products;

(b) Corrosion, stress corrosion cracking (SCC), corrosion products.

1.5.3.3. Example of impact conditions

Table 1 presents examples of situations and conditions used for designing and assessing a DPC package derived from typical operational scenarios. This example is based on a DPC design under the following conditions:

- The DPC package is stored inside a storage building or on a storage pad outdoors.
- No spent fuel retrieval installation is available in the storage facility. Therefore, the storage facility is designed to prevent the DPC and its contents from damage inhibiting the ability of the safety functions to comply with the transport regulations during storage and handling at the facility.
- According to national regulations, off-site transport approval includes on-site transport conducted in conjunction with off-site transport.

Table 1, rows 1 and 2 show typical examples of incidents and accidents that are to be considered, but not limited to, for off-normal conditions and accident conditions. Credible incidents and accidents in the DPCSC have to be carefully selected considering national storage regulations.

TABLE 1. SITUATIONS AND LOADING TO BE CONSIDERED IN EACH OPERATIONAL STEP

No.	Classifications	Conditions	Loading
(a) Preparation and loading			
1	Normal conditions	(i) Pressurization for drainage; (ii) Internal vacuum; (iii) Internal temperature rise; (iv) Transfer inside the facility.	Internal/external pressure Dead load Bolt tightening load Seal reaction load Lifting load Transferring load Thermal load Ambient temperature
2	Off-normal conditions	(to be considered in the facility's safety case)	—
3	Accident conditions	(to be considered in the facility's safety case)	—
(b) Off-site transport			
4	RCT	(i) Transport: - Ambient temperature of -40°C to 38°C; - Solar insolation; - Handling and transport acceleration. (ii) External pressure of 25 kPa.	Internal/external pressure Dead load Bolt tightening load Seal reaction load Lifting load Transporting load Vibration Impact load Thermal load Ambient temperature
5	NCT	(i) Water spray; (ii) 0.3 m drop; (iii) Stacking; (iv) Steel bar drop; (v) Ambient temperature of -40°C to 38°C.	Internal/external pressure Dead load Bolt tightening load Seal reaction load Stacking load Local load Impact load Thermal load Ambient temperature Insolation Irradiation (a.s.) Ageing (a.s.)
6	ACT	(i) 9 m drop; (ii) 1 m drop onto steel bar; (iii) Fire (800°C, 30 minutes); (iv) 15 m immersion; (v) 200 m immersion.	Internal/external pressure Dead load Bolt tightening load Seal reaction load Local load Impact load Thermal load Insolation Heat input form fire Irradiation (a.s.) Ageing (a.s.)

TABLE 1. (Continued)

No.	Classifications	Conditions	Loading
		(c) Handling at storage facility	
7	Normal operation	(i) Lifting acceleration: - Ambient temperature and pressure; - Lifting acceleration. (ii) Transfer inside the facility: - Ambient temperature and pressure; - Transferring acceleration.	Internal/external pressure Dead load Bolt tightening load Seal reaction load Lifting load Transferring load Thermal load Ambient temperature Irradiation (a.s.) Ageing (a.s.)
8	Off-normal conditions	Minor collision with peripheral equipment (e.g. transport frame) or surrounding DPC packages	Internal/external pressure Dead load Bolt tightening load Seal reaction load Impact load Thermal load Ambient temperature Irradiation (a.s.) Ageing (a.s.)
9	Accident conditions	(i) Tip over. (ii) Drop from handling height.	Internal/external pressure Dead load Bolt tightening load Seal reaction load Impact load Thermal load Ambient temperature Irradiation (a.s.) Ageing (a.s.)
		(d) Storage	
10	Normal conditions	(i) Storage; Ambient temperature and pressure Solar insolation, wind, rain, snow (outdoor storage) (ii) Ageing.	Internal/external pressure Dead load Bolt tightening load Seal reaction load Securing load Thermal load Ambient temperature Irradiation Ageing
11	Off-normal conditions	(i) Natural events: - Earthquake, flood; - Tornade (outdoor storage); - Blockage of cooling air (in-building storage); (ii) Human induced events: - Power source failure.	Internal/external pressure Dead load Bolt tightening load Seal reaction load Seismic load Thermal load Ambient temperature Irradiation Ageing

TABLE 1. (Continued)

No.	Classifications	Conditions	Loading
		(d) Storage (continued)	
12	Accident conditions	(i) Extreme natural events: - Earthquake, tsunami, flood, volcanic eruption; - Wind driven missiles. (ii) Human induced events: - Tip over; - Gas explosion; - Aircraft crash; - Fire. (iii) Release of radioactive material (form single DPC with non-mechanistic reason).	Internal/external pressure Dead load Bolt tightening load Seal reaction load Thermal load Ambient temperature Irradiation Ageing
		(e) Unloading	
13	Normal conditions	(i) Pressurization during filling water; (ii) Internal vapour and water; (iii) Internal temperature decrease; (iv) Transfer inside the facility.	Internal/external pressure Dead load Bolt tightening load Seal reaction load Lifting load Transferring load Thermal load Ambient temperature Irradiation Ageing
14	Off-normal conditions	Blockage of exhaust	Internal/external pressure Dead load Bolt tightening load Lifting load Thermal load Ambient temperature Irradiation Ageing
15	Accident conditions	(To be considered in the facility's safety case)	—

* a.s.: after storage.
** Ageing includes creep, stress relaxation and overageing.

1.6. GENERAL DESIGN CONSIDERATIONS AND ACCEPTANCE CRITERIA

When applying the concept of DPC system, safety assessment and approval or licensing procedures have to consider the differences between the two DPC configurations (i.e. the DPC transport package design and the DPC storage package design). The elements of the storage regime, the storage environment, monitoring/inspection, records, that are required to demonstrate compliance with the transport safety case needs be clearly stated in the safety case in compliance with the transport regulations, such that those designing the storage facility and those operating it can clearly understand what has to be implemented in the storage regime and provide the necessary records for future transport that this criterion has been achieved.

In this section, how regulatory requirements for both transport and storage are incorporated with DPC design is described.

1.6.1. Relationship between regulatory requirements, performance criteria, acceptance criteria, design criteria, and design specification

Regulations require the designer to meet ‘performance criteria’ for DPC transport packages and DPC packages used solely for storage (e.g. sufficient shielding, activity release limitations, criticality prevention, and sufficient heat removal). These performance criteria are connected to acceptance criteria. Acceptance criteria are derived from quantitative regulatory limits of performance criteria such as international and national regulations, standards, and requirements

The engineering process for DPC design and technical assessment is the foundation for transport and storage design specifications.

The DPC design has to meet appropriate ‘design criteria’ (e.g. maximum allowable stress for a specified material under a specified loading condition) under the applicable operational or accident conditions as part of the design assessment for each DPC component and the assembled DPC.

The design, justified by technical assessment, is defined in a ‘design specification.’

Figure 3 shows how the design specification has to encompass the acceptance criteria for transport and storage. The transport package design acceptance criteria are derived from the international and national transport regulations, whereas the acceptance criteria in relation to the storage regulation is derived from international standards and national regulations. In addition, acceptance criteria for the DPC need to consider requirements that are specific to storage facility design. More detailed consideration on determining acceptance criteria is given in section 1.6.4. Figure 4 shows the relationship between various elements of the design process.

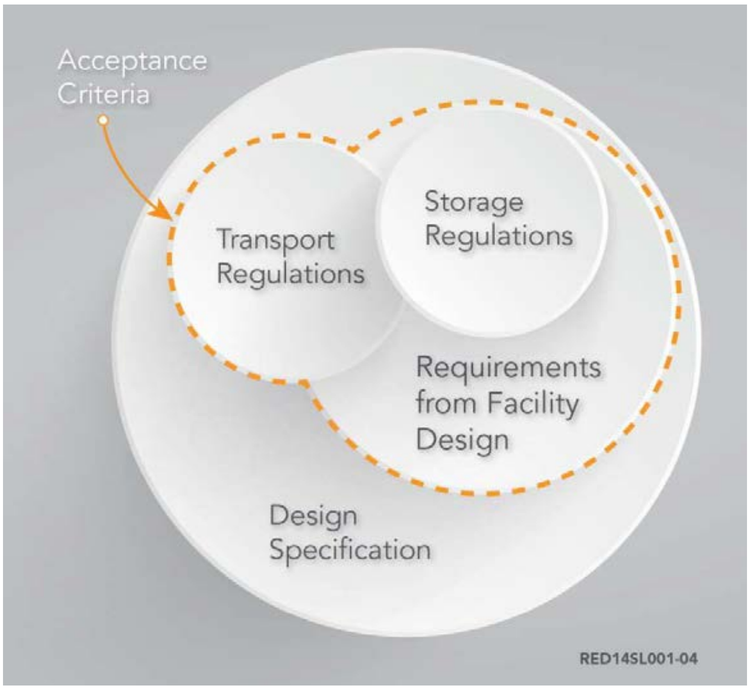

FIG. 3. Relationship between design specification and acceptance criteria.

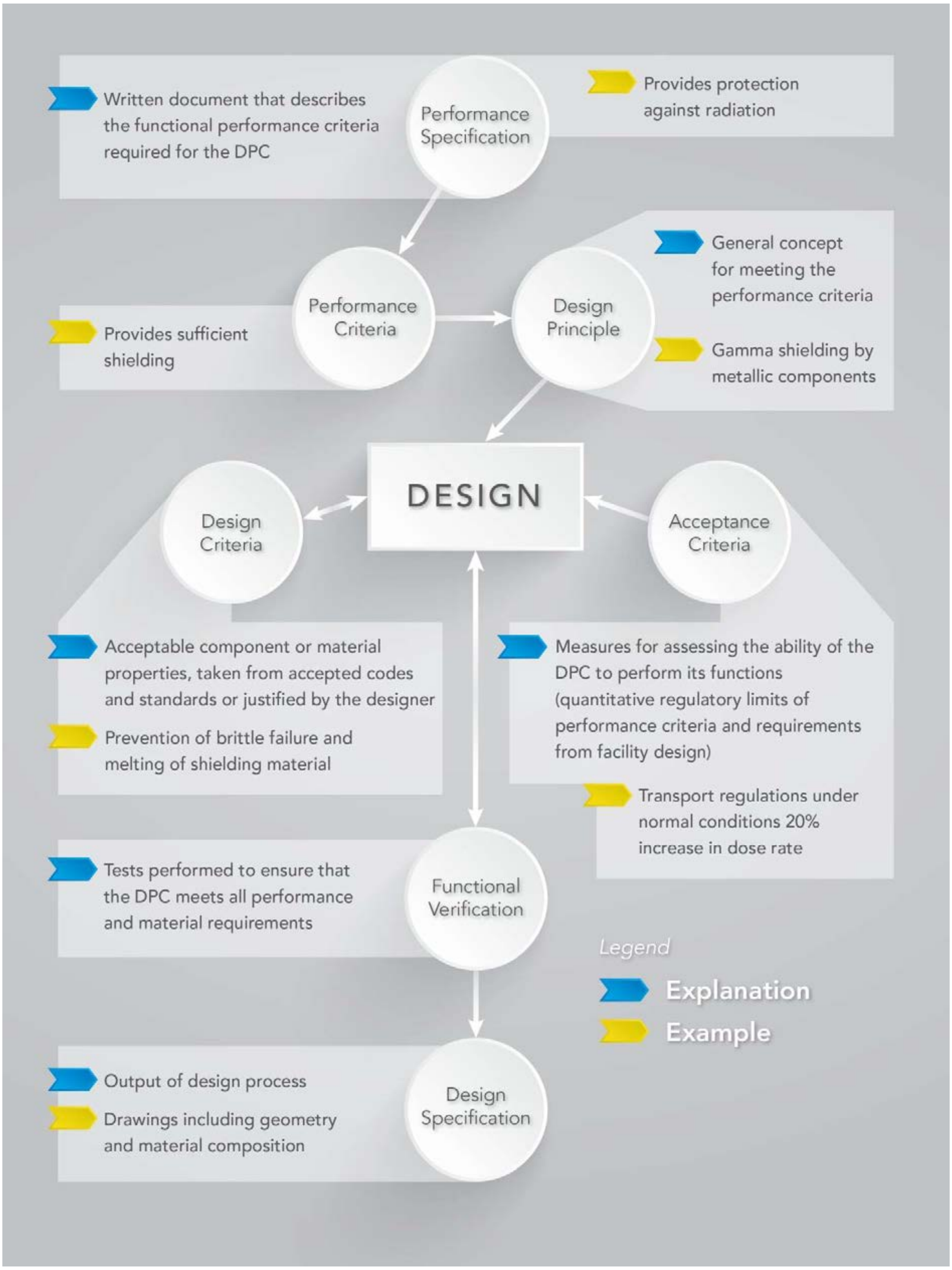

FIG. 4. Relationship between elements of the design process.

1.6.2. Basic design prerequisites

Section 1.3 of the DPCSC describes specifications for the spent fuel contained in the DPC; Section 1.4 describes DPC specifications. The DPC designer has to confirm spent fuel and the DPC specifications comply with basic prerequisite and design principles listed below.

(1) Spent fuel

Prerequisite conditions of spent fuel to be contained in the DPC are important factors for safe storage and transport.

(a) The spent fuel irradiation records can be used to assess the integrity of fuel cladding and need to be maintained throughout the storage period. Special provisions for damaged fuel will be considered to maintain safety functions.

(b) After unloading from the reactor, spent fuel is cooled down in a spent fuel storage pool for a period required to maintain integrity of the fuel cladding throughout the storage period.

(c) When loading spent fuel into the DPC, the spent fuel assemblies integrity has to be confirmed by visual inspection, operational data while in the reactor, nondestructive testing, or fuel assembly sipping inspection, etc.

(d) The records for the previous items have to be properly prepared and maintained by the storage facility operator, and will be available for the transport operator and competent authority as confirmation of safety.

(2) DPC

(a) The design of the DPC is required to comply with national or international transport regulations and be approved by the competent authority. The design principle for the DPC is first to comply with transport regulations that clearly state design requirements for a transport package, and secondly to comply with additional requirements for storage that depend on the national regulations and on-site storage facility design and operations.

(b) The DPCSC may include transport after storage with or without prior direct inspection of spent fuel contained in the DPC.

(c) The DPC will not be used for the period longer than originally evaluated to maintain integrity of spent fuel and components of the DPC important to safety. If the DPC is needed beyond that period, it has to be re-evaluated.

(d) The following instances need to be considered when assessing radiolysis and thermal effects. In all cases where water or hydrocarbon materials are present (polymers, aqueous or organic solutions, absorbed humidity), proof of the absence of the risk of accumulation of combustible gases exceeding the limiting concentration for flammability has to be included. In the event of loading of leaking fuel rods, the possibility of contained water needs to be considered unless its absence can be justified.

In addition, if applicable, the risk of chemical and physical reactions including radiation induced effects for materials reacting with water or oxygen, (e.g. sodium, plutonium, metallic uranium), or suffering a change of phase (e.g. freezing, melting, boiling), needs to be considered.

1.6.3. Performance criteria

DPC safety functions are containment, shielding, criticality prevention, and heat removal and to the extent possible, will be based on passive systems. In addition, retrievability of the DPC contents after storage has to be maintained. The safety functions are based on demonstrating the structural integrity of the DPC. Design goals for the DPC under each operational condition are summarized as follows:

(1) For storage and handling at facilities:

(a) *Normal operation*: Safety functions are maintained for the DPC to store and handle the DPC package safely under normal operation conditions.

(b) *Off-normal operation*: Safety functions are maintained to continue storage and handling with countermeasures such as minor repairs, if necessary, under anticipated off-normal operation conditions.

(c) *Accident condition*: Safety functions are maintained or mitigated from deterioration to prevent excess radiological risk to the operator, public, or environment under anticipated accident conditions.

(2) For transport:

(a) *RCT*: The DPC safety functions are to be maintained for the DPC package to be transported and handled safely according to transport regulations.

(b) *NCT*: Safety functions are maintained to permit transport under conditions stipulated by transport regulations.

(c) *ACT*: Safety functions are maintained or mitigated from deterioration to enable emergency response under accident conditions stipulated by transport regulations.

Design principles to achieve these design goals (for storage and handling at facilities, and for transport) are developed as follows for each safety function.

(1) *Containment:* The DPC has to maintain the containment function to satisfy two items:

(a) No radioactive material contained in the spent fuel can be released beyond the regulatory limits.

(b) To maintain the inert atmosphere in the DPC cavity to retain integrity of the basket and spent fuel.

The DPC design containment function is met through the following requirements:

- The risk of radioactive material release is mitigated when the interior of the DPC maintained at a negative pressure. For positive internal pressures, however, the risk of corrosion of spent fuel cladding may be mitigated due to prevention of moisture or any corrosive gas flow into the DPC cavity.

- The containment system of the DPC has to have multiple barriers against the release of radioactive material. If seals and/or welds are used, the containment function has to be maintained during long term storage.

- The seal function of the closure system has to be designed so that the leaktightness of the DPC can be verified after loading.

- The closure system of the DPC has to be so designed that the seal function can be monitored during storage.

- The DPC has to be designed so the seal function can be repaired or replaced after the unlikely event of loss of seal function.

- The seal function has to meet the transport regulation requirements after the storage period.

(2) *Shielding*: The DPC has to provide the shielding capability needed to maintain the radiation dose limits below the defined limits. The DPC has to be designed to provide sufficient shielding function by itself, or together with shielding capability of a storage building (when it is used), to keep the dose by direct radiation and by skyshine to worker and members of the public within the regulatory limits and as low as reasonably achievable.

(3) *Criticality Prevention*: The DPC has to be designed to prevent criticality under operational states and design basis accident conditions with spent fuel loaded.

(4) *Heat removal*: The DPC design has to provide adequate heat removal capability required to maintain the safety functions of the DPC and, if required, the integrity of the spent fuel.

(5) *Retrievability*: The DPC has to be designed to maintain the retrievability of stored spent fuel assemblies for operational states thus including transport after storage. If spent fuel cannot be retrieved with normal operating procedures, special operating procedures need to be developed.

1.6.4. Design principles and acceptance criteria

The DPC designer has to verify and describe within the DPCSC that the DPC design specifications will fulfill the performance criteria and that the DPC package will meet the acceptance criteria for each safety function.

The design principles and acceptance criteria below are applicable to all states defined in Section 1.6.3.

1.6.4.1. Containment

(1) Design principles:

(a) The containment system for the prevention of the release of radioactive material during storage and transport has to be clearly defined.

(b) The closure system during storage has to be a double lid closure system to allow leak detection by monitoring the interspace pressure. A pressure sensor to continuously monitor interspace and/or internal pressure may be employed. A single lid closure system may be used if the system adopts a seal that can provide an interspace for pressure monitoring. Pressure monitoring is not required if multi-layered welding is employed to seal the DPC.

(c) Seals making up the containment system during storage will need heat, corrosion and radiation resistance and have sufficient durability during the storage period.

(d) For double lid closure systems, the DPC internal cavity and interspace need to be filled with a gas to maintain the pressure barrier against radioactive material gas flow driven release during storage. DPC internal cavity pressure is recommended to be lower than ambient, because even if the pressure barrier is damaged, leakage of radioactive material due to inert filling gas flow from the DPC package will be prevented.

- Initial filling pressures of inert gas to the DPC internal cavity and interspace need to be established to maintain a pressure barrier regardless of temperature atmospheric pressure changes, leakage through seals, loss of primary lid seal function and/or an assumed fission product gas release from spent fuel.

- Residual water in the DPC cover gas has to be within the range specified to prevent deterioration of spent fuel cladding during storage.

(e) Seals that comprise the containment boundary of the DPC during transport have to comply with the transport regulations under all conditions of transport, including ACT.

- If the same seals used during storage are used for transport after storage, ageing effects on the sealing performance need to be considered. For transport after storage, seals on the secondary lid may be changed to new seals. In addition, where applicable, a third lid with seals can be added.

(f) Seals that comprise the containment boundary during storage need to have the capability to maintain the pressure barrier of the DPC under normal, off-normal, and accident conditions in the storage facility.

- The release of activity caused by the leakage rates of the containment system will not cause unacceptable doses to workers and to the public. The sealing capability required during storage is defined as the leakage rate of the DPC closure system (hereinafter referred as 'standard leakage rate for storage'). The closure system has to maintain a pressure barrier within the DPC regardless of temperature and atmospheric pressure changes, ageing of seals (especially, stress relaxation), and has to limit fission product gas release from spent fuel during storage to acceptable values. The primary lid seals have to maintain the standard leakage rate for storage over the storage period. To establish the standard leakage rate of the secondary lid seals for storage, loss of sealing capability of the primary lid must be considered in addition to the conditions above.

- The method to establish the standard leakage rate for storage considering ageing of the metallic seal could be based on the data from the acceleration test adjusted using the Larson-Miller parameters (LMPs) as shown in Ref. [13] and Section 1.7.3.2.

- If a seal is part of the containment system during storage, the seal needs to maintain its function so standard leakage rates specified for storage can be satisfied under routine conditions during transport before storage.

- If the standard leakage rates specified for storage cannot be demonstrated under conditions during transport before storage, then additional measures (a leak test prior to storage, accelerometers during transport, etc.) may be required.

(g) The effects of abnormal deterioration of primary lid seal function will be considered as part of the DPCSC. This may be mitigated either by design or by management arrangements. (e.g. storage with an attached third lid, transport of the DPC to another facility with the existing secondary lid, attached third lid qualified for off-site transport)

(2) Acceptance criteria:

(a) Acceptance criteria for the release of radioactive material from the DPC transport package is required to meet Ref. [1].

(b) Acceptance criteria for the containment are leakage rates of DPC storage package for normal, off-normal and accident conditions of storage. It has to be demonstrated in the DPCSC that containment leakage rates lead to activity release that will cause dose rates acceptable to national regulations for the storage facility.

(c) If the DPC is designed to keep the pressure of the DPC internal cavity below atmospheric, the leakage rate of the seal needs to keep the pressure of internal cavity below atmospheric throughout the storage period.

1.6.4.2. Shielding

(1) Design principles:

(a) The DPC will be designed to shield the radiation emitted from the contents of the DPC to the level stipulated in the transport regulations under the impact conditions of transport.

- The condition of shielding material under the impact conditions of transport has to be considered (e.g. deformation). The condition of shielding materials will be given as input to the shielding analysis from the structural and thermal analyses.

- In transport after storage, the effects of ageing on performance of shielding material (e.g. the reduction in atomic number density of neutron absorber) have to be considered.

(b) The DPC has to be designed to shield radiation emitted from the contents to the specified level.

- Radiation levels specified in the nuclear facilities are generally set to reduce excess dose to workers under normal and off-normal operations, while enabling response in the case of an emergency, while not exceeding the dose limit at the site boundary.

- It is rational to apply the same shielding capability that complies with the transport regulations to storage situations, if possible. Therefore, in the typical DPC design, such a shielding capability may be specified.

(c) Restoration measures (e.g. emplacement of additional shielding) to enable off-site transport have to be provided if the deterioration of shielding capability occurs during a storage accident.

(2) Acceptance criteria:

(a) Acceptance criteria for radiation levels of the DPC transport package must meet the principles of Ref. [1].

(b) Acceptance criteria for the shielding are the radiation levels of the DPC storage package for normal, off-normal and accident conditions of storage. The designer has to provide the radiation levels based on safety assessments.

(c) The storage facility safety case has to demonstrate that expected radiation levels comply with the principles of national regulations for storage. Acceptance criteria have to take into consideration sufficient safety margins.

1.6.4.3. Criticality prevention

(1) Design principles:

The DPC has to be designed to prevent criticality of the contents by geometric configuration of the basket and with neutron absorbers contained in the basket during transport or operations at nuclear facilities.

(a) Structural integrity of the basket has to be maintained during transport or operations at nuclear facilities in the case that the geometrical configuration of the contents has to be maintained as part of criticality prevention function.

(b) Ageing of basket material, neutron absorber and the content has to be considered in the criticality prevention design for storage and transport after storage.

(c) The criticality assessment for transport has to be conducted in accordance with the principles for packages containing fissile material as stipulated in Ref. [1].

(d) The criticality assessment for storage needs to consider the environmental conditions (e.g. existence of water, specifications of spent fuel, position of spent fuel assemblies in the basket, possible dimensional changes of basket and spent fuel assemblies, and the concentration, homogeneity, or diminution of the neutron absorber material) and arrangement of the DPC packages (e.g. change of spacing by external events) that result in the maximum effective neutron multiplication factor.

(e) The basket inside the DPC has to be designed to maintain its structural integrity throughout the storage period, when it bears part of criticality prevention function.

(2) Acceptance criteria:

Acceptance criteria for criticality safety of the DPC package are neutron multiplication factors (k_{eff}). The DPC designer has to provide k_{eff} values for RCT, NCT, and ACT and normal, off-normal, and accident conditions of storage based on the principles of national and international regulations. Acceptance criteria need to include sufficient safety margins. The safety margins have to be determined by taking into account the system to be analysed and recommendations from the transport regulations or guidance (e.g. Ref. [4], VI.35-VI.38), standards (e.g. Ref. [14]), or the competent authority.

1.6.4.4. Heat removal

(1) Design principles:

(a) The DPC has to be designed to dissipate external heat input and decay heat of the contents to maintain i) temperatures of the DPC components important to safety and ii) spent fuel cladding temperatures within specified ranges to maintain integrity of these items under RCT and NCT, and normal and off-normal nuclear facilities operations.

- The thermal analysis to demonstrate compliance with transport regulations has to be conducted for a single DPC package. In the case that the DPC package is transported under conditions not covered by the transport regulations (e.g. transport with canopy, consignment in an array), additional analyses to address those conditions have to be included in the DPCSC.

- For the thermal analysis under storage conditions, external heat input from surroundings has to be considered.

- The DPC designer has to select proper material keeping in mind compatibility with other safety functions, and has to clearly define temperature limits for these components and parts. Examples of the DPC components and parts that may have safety functions include:

  - Structural components (e.g. cask body, lids, bolts, basket, trunnions);
  - Seals (e.g. metallic, elastomeric);
  - Shielding components (e.g. lead, high molecular weight compounds);
  - Neutron absorber components (e.g. boron-containing parts);
  - Heat removal aids (e.g. internal fins, radial fins) .

(b) The DPC has to be designed to dissipate external heat input and decay heat of contents to maintain safety functions under ACT and nuclear facilities accidents.

The DPC designer has to define temperature limits for components and parts under accident conditions with consideration to compatibility with other safety functions to be maintained under the accident conditions of transport and accidents in the nuclear facilities. For example, if the required radiation level can be maintained under the accident conditions without certain shielding, then the limiting temperature for that shielding does not need to be defined.

(c) The DPC has to be designed to dissipate external heat input and decay heat of the contents to maintain spent fuel cladding temperature below the limiting temperature defined to maintain integrity of the cladding.

- The limiting temperature for spent fuel cladding is defined as the lower of either the initial temperature of the cladding whose cumulative creep will not exceed 1% during storage period, or the ceiling temperature to prevent deterioration of mechanical properties due to hydride reorientation. Furthermore, in the case that the strength of irradiated cladding is applied in the structural evaluation of the cladding, the temperature to trigger recovery from embrittlement (annealing) will be considered.

- In the assessment of fuel cladding integrity, all temperature histories for the cladding (i.e. during DPC package preparation, transport before storage, handling at the storage facility, storage, transport after storage, etc.) need to be considered. The temperature rise during the vacuum drying process after loading the spent fuel needs to be fully understood and carefully controlled and noted for future reference.

(d) A temperature monitoring system for the DPC package, if necessary during storage, could be installed.

(2) Acceptance criteria:

The DPC needs to have sufficient heat removal capability to ensure the following acceptance criteria are met:

- Criticality;
- Release of radioactive materials to the environment;
- Radiation doses.

These acceptance criteria are described as follows:

(a) Acceptance criteria for the external surface temperature of the DPC for transport purposes needs to meet the principles of Ref. [1].

(b) Acceptance criteria for the heat removal from the DPC for normal, off-normal, and accident conditions of storage are temperature of DPC components and its contents. The designer needs to justify the DPC would have sufficient heat removal capability as follows:

- During transport or operations in the nuclear facilities, the temperature of DPC components and parts important to safety will not exceed the limiting temperature defined to maintain such functions or integrity commensurate to the operational situations.
- The temperature of spent fuel cladding will not exceed the limiting temperature defined to maintain its integrity under RCT and NCT, or normal and off-normal nuclear facilities operations.

1.6.4.5. Structural integrity

The structural integrity of the DPC package is fundamental to meet the acceptance criteria necessary to demonstrate the design principles for each of the safety functions. The structural analysis will therefore provide the evidence upon which the subsequent analyses depend for their safety arguments. The following elements will be considered:

(1) Design principles:

(a) The DPC designer has to define and classify the necessary levels of structural integrity for components of the DPC and contents, commensurate with the safety functions required at situations in each of the operational steps. The levels of structural integrity could be expressed in terms such as: ‘stress level within the elastic range,’ ‘deformation allowable, but not rupture,’ or ‘allowable rupture.’ Components and parts to be evaluated and their levels of structural integrity are dependent on the DPC design, transport conditions, and design conditions of adjacent nuclear facilities. Some examples are provided below.

- *Containment components (cask body, lids, lid bolts, etc.)*: Under RCT and NCT and normal and off-normal conditions of storage, stresses created in the components have to be within the elastic range. Under ACT and accident conditions of storage, they may undergo plastic deformation but only to the extent that the DPC can still meet the accident containment criteria.

- *Basket*: Stresses created have to be kept within the elastic range under RCT and NCT and normal and off-normal conditions of storage. Under ACT and accident conditions of storage, the basket may be deformed but not ruptured. Basket deformation needs to be calculated and incorporated into the criticality assessment model.

- *Trunnions*: Under RCT and NCT and normal and off-normal conditions of storage, they have to be kept within the elastic range. Under ACT, no structural integrity is required. If facility design requires a cask to be tied on the floor or pad for earthquake or other natural disaster considerations, structural integrity might be requested under certain accident conditions of storage. Otherwise, no structural integrity is required under the accident conditions of storage.

- *Components supporting shielding (e.g. DPC outer shell)*: Under RCT and NCT and normal and off-normal conditions of storage, components supporting shielding have to be kept within elastic range. Under ACT and accident conditions of storage, they may be deformed or even ruptured in the case that shielding capability is not required under accident conditions.

- *Heat removal aids*: They have to be kept within elastic range under RCT and NCT and normal and off-normal conditions of storage. Under ACT and accident conditions of storage, they can be deformed but not ruptured.

- Spent fuel integrity has to be confirmed under any loading conditions during handling and storage (e.g. earthquake).

(b) The DPC designer has to determine limiting stress levels (or allowable stresses) for components and parts under operational conditions to follow the level of structural integrity defined in design principle (a) by applying the rules for fabrication of the DPC design approved by the competent authority [15][16].

(c) Table 2 provides an example of application of DPC fabrication rules.

(d) If not specified by the regulator, the DPC designer may refer to industry, national, or international design and construction codes for nuclear components. In the application of such codes, rules on components with functions similar to those of the DPC component (e.g. pressure retaining, support structure) have to be applied considering structural characteristics, stress types, and rupture aspects.

(e) The DPC designer has to also determine the necessary level of containment (e.g. allowable stresses) for spent fuel cladding under operational conditions.

TABLE 2. EXAMPLE OF THE RELATIONSHIP BETWEEN OPERATIONAL CONDITIONS AND ALLOWABLE STRESS CONDITIONS

Components	Operational Conditions			Service Condition Level (allowable stress conditions) in the ASME B&PV Code [15]
	Conditions of Transport	Handling Operations	Storage Operations	
Containment Components	RCT	Normal	Normal	A
	NCT	Off-normal	Off-normal	B
	ACT	Accident	Accident	D
Basket	RCT	Normal	Normal	A
	NCT	Off-normal	Off-normal	B
	ACT	Accident	Accident	D
Trunnion	RCT	Normal	—	A
	NCT	Off-normal	—	B
	ACT	Accident	—	—
Support Structure for Shielding	RCT	Normal	Normal	A
	NCT	Off-normal	Off-normal	B
	ACT	Accident	Accident	—
Thermal Path	RCT	Normal	Normal	A
	NCT	Off-normal	Off-normal	B
	ACT	Accident	Accident	D

(2) Acceptance criteria:

In general, components of the DPC and its internals important to safety and its contents need sufficient structural capability to withstand the combined loads anticipated during normal, off-normal, and accident conditions to ensure the following acceptance criteria are met:

- Criticality;
- Release of radioactive materials to the environment;
- Radiation doses and dose rates to the public and workers;
- Heat removal.

These acceptance criteria do not necessarily imply that all the structures important to safety survive without any permanent deformation or other damage. The results of the structural analysis have to include determination of the maximum extent of potentially significant accident deformations and any permanent deformations, degradation, or other damage that may occur, and must clearly demonstrate that no damage would render the system performance unacceptable.

1.7. AGEING CONSIDERATIONS

1.7.1. Introduction

Safety related components are subjected to degradation mechanisms and ageing processes that depend on the component and its operational and environmental conditions. The IAEA has worked on ageing problems and their relevance for the safety of nuclear power plants since the mid-1980s and the overall approach can be applied to spent fuel storage facilities.

Components of the fuel and container/packaging are especially important because of the potential for degradation processes to lead to fuel fragmentation, loss of container integrity, and other structural alterations that could directly impact confinement, subcriticality control and/or retrievability.

Thus, it is important to evaluate the potential degradation phenomena over time and their impact on the functions important to safety.

Although storage in a DPC can be licensed with state-of-art knowledge, periodic reassessments of the condition of the DPC package with respect to evolving regulations and evolutions in technology have to be performed to ensure the DPC package licensing basis remains in compliance throughout the storage period, during which ageing mechanisms may cause changes from the original licensing basis (refer to Section 1.12).

An ageing programme for the DPC and its contents over the period of long term storage minimizes uncertainties in the safety relevant functions of the system for which may otherwise be impaired by ageing mechanisms (refer to Section 1.12).

1.7.2. Components and ageing mechanisms to be considered

Ageing of DPC components and contents is categorized in terms of the degradation mechanisms or phenomena that may affect the various components, particularly during the storage period. Various organizations have evaluated potential mechanisms that may cause degradation of key components. The US NRC [17], IAEA [18], EPRI [19] and US DOE [20] have prepared tables identifying potential degradation mechanisms for all the components and contents of a DPC (and other storage systems). Although some of these tables were developed for ageing related to the storage of spent fuel beyond the long term (as defined in Ref. [4]), they are also applicable to ageing periods up to 100 years.

For example, Table 3, adapted from a forthcoming revision of Ref. [20], and Table 4, adapted from Ref. [18] highlight the type of degradation mechanisms of potential concern to DPC components. In addition, Table 4 shows an assessment for spent fuel cladding summarizing the type of degradation mechanisms of potential concern to that particular component for long term dry storage.

More recently, the US DOE has documented in Ref. [21] the initial gap analysis performed to identify data and modelling needs to develop the desired technical basis to enable storage of spent fuel. Reference [22] provides information on materials performance during storage beyond the long term (as defined in Ref. [4]) for a dry storage system license renewal (including DPC).

TABLE 3. STORAGE AND TRANSPORT SYSTEM COMPONENT DEGRADATION MECHANISMS ADAPTED FROM A FORTHCOMING REVISION OF REF. [20]

Stressor	Degradation Mechanism	Importance	
		Storage	Transport
Cladding			
Thermal	Annealing of Radiation Damage	Med	High
	Metal Fatigue Caused by Temperature Fluctuations	Low	Low
	Phase Change	Low	Low
Chemical	Emissivity Changes	Low	Low
	H_2 Effects: Embrittlement and Reorientation	High	High
	H_2 Effects: Delayed Hydride Cracking	High	Med
	Oxidation	Med	Med
	Wet Corrosion	Low	Low
Mechanical	Creep	Med	Med
Assembly Hardware			
Thermal and Mechanical	Creep	Low	Low
	Metal Fatigue Caused by Temperature Fluctuations	Low	Low
Chemical	Corrosion and Stress Corrosion Cracking (chemical)	Med	Med
	Hydriding Effects	Low	Low
Fuel Baskets			
Thermal and Mechanical	Creep	Low	Low
	Metal Fatigue Caused by Temperature Fluctuations	Low	Low
Chemical	Corrosion	Low	Low
Neutron Poisons			
Thermal	Thermal Ageing Effects	Med	High
Thermal and Radiation	Embrittlement and Cracking	Med	Low
Thermal and Mechanical	Creep	Med	Med
	Metal Fatigue Caused by Temperature Fluctuations	Low	Low
Neutron Radiation	Poison Burnup	Low	Low
Chemical	Corrosion (blistering)	Med	Med
Neutron Shielding Materials			
Thermal and Mechanical	Embrittlement, Cracking, Shrinkage, and Decomposition	Low	Low
Radiation	Radiation Embrittlement	Low	Low
	Poison Burnup	Low	Low
Chemical	Corrosion	Low	Low

TABLE 3. (Continued)

Stressor	Degradation Mechanism	Importance	
		Storage	**Transport**
	Container		
Welded Canister			
Chemical	Atmospheric Corrosion	High	Med
	Aqueous Corrosion: General, Localized (pitting, crevice), SCC, Galvanic	High	Med
Bolted Direct-Load Casks			
Thermal and Mechanical	Embrittlement of Elastomer Seals	Low	Low
	Thermomechanical Fatigue of Seals and Bolts	Med	High
Radiation	Embrittlement of Elastomer Seals	Low	Low
Chemical	Atmospheric Corrosion (including marine environment)	High	Med
	Aqueous Corrosion: General, Localized (pitting, crevice), SCC, Galvanic	High	Med
	Inert Fill Gas		
Thermal and Mechanical	Diffusion through Canister Wall	NA	High
Radiation	NA	NA	
Chemical	NA	NA	

Note: The importance ranking given is an example. The importance of degradation mechanisms could be different for storage and transport.

TABLE 4. EXAMPLES OF FACTORS AFFECTING SPENT FUEL INTEGRITY DURING LONG TERM DRY STORAGE ADAPTED FROM REF. [18]

Effective Factor		Phenomenon	Related Parameter	Related Cask Property
Creep		By cladding hoop stress according to internal pressure of fuel rod. Cladding temperature is restricted so that the accumulated creep strain within a design storage period may not exceed 1%	Fuel temperature under storage conditions	The degradation of cask cooling performance
			Fuel temperature at the time of vacuum drying	Vacuum-drying conditions (the degree of vacuum, time)
Hydrogen Effect	Embrittlement	Affecting cladding mechanical properties by hydrogen absorption in the atmosphere in a cask	The atmosphere ingredient in the cask	Degradation of the atmosphere in a cask or bad drying
	Reorientation	In excessive hoop stress is acting on the cladding, hydride may precipitate in the radial direction and may affect mechanical properties	Fuel temperature under storage	Degradation of cask cooling performance
	Axial Diffusion and Migration	The hydrogen in a cladding may diffuse according to the direction temperature gradient of an axis at the degree side of low temperature, and may affect a mechanical property	Fuel temperature at the time of vacuum drying	Vacuum drying conditions could mean a fuel thermal transient
Irradiation-hardening Recovery		The irradiation hardening (higher strength, lower ductility) recovers according to recovery of radiation damage by high temperature maintenance under storage, At the time of the transport after storage, when using the mechanical property of irradiation material for evaluation of fuel integrity, it is required that irradiation-hardening recovery should not occur	Fuel temperature under storage	Degradation of cask cooling performance
			Fuel temperature at the time of vacuum drying	Vacuum-drying conditions (the degree of vacuum, time)
Stress Corrosion Cracking		The combinations with corrosive fuel products like iodine, and the hoop stress by internal pressure in a fuel rod	Fuel temperature under storage	
Oxidation		By reaction with oxygen in the atmosphere in a cask. May affect the mechanical properties	The atmosphere in the cask	Degradation of the atmosphere in a cask or bad drying
Helium Generation by Alpha Decay		The helium produced by alpha decay in a fuel pellet causes internal pressure in a fuel rod to increase during storage	Fuel temperature under storage	Degradation of cask cooling performance
Physical Properties Change of a Pellet		The lattice constant of a pellet changes with alpha irradiation, and swelling (volume expansion is started)	—	—

1.7.3. Component evaluation

1.7.3.1. Spent fuel

Integrity of spent fuel to be stored in the facility has to be confirmed when the fuel is placed in the DPC through various means, such as reviewing the data collected during operation of the fuel in a reactor and by inspection (e.g. sipping, ultrasonic), if necessary.

NOTE: This discussion assumes the spent fuel is intact. Fuel that is not intact or otherwise not 'typical' might possibly be placed within a DPC only under special licensing conditions (e.g. inside a special canister for damaged spent fuel, which is loaded in specific basket positions).

Also during storage, integrity of fuel cladding has to be maintained for the entire designed storage period. Moreover, the storage facilities are required to be designed to maintain such integrity through the designed storage period, while considering ageing deterioration and other factors.

Thus, during storage, spent fuel integrity is required to be maintained. Integrity in this sense means fuel cladding is not damaged (cladding with pin holes and hairline cracks, which may accidentally occur with low frequency, is not regarded as damaged), and integrity of spent fuel once it is placed in the DPC is properly maintained (excessive deformation or degradation of material properties have not occurred).

At the beginning, a specific method to evaluate the integrity of spent fuel, as defined above, is maintained during storage and will be discussed in the license application. As can be seen in Table 4, damaged fuel could produce a degradation of the cask atmosphere and a degradation of cooling performance functions.

Spent fuel degradation factors are chemical, thermal, mechanical, and radioactive. Each factor is evaluated as follows:

(1) Chemical

Chemical factors include the use of specific backfill gases, radiolysis on the internal atmosphere composition, and remaining moisture after drying. These factors may produce an environment that favours conditions for stress corrosion cracking or embrittlement phenomena.

Corrosion of fuel cladding due to atmospheric moisture remaining inside the DPC is one of the examples of degradation caused by chemical factors.

It is assumed that the DPC retains an inert gas environment during storage and the DPC cavity is dried to an acceptable level prior to the storage period. Thus, if the gas environment within the DPC is maintained during storage, degradation due to chemical factors is judged to cause no problem in relation to integrity of spent fuel. If necessary, water-absorbing material may be placed within the DPC. If ageing of absorbing material is allowed depending on regulations of the individual country, the degradation behavior of the absorbent needs to be considered during the storage period. Reference [23] provides supporting knowledge regarding chemical factors.

(2) Thermal

Spent fuel originates all degradation mechanisms due to thermal factors. The effect of thermal factors decreases with time, depending on the initial heat load, as well as the heat removal capability.

Examples of degradation due to thermal factors include fuel cladding fracture due to high-temperature creep deformation, reduction of fuel cladding strength due to recovery of irradiation hardening under the condition of high temperature, fuel cladding embrittlement due to hydrides reorientation in association with high-temperature and stress corrosion cracking.

Spent fuel to be stored is assumed to be uranium dioxide fuel or mixed oxide fuel, which is irradiated in commercial power generation reactors. In addition, scientific and technical knowledge has to be obtained to determine whether the integrity of fuel cladding can be maintained for the entire designed storage period. After being permanently removed from a reactor core, spent fuel is cooled in the nuclear power plant spent fuel pool for a required period. It is assumed that the DPC is designed to ensure fuel cladding temperature is kept sufficiently low for the designed storage period (not to exceed a certain fixed level) to maintain fuel cladding integrity (e.g. by focusing on the cumulative creep deformation of the cladding).

NOTE: Some countries limit maximum spent fuel temperature to a specified value to avoid hydride reorientation and to limit creep deformation. They could also require a limit on the number of thermal cycles [24]). Other countries base their maximum spent fuel temperature limitation on the creep deformation limitation.

It is also assumed that the DPC is designed such that spent fuel decay heat can be appropriately removed in terms of maintaining spent fuel integrity.

If the fuel cladding temperature is kept below the design temperature, it can be considered that there is no degradation due to thermal factors for the entire storage period.

Reference [23] provides supporting knowledge and examples regarding thermal factors, including evaluating damage of the fuel cladding due to progress of creep deformation, decrease of fuel cladding strength due to recovery of irradiation hardening, fuel cladding embrittlement due to hydride reorientation, and stress corrosion cracking.

(3) Mechanical

Examples of degradation due to mechanical factors include damage of fuel cladding due to external forces (incidents or accidents) during storage and transport. The effect of mechanical factors could increase with time due to changes in fuel cladding properties. To minimize fuel damage due to mechanical factors, it is important to impose limits on handling activities. Thus, the incidental and accidental spent fuel conditions have to be evaluated accounting for expected degradation over the time.

It is required to maintain DPC basic safety functions (containment, shielding, criticality prevention, and heat removal) when handling the DPC package. During storage, it is required that the DPC is designed to maintain basic safety functions against the design basis loads (e.g. seismic loads based upon the historical records and field investigation results of the storage site and the surrounding area). Between the power plant and the storage facility, transport has to be conducted to satisfy the DPC safety requirements. Impulsive force due to drop, collision, and vibration during transport, and seismic force due to seismic motion during storage are examples of external force that might be applied to the DPC.

For the period of transport, DPCs need to be designed to maintain spent fuel integrity against external forces. For the period of storage, the DPCs need to be designed in such a manner that they will not undergo external forces beyond those assumed for transport. When expecting external forces to exceed those during transport, such forces have to be considered in the DPC design. Confirming the external force actually applied to the DPCs is within the range of those considered during design ensures spent fuel integrity is maintained against mechanical factors.

(4) Radiation

Radiation affects the fuel pellet structure, especially for high burnup (i.e. higher than 45 W•d/MTU in United States of America [25]) spent fuel, and produce release of inter- and intra-granular gases, which may increase cladding internal pressure. As a result, the probability of occurrence of degradation such as spent fuel creep, spent fuel stress corrosion cracking, and hydride reorientation may also increase.

In addition, due to the effect of radiation on cladding behaviour, evaluations of incidents and accidents during storage and transport have to consider increases in strength and decreases in ductility and fracture toughness of the cladding.

Concerning changes of mechanical properties of the fuel cladding due to neutron irradiation during storage period, the amount of such irradiation is small in comparison to neutron irradiation in the reactor. Therefore, there is no problem related to degradation due to neutron radiation regarding integrity of spent fuel.

Reference [23] provides supporting knowledge regarding irradiation factors.

1.7.3.2. DPC

Ageing deterioration is not expected to affect safety functions for the majority of component materials currently expected to be used for the DPCs. Table 5 shows DPC component material for which ageing deterioration needs to be considered.

TABLE 5. EXAMPLE OF DESIGN CONSIDERATIONS AGAINST AGEING DETERIORATION OF COMPONENT MATERIAL

Component Material	Material	Degradation Factors	Design Consideration
Neutron Shielding Material	Resin, polyethylene	Thermal, radiation	Establishment of weight loss rate of neutron shielding material in shielding analysis
Basket	Aluminum alloy, boron-aluminum alloy; neutron absorbers	Thermal, radiation	Establishment of allowable stress, considering ageing deterioration in structural and compositional analysis for criticality control
Metal Seal	Aluminum, silver	Chemical, thermal	Moisture control and establishment of temperature limit of the metal seal
Elastomeric O-ring	Ethylene propylene diene monomer (EPDM), Fluorocarbon rubber (FKM)	Chemical, radiation, thermal	Material selection
Cask Body	Coating	Chemical	Inspection and necessary maintenance
Trunnions	Polymer sealants	Chemical	Inspection and necessary maintenance

(1) DPC body, trunnions, neutron shielding material, shock absorbers

The DPC needs to be designed to ensure the necessary safety functions during storage and subsequent transport after storage, while considering potential ageing deterioration of component material that may occur during DPC package operation.

An appropriate method of verification to confirm that integrity of the DPC is maintained throughout the storage period for each of these components, as described below.

As the main body of the DPC is important in terms of maintaining basic safety function, sufficiently reliable materials need to be chosen, considering environment factors such as temperatures during the design storage period, radiation, and ageing deterioration such as corrosion, creep, and stress corrosion cracking.

In addition, the DPC components have to be designed to maintain required strength and performance, and to maintain required safety functions.

If shock absorbers are fabricated for a DPC at a significant period prior to transport of the DPC package, ageing degradation of the shock absorber material (wood, foam, or aluminium honeycomb) has to be considered.

Polymeric materials for neutron shielding are more sensitive to radiation and temperature than metals. The radiation exposure conditions for safety related neutron shielding materials can be determined and compared with the radiation resistance for the particular polymer (if available).

The primary irradiation alteration mechanisms of polymeric material systems in DPC are gamma radiation induced changes causing scission, crosslinking, or both, that lead to degradation of the polymer. In addition, the release of gases during degradation (e.g. hydrogen from neutron shielding material) has to be considered for any potential effect of the gases on safety related DPC components. References [26–29] provide examples of ageing behaviour studies for neutron shielding materials.

(2) Basket

The DPC basket is designed to safely contain spent fuel, to ensure proper geometrical configuration to meet the subcriticality and thermal performance functions, and to allow for fuel loading and retrievability (if required). Baskets are made from a variety of metals such as stainless steel, carbon steel, aluminum alloys, or metal matrix composite. When the basket inside the DPC constitutes a part of the criticality prevention function, it is designed to maintain structural integrity for the entire period of operation of the DPC package.

Baskets are exposed to decay heat and radiation of the contained spent fuel, and to external forces caused by vibration due to handling and transfer operations, or off-normal or accident events, such as earthquakes. Therefore, baskets have to be designed (including material selection) and manufactured to achieve long term integrity during storage. The environment (which is presumed to be achieved at the time of sealing) needs to be retained. Hence, when DPCs are loaded in the power plants (baskets with spent fuel are installed), their cavity has to be dried up to remove moisture sufficiently, filled with inert gas, and then sealed using multiple lid structures. The baskets are exposed to the same environment as the spent fuel and are subject to chemical, thermal, mechanical and radioactive degradation factors, each of which is evaluated as follows:

(a) Chemical

Chemical factors cause many forms of degradation, including basket corrosion due to exposure from moisture remaining inside DPCs. It is assumed that the DPCs are used for storage with an inert gas environment.

(b) Thermal

Basket components are subject to creep at normal or off-normal temperatures during dry storage. Basket components are also subjected to metal fatigue caused by temperature fluctuations.

The long-term effects of thermal ageing on basket components and especially on neutron poison materials need to be evaluated.

(c) Mechanical

Examples of degradation due to mechanical factors include damage of basket due to external forces during storage and transport.

(d) Radiation

Change of properties of the basket components, including the neutron absorber, due to neutron irradiation during storage period has to be considered.

(3) Closure system

The DPC closure system, either bolted or welded, serves to seal its contents, and maintain an inert internal environment. The DPC has to be designed to ensure containment (e.g. considering ageing deterioration of the seals during storage for bolted closure systems). The DPC needs to be designed to separate the space containing spent fuel from the outside of the container by incorporating multiple containment structures in the lid. For some DPCs with bolted closure systems, the design may enable operators to monitor the containment function, or allow for an additional lid to be installed in case a lid containment function abnormality is encountered.

Radiation may not affect metal seals (e.g. consisting of coil spring and an inner liner and outer liner or coiled spring and coated liner) because of the high threshold value required to alter the mechanical properties of metals. The repulsion force of the coil spring pushes the outer liner on the seal surface to ensure containment. However, time and temperature effects on metal seals have to be carefully assessed to ensure continued safe performance. In particular, containment functions degradation due to corrosion or creep of metal seals has to be considered.

References [20, 30, 31] provide detailed examples of storage cask reopening and inspection. Concerning corrosion for example, a DPC condition inspection at Fukushima Daiichi Nuclear Power Station revealed whitening of part of the metal seal surface due to the influence of moisture remaining on the primary lid flange. Even though there was no abnormality discovered in the results of the leaktightness test of the primary lid, it was necessary to thoroughly remove the remaining moisture during preparation of the storage cask. A similar condition inspection at Tokai Daini Nuclear Power Station showed no whitening on the surface of the metal seal as the remaining moisture was thoroughly removed from the primary lid, thus confirming validity of this improvement [23].

Several ageing degradation experiments have been conducted on metallic seals [32–35]. In addition, a long term containment performance test using full scale lid models was conducted in Japan from October 1990 to February 2009 [36, 37]. The experiment results provide a basis by which to evaluate the long term seal performance using the LMP approach.

Furthermore, Reference [38] provides a demonstration of full scale DPC model performance of metallic seals in a DPC under transport accident conditions after storage.

The potential for degradation products to affect the integrity of safety related DPC components has to be considered when using elastomeric seals as they are more sensitive to radiation and temperature than metals. The radiation exposure conditions for safety related elastomeric seals can be determined and compared with the radiation resistance for the particular polymer (if available). The release of gases during degradation (e.g. corrosive fluorine from an elastomeric seal) has to be considered for potential effects of the gases on safety related DPC components.

Usually, elastomeric seals are not included in the safety relevant closure system, and in this case, the degradation behaviour of elastomeric seals is of minor importance for long term safety. References [39–42] provide an overview of ageing behaviour studies for elastomeric seals.

(4) Canisters

In some specific designs, the DPC includes a welded canister in which the fuel assemblies are loaded. The canister provides an additional physical barrier to prevent release of radioactive material, maintains an inert atmosphere for the container internals to prevent chemical degradation, and prevents ingress of neutron moderator to provide additional criticality protection.

The canister is exposed to the DPC internal inert atmosphere. The internal environment of the canister might be similar to that of the basket; therefore, degradation mechanisms for canisters within a DPC during storage are considered to be the same as those for the basket. The internal pressure of canisters might also be taken into account. Based on the four potential stressors (thermal, radiation, chemical, and mechanical), the identified possible canister degradation mechanisms during normal or off-normal conditions are wet corrosion, creep, and metal fatigue caused by temperature fluctuations.

1.7.4. Preshipment inspection after storage period

1.7.4.1. Items to be confirmed before transport of DPC package after storage

Transport after ageing during storage requires careful inspection of the DPC package. When spent fuel is transported, generally the following items are inspected.

(1) External appearance;

(2) Leaktightness;

(3) Pressure retention;

(4) Dose rate;

(5) Subcriticality;

(6) External surface temperature;

(7) Lifting capability;

(8) Weight;

(9) Condition of contents;

(10) Surface contamination.

Of these, items 3), 5), and 9) are difficult to perform after storage. Alternate means of inspection can be performed by verification as described in the next section, which in combination with the ageing evaluation, provide assurance that the DPC package can be safely transported.

1.7.4.2. Concept of alternative inspections

Integrity of the DPC and its contents needs to be checked to confirm safety of transport at the end of the storage period (e.g. by visually checking the condition of the contents and baskets by opening the DPC lid, or by inspecting the atmosphere inside the DPC before shipment in the storage facilities).

However, the following facts need to be considered before such an inspection: storage facilities are very stable and static, activity from spent fuel contained in the DPCs gradually decays by releasing heat, and visual inspection of internals requires opening the DPC containment boundary. This action is undesirable not only because it increases radiation exposure or release of radioactive material risks, but also may increase other risks caused by incidents during handling of the DPC package.

Consequently, it is more convenient to perform the following inspections based on alternative approaches when the same level of safety can be ensured as when performing a visual check.

(1) Subcriticality inspection

There is reasonable assurance of no significant deformation or damage if the following points are confirmed:

(a) The baskets are manufactured following the design in the factory.

(b) Moisture is removed and inert gas is filled according to the design principles during preparation of the DPC packages in the power plant.

(c) DPC packages passed subcriticality inspection for transport from the power plant to the storage facility, and there are no abnormal external forces encountered during transport.

(d) The inert atmosphere of the basket (neutron absorber material) has been maintained during storage.

As a consequence, when the DPC packages are shipped from the storage facilities that have no fuel reloading equipment, subcriticality inspection during the preshipment inspection can be substituted by the documents confirming the previously listed items.

(2) Contents Inspection

When DPC packages are originally shipped from the power plant to the storage facility, operational records or other documentation already confirm the quantity and configuration of the spent fuel within the DPC. If there is no factor that will change these conditions, the above mentioned items can be reconfirmed by using the same records for the shipping of the DPC packages from the storage facility.

Although the DPC contents cannot be visually checked to determine appearance as they are in a sealed DPC with inert gas and have the necessary heat removal functions during storage, spent fuel integrity is considered to be maintained and will not be impaired due to chemical, thermal, or radiological degradation, as explained in Section 1.7.3.1.

Specifically, if the following points are confirmed, it can be judged that no abnormal change in the condition of spent fuel occurred:

(a) Moisture is removed and inert gas is filled in a way that satisfies the design condition during preparation of the DPC packages in the power plant.

(b) DPC packages pass the inspection of contents for transport from the power plant to the storage facility, and there are no abnormal external forces added during transport.

(c) There have been no incidents that may damage the integrity of the spent fuel during storage (that is, all the items presented in Section 1.7.3.1 were satisfied).

(d) The inert atmosphere of the DPC has been maintained during storage.

As a consequence, when the DPC packages are shipped from the storage facilities, especially if there is no fuel reloading equipment, the inspection of the contents during the preshipment inspection can be substituted by the documents that confirm the listed items.

(3) Pressure retaining inspection

Pressure measurements need to confirm that the atmosphere inside the DPCs is within the range of design principles. However, as the internal cavity of the DPC is sufficiently dried, filled with an inert gas, sealed by a multiple lid structure, and did not exceed the maximum recommended temperature, as long as the containment function is maintained throughout the storage period the original atmosphere can be assumed to be preserved.

Specifically, if the following points are confirmed, the atmosphere inside the DPCs is within the range assumed at the design stage:

(a) Moisture is removed and inert gas is filled in the way that satisfies the design principles during preparation of the DPC packages in the power plant.

(b) DPC packages pass the pressure measurement test for transport from the power plant to the storage facility and no abnormal external force acted during transport.

(c) Containment function of the DPCs was confirmed by the acceptance test in the storage facility.

(d) Containment function of the DPCs was not lost during storage.

As a consequence, when DPC packages are shipped from the storage facilities, especially those without fuel reloading equipment, documents confirming items (a) to (d) can substitute for pressure measurement during the preshipment inspection.

1.8. COMPLIANCE WITH REGULATORY REQUIREMENTS

The DPC design specifications are to comply with:

(1) Transport regulations.

(2) Storage and on-site transport requirements that depend on national regulations and on storage facility design. Meeting the acceptance criteria for storage specified in Section 1.6 shows compliance with the storage requirements.

In general, the DPCSC has to include a complete list of:

(a) Applicable paragraphs of regulations for transport.

(b) Acceptance criteria for storage and on-site transport, as applicable, to the respective DPC design. Demonstration of compliance with these paragraphs will be verified by reference to where in the DPCSC compliance is established or other justification.

Sections 1.8.1 and 1.8.2 discuss licensing considerations.

1.8.1. Transport package design approval and storage licensing period

A transport package design approval is usually issued for a period of a few to several years. At the end of the approval period, the license needs to be revalidated for the next period by demonstrating compliance with current transport regulations. In contrast, a storage license (storage facility operational license) could be issued for a period of up to several decades. At the end of the licensed period, the storage license may be terminated and the facility could be decommissioned, or the operational license could be extended by a demonstration of compliance with the current storage facility regulations.

IAEA transport regulations [1] may change from time to time, but with every change gap analyses between the current and the revised provisions need to be done. Transitional provisions are provided for the transport regulations where appropriate and/or needed. In that case, DPC packages licensed under the old transport regulations may be transported when they comply with the specified arrangement.

Section 1.7 addresses storage license evaluation considerations for determining acceptable storage period lengths. For example, for a license period of 50 years, it may not be difficult to evaluate the integrity of the DPC and contents based on available ageing data on spent fuel and DPC components. On the other hand, for a storage period of 100 years or more, ageing data is not readily available so an investigation and reevaluation of ageing of spent fuel and the ability of DPC to continue to perform its safety functions needs to be performed in advance of a commitment to extended storage and/or transport licenses.

When the transport regulation is changed or new technology is developed during storage, a gap analysis has to be conducted and the DPCSC has to be updated (see Sections 1.12.3 and 1.12.4).

1.8.2. License types for storage

Depending on national storage regulations, there are generally two types of storage licenses.

(1) General DPC License (included in a storage license): A stand-alone DPC design licence issued independently of a specific storage site. The DPC is designed for transport regulations, specific fuel specifications, and generic storage conditions, including normal operations, off-normal operations, and accident conditions. A storage facility operator will choose and implement one or more types of general DPC designs that fit the storage facility conditions. When storage conditions of a facility differ from generic DPC design conditions, a separate evaluation needs to be conducted by the storage facility and included in the facility safety case.

(2) Storage License on the Basis of Site Specific Conditions: The DPC is designed for transport regulations, spent fuel specific to the site, and specific storage site/facility conditions. This type of DPC can only be stored at the site for which it is evaluated, and the license may be a part of the storage facility license. In the safety case for this type of DPC, safety analyses of the specific storage site/facility conditions are provided.

There may be other licensing methodologies based on national regulations.

Depending upon national regulations, the DPC package may need transport approval before the start of the storage period.

1.9. OPERATION

The minimum requirements for the following activities need to be fully defined for the DPC package, as applicable:

(1) Testing requirements (including cold and/or hot tests, when applicable) and controls before first use.

(2) Testing requirements and controls before each operational step.

(3) Handling and tie down requirements, if applicable.

(4) Requirements for loading and unloading DPC contents.

(5) Requirements for assembling DPC components.

(6) Proposed supplementary equipment and operational controls to be applied during each operational step that are necessary to ensure the DPC package meets the regulatory requirements for transport and storage considering heat dissipation, thermal barriers, duration limits, and temperature limits.

(7) Re-establishing containment boundary functions (change of seals, installation of additional lids, etc.). Ensuring parts or components are replaced without major impact on the storage/transport operations and preferably while shielded from the radiation field around the DPC package.

8) The DPCSC scope may include transport after storage with or without direct inspection of the contained spent fuel.

1.10. EMERGENCY PLAN

In the event of incidents or accidents during radioactive material transport and storage, emergency provisions, as established by relevant national and/or international organizations, have to be implemented to protect the public and workers, the environment, and the property. Reference [43] contains transport guidelines for such provisions. For storage, the DPC designer needs to supply information to assist the facility operators in establishing the emergency plan of the related facility, which may also be included in the safety case for the storage facility. References [44] and [45] provide typical guidelines for the emergency plan for nuclear facilities.

Considerations need to include the development of scenarios of anticipated sequences of events, establishment of emergency procedures, and an emergency plan to deal with each of the scenarios, including procedural checklists and lists of persons and organizations to be contacted.

This DPCSC has to either interface with the transport or storage facility emergency plans or, where they do not exist, provide emergency plans.

1.11. MANAGEMENT SYSTEMS

A management system is the plan for the systematic actions necessary to provide confidence that the storage and transport systems will perform satisfactorily and specified requirements will be fulfilled. The management system needs to apply to all activities relating to the DPC and its contents including, but not limited to, the design, fabrication, assembly, inspection, testing, record management, training, maintenance, repair, modification, use, procurement, handling, shipping, in-transit storage, short and long term storage, transport after storage, and decommissioning. The scope of a management system has to clearly identify management roles and responsibilities during all phases of the storage and transport processes. Useful references regarding management systems are Refs [46–48].

Special attention needs to be paid to the 'Ageing management programme' in this publication.

1.11.1. Maintenance plan

As part of the management system, a maintenance programme has to be established for the DPC and its contents including and fully defining, as a minimum, the requirements for the following activities:

(1) Maintenance and inspection requirements before each operational step;

(2) Maintenance and inspection requirements at periodic intervals throughout the lifetime use of the DPC;

(3) Monitoring and repair of DPC package (e.g. restoration of surfaces, etc.).

The terms 'maintenance' and 'inspection' used in this publication include examination and testing. Sections 1.12.2.5 and 1.12.3(5) provide a more detailed discussion of maintenance programmes.

1.11.2. Lessons learned from literature on ageing management

It has to be ensured in the DPCSC that the entire history of ageing of the DPC and its contents is considered and that the specified maintenance and monitoring had been completed. For example, in the possible case where the DPC package has been transported after storage to a second storage facility, ageing at the first storage facility must be considered for the application of the storage license at the second storage facility.

While aging problems and their management for DPC are still to be investigated, since the mid-1980s the IAEA has worked on ageing problems and their relevance for the safety of nuclear power plants. In 2009 the collective experience of these documents was summarized with the publication of a Safety Guide on ageing management, which is superseded by Ref. [49]. The principle established in the IAEA Safety Guide can be applied to spent fuel storage facilities.

Figure 5 illustrates this, which indicates the continuous improvement of the ageing management programme for a particular structure or component, on the basis of feedback of relevant operating experience, results from research and development, and results of self-assessments and peer reviews, to help ensure emerging ageing issues will be adequately addressed.

The US NRC addressed ageing management of spent fuel dry cask storage systems in Ref. [50], Chapter 3. At first, materials of construction and the environments to which these materials are exposed need to be identified. Next, those ageing effects requiring either an Ageing Management Programme (AMP) or Time-Limited Ageing Analysis (TLAA) need to be identified. The Ageing Management Activity (AMA) defines two methods for addressing potential ageing effects: TLAA and AMP. A TLAA is a process to assess structures, systems, and components (SSCs) that have a time dependent operating life. At the end of the identified operating period, the component is typically replaced or renewed. As the DPC interior and cladding cannot readily be inspected, increased reliance on lessons learned from research reports in the literature is necessary. Similar to the ageing management of nuclear power stations, where components are grouped in relation to their safety importance, replaceability, etc., storage cask components also need to be grouped [51]. The US EPRI presented ageing management options [52], including additional analyses of degradation mechanisms, enhanced monitoring and inspection, and, if necessary, repackaging or overpackaging, or both. Recently, likewise the US Department of Energy addressed ageing management of spent fuel dry cask storage systems [53]. The goal of this report is to help establish the technical basis for spent fuel storage beyond the long term and subsequent transport.

OECD/NEA [54] developed the technical basis for commendable practices on ageing management for SCC and cables in nuclear power plant.

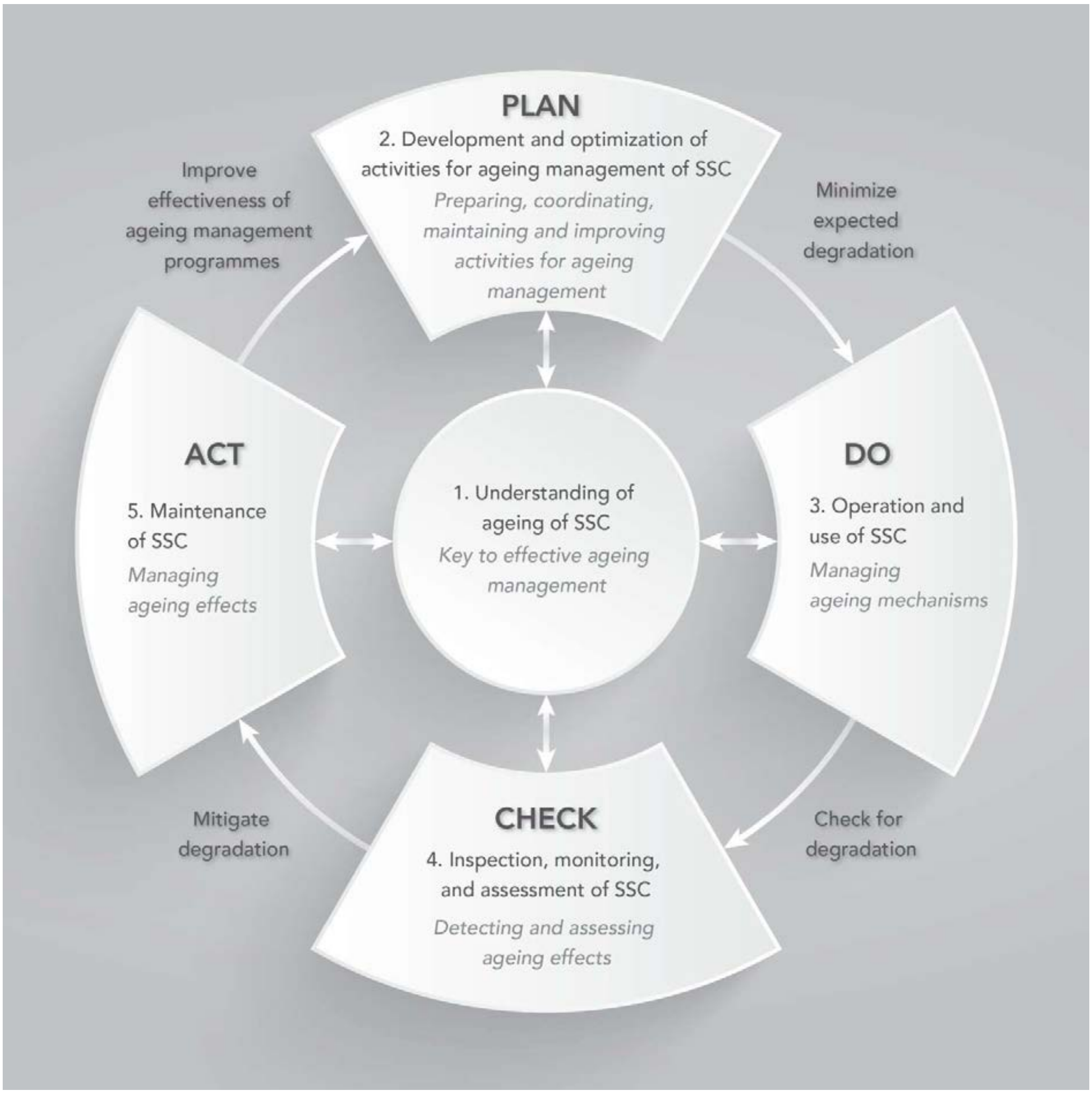

FIG. 5. Systematic approach to manage ageing of a DPC.

1.11.3. Essence of the systematic approach to ageing management

This section describes the essence of the systematic approach to DPC ageing management according to Figure 5.

1.11.3.1. Understanding ageing

Effective ageing management involves taking informed actions to mitigate degradation of SSCs in DPC storage facilities. Developing an AMP that identifies SSCs subject to ageing processes, SSCs that need specific actions to mitigate ageing, and the processes to be applied to each SSC is important to effective ageing management [55].

Safety related SSCs are subjected to specific degradation mechanisms and ageing processes that depend on the component and its operational and environmental conditions, as described in the Material Performance section. Characteristically in DPC storage system, spent fuel decay heat and radiation levels will decrease as the storage period continues. Section 1.7.2 describes how mechanisms will degrade spent fuel cladding and SSC integrity.

1.11.3.2. Plan: Development and optimization of activities for ageing management

Ageing management includes the documentation of relevant programmes and activities and a description of how the different programmes are coordinated in a systematic manner that guarantees continuous improvement by incorporating operational experience and relevant research results.

Ageing issues are best addressed through a systematic programme in which relevant activities for ageing management are coordinated. The documentation needs to also address maintenance, control, and inspection and monitoring processes as necessary, as well as the frequency and the scope of these activities.

1.11.3.3. Do: Managing ageing mechanisms

To limit degradation to an acceptable level, it is necessary to understand potential degradation mechanisms; suitable operational conditions designed to minimize degradation; control, inspection, and monitoring techniques that need to be used to detect degradation; evaluation criteria to determine whether sufficient safety margins remain when degradation is detected; and methods to manage, repair, or replace degraded components.

1.11.3.4. Check: Monitoring, inspection and assessment

Component evaluations have to demonstrate the validity of the safety functions considering potential ageing degradation. Safety related SSCs, therefore, include:

(1) Monitoring throughout the storage period;

(2) Periodic inspection for components that may degrade during the storage;

(3) Preshipment inspections.

As a result of these evaluations, a monitoring programme, an inspection programme, and a maintenance programme, or all, are necessary. Reference [56] provides an example of a periodic safety review guide.

1.11.3.5. Act: Maintenance

A maintenance programme needs to consider components with a time dependent operating life. At the end of the identified operating period, the component is typically replaced or renewed. Effective ageing management involves taking informed actions to mitigate degradation of safety related SSCs. The actions are based on an understanding of the types of material and environments at the facility. The key elements of ageing management involve maintenance and condition assessment.

1.11.4. Ageing management programme for DPC storage facilities

An AMP for the storage period addresses uncertainties in the safety relevant functions of the system that may be impaired by ageing mechanisms. The AMP identifies SSCs that need specific actions to mitigate ageing and ensures that no ageing effects result in a loss of intended function of the SSCs, during the license period.

Reference [57] provides generic templates for common nuclear power plant equipment, which can be similarly applied to developing AMPs for SSCs in the DPC storage facility.

AMPs generally include the following programmes:

(1) Prevention programmes:

A prevention programme can inhibit ageing effects.

(2) Mitigation programmes:

A mitigation programme can slow the effects of ageing. For example, cathodic protection systems can minimize corrosion of inaccessible metallic components.

(3) Monitoring programmes:

Monitoring means continuous or periodic measurement, including inspection. Inspection means an examination, observation, measurement, or test undertaken to assess SSCs and materials of the DPC storage facility.

Ongoing verification in storage facilities is needed to ensure adequate performance of critical SSCs to meet effective ageing management requirements. Early detection of degradation is desired before any loss of safety function by either condition monitoring or performance monitoring.

(a) Condition monitoring:

Condition monitoring will search for the presence and extent of ageing effects.

Examples for DPC storage include determining the condition of concrete structures and pads, external coatings and housings, and instrumentation and cables.

(b) Performance monitoring:

Performance monitoring will verify the ability of the SSCs to perform their intended functions. Some examples for specific performance follow.

(i) Shielding:

A DPC operator will obtain historic radiation survey data and evaluate trends. Either through measurement or analysis, one can adequately assess trends of historical measurements or deviations from calculated radiation levels, which would indicate shielding degradation. For example, this assessment can be directed at polymeric neutron shielding materials, because the organic resins incorporated in DPCs are subject to thermal and radiation induced degradation.

(ii) Containment:

An essential component for containment is the closure system. For DPC storage, pressure monitoring between cask lids or lid seals can be used. A decreasing pressure may indicate closure system degradation and has to be considered as an indicator to implement corrective actions.

(4) Inspection programmes:

An inspection programme will ensure that the safety related components fulfil all applicable storage requirements and transport requirements:

(a) Periodic inspection of the storage system (e.g. pressure transducers) and preparation of a report about its condition.

(b) Random inspections of the storage system may be carried out.

(c) The results of recurrent inspections have to be evaluated.

(d) Periodic reassessments of the condition of the storage system with respect to evolving regulations and technology need to be performed to ensure the storage licensing basis remains in compliance throughout the storage period, during which ageing mechanisms may cause changes from the original licensing basis.

(e) The time span for inspection depends on the extent of SSCs degradation, which is assessed based on the understanding of the degradation mechanisms. Inspections are made before degradation affects the safety function of the SSCs. During storage, the time span for inspection may be revised iteratively based on the history of operation, the results of the past inspection, etc.

After the tsunami disaster at Fukushima Daiichi Nuclear Power Station, a dry spent fuel storage cask stored on-site was investigated to evaluate potential damage to the cask. This evaluation is described in Ref. [58]. The evaluation indicated the robustness of the storage cask.

(5) Maintenance programmes:

Operating history, including corrective actions and design modifications, is an important source of information for evaluating the ongoing condition of pertinent SSCs. One has to discuss such history in detail. One may consider relevant site specific and industry wide experience as part of the overall condition assessment of pertinent SSCs.

(a) The AMP ensures that no ageing effects result in a loss of any safety function of the SSCs.

(b) Pressure transducers or pressure switches are used for monitoring the pressure between the lids or the metal seals. Transducers may be periodically calibrated or controlled.

(c) If the SSCs are significantly degraded, the AMP might require replacement of the degraded SSCs based on an assessment of the decrease in the functional performance of the SSCs.

Note that the maintenance programme will focus on safety related SSCs for technical reasons. However, the public may be concerned with more visible through non-safety related SSCs as well (e.g. deteriorated paint).

1.11.5. DPCSC periodic review

Once a DPCSC is developed, the DPCSC needs to be a controlled and include a record of its compilation and review and its approval by the DPC designer.

Gap analyses considering regulatory changes have to be performed to recognize effects of subsequent design changes on the DPC already in use, and changes due to developments in technology have to be monitored. The renewal of the license will be affected by changes in regulations if new regulations require additional safety considerations. Evolving technological developments, DPC design changes, or results from research on the effects of ageing mechanisms on components may, but not necessarily, justify modifications during routine maintenance, at the renewal of the license, or prior to transport.

The DPCSC has to be kept up to date by periodic review. For DPCs that will be in operation for several decades, it is important that the essential information on the DPCSC development and justification are kept present during the lifetime of the DPC. Periodic safety reviews and gap analyses are to be performed to keep the DPCSC updated; those periodical reviews are an important element of knowledge management, and force designer and regulators to keep knowledge on DPC safety present to all relevant institutions. It is recommended to perform gap analyses for transport package design approval renewal and periodic reassessments of storage systems in a coordinated and systematic approach (see Section 1.7.1). As the DPCSC is a 'rolling process' the issue versions of separate DPCSC documents or subdocuments have to be clearly identified in them. It is preferable for the DPCSC to contain a list of the documents it refers to, including a description of each document version. For the documentation and use of a safety case, see also in Ref. [3], Chapter 7.

A gap analysis concludes when the DPCSC based upon the new findings is deemed sufficient or measures are taken to provide the required level of safety.

1.11.6. Record management

Confirmation is required that the prerequisites for and the results of each operational step involving the DPC storage system were properly inspected, tested, and recorded. A record has to be available to the operators concerned for each step and to competent authorities for the confirmation of safety of the system. The availability of such records has to be clearly defined during the entire storage period and transport after storage in the DPCSC.

(1) In the DPC package preparation step, the inspection record confirming that the spent fuel to be stored is in compliance with applicable specifications has to be provided by the nuclear

power plant operator, and has to be made available for the safety assessment of the DPC and the integrity of the spent fuel stored to inform subsequent operational steps.

(2) During DPC package preparation, suppliers have to provide the inspection record for DPC fabrication to nuclear power plant operators to confirm DPC design compliance. The inspection record has to also be made available for safety assessment of the DPC and spent fuel integrity in subsequent operational steps.

(3) DPC safety function and spent fuel integrity inspection records may be used to confirm safety for conducting off-site transport after storage (i.e. the inspection before shipment as a transport package). For the operational scenario that includes storage at a facility without fuel retrieval capability, it is especially important to conduct proper inspection or alternative evaluations at various stages of DPC package preparation. Stages include receipt of the DPC package at the storage facility, storage and transport after storage with proper items, and methods established beforehand to confirm safety functions of components inside the DPC and the integrity of spent fuel without direct observation, such as visual inspection by opening the DPC lid. The applicable inspection records and evaluation results, or both, will be properly managed, maintained, and provided upon request.

(4) Preservation and transfer of technology and knowledge to new programme or organizational staff is essential, particularly for long term storage periods.

(5) Consideration has to be given to the transfer of storage records to transport operations personnel.

1.12. DECOMMISSIONING

The DPCSC needs to provide an initial plan for decommissioning of the DPC including consideration for financial arrangements.

PART 2: SPECIFIC TECHNICAL ASSESSMENT

Part 2 of the safety case provides the detailed technical analyses to support the demonstration of compliance with the regulations and acceptance criteria in Part 1 of the safety case, as referred to in Section 1.8.

Section 2.1 of this guidance provides the common provisions which need to be applied to all technical analyses to be included in Part 2 of the DPCSC and will not constitute a separate section of the DPCSC.

Sections 2.2 to 2.6 of this guidance give a list of the technical analyses that may be necessary in the DPCSC together with their main contents.

2.1. COMMON PROVISIONS FOR ALL TECHNICAL ANALYSES IN PART 2 OF THE SAFETY CASE

Section 2.1 contains the common provisions that need to be included in each of the technical analyses in Sections 2.2 to 2.6.

2.1.1. Bases for technical assessment

Each technical analysis in Sections 2.2 to 2.6 of the DPC design being evaluated needs to precisely reference the DPC design specification and the contents specification defined in Sections 1.3 and 1.4.

As described in Section 1.5, the impact conditions for the applicable operational scenarios have to be derived and used in the technical analyses.

The acceptance criteria for the technical analysis and the DPC design criteria in terms of geometry or performance characteristics need to be defined and justified when necessary (Section 1.6). The acceptance criteria may be derived from regulatory limits taking into account an appropriate safety margin. The design criteria have to be chosen from accepted codes and standards or justified by the designer.

For the technical analyses, the DPC designer has to use properties of new or aged materials (whichever is most restrictive) while considering factors in Section 1.7. If experimental tests are used, the aged condition of the DPC package will also be considered.

2.1.2. Description and justification of analysis methods

The safety demonstration of a DPC design can be accomplished by a combination of the following as appropriate. The methods or standards used in each analysis listed in Sections 2.2 to 2.6 will include a description of the analysis technique used, its limitations, and its accuracy. In all cases their use has to be justified.

(1) The results of physical testing of prototypes or models of appropriate scale. When a campaign of tests is implemented for a specific design to be approved by competent authorities, the designer is advised to notify the competent authorities in advance of the testing programme and they are allowed to witness testing.

(2) By reference to previous satisfactory demonstrations of a sufficiently similar nature. Test results of designs similar to the design under consideration are permissible if the similarity can be demonstrated sufficiently by justification and validation.

(3) By calculation, or reasoned argument, when the calculation procedures are generally agreed to be suitable and conservative. Assumptions made may require justification by physical testing.

If computer programs are used for the safety analysis, then additional information will be required to:

(a) Verify/validate the program in terms of the operating platform (computer), method, modelling approach, and assumptions used.

(b) Justify the applicability of these programs including a statement of possible sources of errors, particularly for conditions for which sufficient verification has not yet been provided.

(c) Assess the effects of modelling assumptions and simplifications as well as any other parameters that may influence the calculated results.

(d) Special attention has to be paid to situations for which the existing or available database is not applicable (due to missing or insufficient data). In those cases, the use of calculation methods and assumptions needs to be conservative to provide margins of safety to compensate.

(e) In general, program validation is accomplished by comparing with analytical solutions and with other validated programs (benchmarking). More guidance can be found in Ref. [], Section VI.14.

2.1.3. Analysis of DPC design

The DPC design has to be assessed, as appropriate, with the results subject to an appropriate and identified sensitivity analysis with stated levels of accuracy.

It is probable that more than one accident and its consequences need to be considered to ensure various safety functions that may be fulfilled by different components of the DPC design comply with regulatory requirements.

Other factors that may have a consequential effect on the safety functions have to be analyzed. These may be corrosion, combustion, pyrophoricity or other chemical reactions, radiolysis, phase changes, etc.

2.1.4. Comparison of acceptance criteria with results of analysis

The results of the analyses detailed in Section 2.1.3 have to be compared with the acceptance criteria and DPC design criteria and regulatory compliance has to be justified accordingly.

2.2. STRUCTURAL ANALYSES

2.2.1. Reference to DPC design for structural analysis

The design of the DPC and the description of the contents have to be referenced according to Section 2.1.1.

2.2.2. Assumptions for structural analysis

The structural behavior has to be demonstrated for normal operation, off-normal operation, and accidents. For off-site transport, the conditions to be analyzed are given in the international modal regulations or national transport regulations. According to Ref. [1], analysis is required for routine conditions of transport (RCT, no incident), normal conditions of transport (NCT, including minor mishaps), and accident conditions of transport (ACT), each defined by testing conditions. For on-site transport and storage the conditions to be addressed need to be taken from the analysis of the operational conditions, incidents, and accidents that must be considered for these activities as described in Section 1.5.2.

Most of the acceptance criteria for transport are derived from Ref. [1]. In addition, the criteria are to be derived from national regulations or as agreed upon with national regulators.

In general, components of the DPC and its contents important to safety need to have sufficient structural capability to accommodate the combined loads anticipated during normal and off-normal events and to withstand the worst case loads under accident level events to ensure the following acceptance criteria are met:

(1) Criticality;

(2) Release of radioactive materials to the environment;

(3) Direct radiation doses to the public or workers and derived dose rates;

(4) Heat removal.

This position does not necessarily imply that all the structures important to safety survive without permanent deformation or other damage. The results of the structural analysis have to include determination of the maximum extent of potentially significant accident deformations and any permanent deformations, degradation, or other damage that may occur, and have to clearly demonstrate that no damage would render the system performance unacceptable.

2.2.3. Description and validation of methods for structural analysis

2.2.3.1. Experimental drop testing

(1) Determine the most damaging test orientation and sequence and analyse the effect on the containment, criticality safety and shielding functions.

(2) For the mechanical ACT, the sequence of 9 m drop tests and 1 m puncture tests need to be analysed or performed to maximise damage and loading of the DPC (in terms of deformation,

stress, strain, acceleration and damage before the second test) while considering different DPC components (cask body, closure system, impact limiters, basket, etc.) and contents. The drop test positions and sequences are to be selected to maximise loading of the individual DPC components and contents.

(3) An assessment needs to be made of storage facility conditions defined in Section 1.5 and of the DPC package configuration. The following aspects need to be considered:

(a) Drop tests which maximise the stresses and acceleration.

(b) Drop tests which maximise the deformation.

(c) Drop tests that maximise the damage to orifices, notably by a puncture bar. The containment components in the orifices are often thin and more liable than the body to be damaged.

(4) For drop tests performed with a scale model of a DPC package, the following needs to be considered:

(a) Similar or conservative geometry and component/material properties are to be used.

(b) Demonstration that the results of the drop test with the scale model DPC can be correlated to the original design.

(c) It may be necessary to increase drop heights to simulate the total potential energy that would have been received by the DPC package at full scale. This is particularly so where the characteristic deformation of the structure is not negligible in comparison to the drop height [59].

(d) Appropriate geometric scaling of all containment system components is important [60], including:

- Metallic seals: same design, materials and similar force-deflection characteristic.

- Elastomeric seals: the similarity has to be based on the useful elasticity taking into account the compression set. The change of material properties with temperature and radiation has to be considered.

- The scaling of tightening torques for bolts of the scale model DPC package has to consider friction, precision of torques, and technical limitations in an exact geometric and physical scaling of the containment system components.

- Similar welding seams.

- In the case of scale model DPC package drop testing with significant deformations of impact limiters or yielding targets, the correlation to the behaviour of the full scale DPC package performance has to be carefully justified.

2.2.3.2. Structural analysis calculations

(1) Calculations using computation models are to be verified and validated. It must be demonstrated that input parameters (material laws, characteristic values, boundary conditions, etc.) describe sufficiently and precisely the actual conditions which the DPC package may experience.

(2) If uncertainties exist regarding important input parameters (e.g. material laws), conservative design calculations including the possible range of material properties have to be performed to assess limiting values.

(3) All data used (material laws, boundary conditions, load assumptions, etc.) and calculation results are to be documented in detail.

2.2.4. Structural assessment

The following are some of the points that need to be considered in a structural analysis.

(1) An assessment needs to be made of the mechanical behaviour (including fatigue analysis, brittle fracture, creep, and effects of ageing during storage) under RCT, NCT, and SCT before and after storage and under normal, off-normal, and accident conditions of storage for:

  (a) DPC components of the containment system;

  (b) DPC components that provide radiation shielding;

  (c) DPC components for criticality control;

  (d) DPC components for which their performance will have a consequential effect upon (a), (b), and (c);

  (e) Packaging attachments used for lifting the DPC package (RCT and NCT, and normal and off-normal conditions of storage);

  (f) Packaging attachments used for restraining the DPC package to its conveyance during transport (RCT and NCT only);

  (g) External features used in special storage configurations such as DPC package anchored to the pad.

  This includes the mechanical stability of the contents and any structure that is used to maintain its geometry if necessary for the criticality safety assessment. Other important criticality safety relevant items to be considered include water leaking into or out of the DPC, the rearrangement of the fissile material, and the degradation of neutron absorbers.

(2) Demonstration of the compliance with performance standards is accomplished by methods listed in Section 2.1.2.

(3) The mechanical properties of the materials considered need to represent the range of mechanical properties of the DPC components considering (e.g. i) the applicable temperature ranges between the minimum and the maximum temperature of the respective DPC components and ii) the loading rates to which the components may be subjected in transport and storage).

(4) The following points have to be considered in the assessment of the mechanical behaviour of the DPC components:

(a) The effects on the DPC package response due to variations in the shock absorbing properties of the impact limiter material (wood, polymers, plaster, concrete, etc.) with consideration given to the temperature range and the moisture content of the impact limiters.

(b) The possibility of brittle fracture of components at the minimum design temperature.

(c) The strength of the lid bolts has to be justified for accident conditions.

(d) It is preferable to avoid plastic deformation of containment system components such as bolts, seal seats, etc. Plastic deformation analysis would require complex proofs concerning the mechanical behaviour of the components and sufficient seal seating.

(e) Possible damage of seals due to vibrations or sliding of the lid has to be evaluated.

(f) The condition of the containment system has to be determined to enable Section 2.4 requirements to be demonstrated within the temperature range concerned.

(g) Retention of sufficient thermal protection to guarantee the safety functions of DPC components for accident conditions has to be evaluated.

(h) Verification of the mechanical behaviour of the fuel and the internal structure.

(i) The effect of the thermal loads on the mechanical behaviour of the DPC components are to be considered (e.g. thermal stresses and strains and interactions between DPC components due to changes in dimensions).

(j) Proof of the ability to withstand the maximum pressure (taking into account fire and radiolysis, physical changes, chemical reactions, etc.).

(k) Verification that the DPC can withstand water immersion. For storage, impact on the DPC due to potential floods at the facility site needs to be considered.

(l) Analysis of the influence of any devices described in Section 1.4(e) on the performance of the DPC package in accident conditions.

(5) The spent fuel integrity and geometries required to maintain subcriticality and heat removal, and its related confinement system, have to be maintained and verified throughout the storage period.

(6) Consideration has to be given to potential cumulative effects of radiation on materials likely to be subjected to significant radiation fields. In addition, potential thermal effects on material degradation need also to be considered. Other ageing effects such as stress corrosion cracking, creep, and stress relaxation have to be considered (Section 1.7).

(7) Static, dynamic, and seismic loads have to be considered in the design of casks or baskets.

2.3. THERMAL ANALYSES

2.3.1. Reference to DPC design for thermal analysis

The design of the DPC and the description of the contents need to be referenced according to Section 2.1.1.

2.3.2. Assumptions for thermal analysis

The thermal behavior has to be demonstrated for normal operation, off-normal operation, and accidents. Reference [1] lists off-site transport conditions that have to be analyzed. According to Ref. [1], analysis is required for RCT, NCT, and ACT, each defined by testing conditions. For on-site transport and storage, the conditions to be addressed have to be taken from the analysis of the operational conditions, incidents, and accidents that have to be considered for these activities as described in Section 1.5.2.

Most of the acceptance criteria for transport are derived from Ref. [1]. In addition, the criteria are also derived from national regulations or as agreed upon by the national regulators.

In general, components of the DPC and its contents important to safety need sufficient heat removal capability to ensure the following acceptance criteria are met:

(a) External surface temperature of the DPC package for transport purposes have to meet national and international transport regulations requirements.

(b) Criticality.

(c) Release of radioactive materials to the environment.

(d) Direct radiation doses and dose rates to the public or workers.

2.3.3. Description and validation of methods for thermal analysis

The following are some of the points that need to be considered in a thermal analysis.

(1) An assessment needs to be made of the thermal behaviour under RCT, NCT, and ACT each before and after storage, and under normal, off-normal, and accident conditions of storage for:

(a) The containment system;

(b) Components providing radiation shielding;

(c) Components providing criticality control;

(d) Components for which their performance will have a consequential effect upon (a), (b), and (c).

This assessment includes the fissile material thermal behaviour and any structure used to maintain the geometry of the fissile material for the criticality safety assessment.

(2) Evaluate the effects of insolation for a period of 12 hours according to Ref. [1], para. 657. Averaging insolation over 24 hours is not acceptable. For outside storage, the same effects need to be considered.

(3) Consider the presence of protective systems liable to impede heat dissipation in RCT (e.g. tarpaulins, canopies, additional screens, outer packaging [containers, boxes, etc.]), if applicable.

(4) For storage, as well as 3), consider adjacent DPC packages.

(5) Justify simplifying assumptions used for calculation (for example the absence of trunnions).

(6) The DPC package in accident conditions needs to be analysed in the position (horizontal or vertical) which is most thermally challenging to the DPC and contents.

(7) The solar insolation before and after the fire test needs to be considered as defined in Ref. [1], para. 728. For storage, a different solar insolation may be applicable.

(8) The absorptivity of the external surface of the DPC according to Ref. [1], para. 728 will not be lower than 0.8 without additional justification during and after the fire test to account for deposits upon the DPC surface. The absorptivity will also not be lower than the possible maximum value of the emissivity.

(9) The evaluation of the minimum and maximum temperatures of the various components of the DPC has to take account of all the possible positions for the contents.

(10) The time dependent temperatures of fuel and components have to be determined during the total storage period. This information can be used for the evaluation of ageing effects (Section 1.7).

(11) The profile of burnup distribution and decay in irradiated fuels has to be taken into account in the thermal analyses.

(12) The influence of combustible materials that generate additional heat input and affect the fire duration has to be taken into account for safety analyses.

(13) Analysis of the influence of the devices specified in Section 1.4(e) in fire conditions on the performance of the DPC package needs to be performed, if applicable.

(14) It has to be demonstrated that the spare volume in the seal grooves allows for thermal expansion unless appropriate justification is provided.

(15) Operational conditions during DPC loading as well as storage and transport have to be described. The heat removal capability in combination with operational conditions (which can be very important during the loading procedure, for example if using vacuum drying) has to be such that the temperature of the spent fuel assembly, including that of the cladding, does not exceed the maximum allowable value. In addition, other safety related components of the DPC also have to not exceed their maximum allowable temperatures. This can be demonstrated by measurements or calculations.

(16) Analysis has to consider processes foreseen to degrade or impair the system over time. Changes to thermal properties related to ageing (Section 1.7), for example changes to the internal gas composition, need to be considered.

(17) All thermal loads and processes resulting from the spent fuel decay heat have to be given appropriate consideration in the design. Typical items for consideration include:

   (a) Thermally induced stresses;

   (b) Internally and externally generated pressures;

   (c) Heat transfer requirements;

   (d) Effect of temperature on subcriticality.

2.3.4. Thermal assessment

The thermal assessment has to be conducted for all operational scenarios planned for the DPC package (Section 1.5.2). Sections 2.3.1 to 2.3.3 describe conditions to be considered for the thermal analysis.

2.3.4.1. Experimental thermal test

Experimental thermal tests for transport have to be carried out in accordance with guidance provided in Ref. [4], para. 728. Analogous methods may be applied to storage situations.

(1) When thermal analysis is based on test results, show that the temperature measurements were performed at thermal equilibrium.

(2) When the thermal test is made in a furnace and where some DPC components burn, the concentration of oxygen present in the environment of the furnace has to be controlled to be the same as that obtained in a hydrocarbon fire. In addition, control of heat input has to be considered thoroughly.

2.3.4.2 Thermal analysis calculations

(1) Calculations using computational models are to be verified and validated. It must be demonstrated that input parameters (material properties, characteristic values, boundary conditions, etc.) describe sufficiently and precisely the bounding conditions that the DPC package may experience.

(2) The safety margins on temperature results derived using numerical modelling need to be commensurate with the uncertainty of the numerical model.

(3) If uncertainties exist regarding important input parameters (e.g. material properties), conservative design calculations including the possible range of material properties need to be performed to assess limiting values.

(4) All data used (material properties, boundary conditions, etc.) and calculation results are to be documented in detail.

2.4. ACTIVITY RELEASE ANALYSIS

2.4.1. Reference to DPC design for activity release analysis

The design of the DPC and the description of the contents have to be referenced according to Section 2.1.1.

2.4.2. Assumptions for activity release analysis

The limitation of activity release has to be demonstrated for NCT and ACT, and normal operation, off-normal operation, and accidents during storage. IAEA transport regulations [1] provide the off-site transport conditions that have to be analysed. According to Ref. [1], analysis is required for NCT (including minor mishaps) and ACT, each defined by test conditions. For on-site transport and storage, the conditions to be addressed have to be taken from the analysis of the operational conditions, incidents, and accidents that must be considered for these activities at the affected facilities as described in Section 1.5.2.

The basic condition of the DPC package for each step in the operational scenario has to be taken from the history of the fuel and the DPC as described in Section 1.5.1, including irradiation of the fuel and all ageing processes of the DPC, its inserts and seals, and the fuel after loading (Section 1.7). Then, based on this state for the assessment conditions given above, the influence on the properties of the DPC, the inserts and seals, and the fuel elements have to be determined (refer to analysis results from Sections 2.2 and 2.3). The mechanical and thermal impact conditions (DPC package orientation during tests or accidents, temperatures, etc.) have to be selected to lead to the configuration with maximum release. These conditions may differ from those leading to the most severe situation regarding dose rate calculation or criticality safety; therefore these conditions need to be carefully selected and justified in the DPCSC.

Basic information needed to assess activity release is as follows:

(1) The leakage rate of the containment system of the DPC based upon leakage rate test (see Section 1.9) and upon structural and thermal analysis (Sections 2.2 and 2.3).

(2) The releasable source term (gaseous, aerosols, volatiles) of the contents of the DPC based upon a structural integrity assessment of the spent fuel (including cladding) and the physical and chemical properties of radionuclides inventory (taking into account ageing, release processes, pulverization, and other changes in physical form). The determination of the releasable source term needs to consider:

(a) Mechanical resistance of the spent fuel assemblies with respect to the internal pressure;

(b) The risk of rupture due to creep of the rods under the effect of the internal pressure, taking into account the mechanical properties of the fuel rods for the temperature conditions and for the history (burnup rate, cooling time, etc.) of the spent fuel assemblies;

(c) The risk of rupture of the rods from mechanical impacts, taking into account the mechanical properties of the fuel rods and cladding for the temperature conditions and the history (burnup rate, cooling time) of the spent fuel assemblies;

(d) Analysis of the condition of the spent fuel assemblies (for example, the risk of cracking or rupture of the fuel rod at their ends), if necessary for the safety demonstration;

(e) Condition of internal canister or basket for spent fuel (damaged or not);

(f) Fission gas release rate from spent fuel;

(g) The presence of debris and of aerosols in the DPC cavity following the analysis of risks of rupture and cracking of the spent fuel cladding;

(h) The formation of aerosols.

(3) Pressure condition inside the DPC (resulting from possible radiolysis, corrosion, cladding failure, temperature, etc.).

(4) For off-site transport, a reduction of ambient pressure to 60 kPa has to be considered for evaluation of activity release according to Ref. [1], Para. 645. For on-site transport and storage, the minimal atmospheric pressure of the site has to be considered.

Relevant values for activity release limits have to be taken from Ref. [1] or derived from criteria for the facility (Section 1.8).

Example for transport: IAEA transport regulations [1], para. 659 specify the restrictions for the loss of radioactive contents from Type B(U) or Type B(M) packages under NCT and ACT in terms of activity per time: limits of 10^{-6} A_2 per hour for NCT and A_2 (10 A_2 for ^{85}Kr) per week for ACT have to be kept by an appropriate function of the containment system.

2.4.3. Description and validation of calculation method for activity release analysis

Activity release has to be calculated for NCT and ACT, and normal operation, off-normal operation, and accident conditions during storage. Some of these calculations usually are done by using computer programs.

The selection or calculation of activity release source term for a DPC package has to be based on a bounding case of the radioactive inventory in the DPC.

The computer program or calculation method used has to be accurately specified. The validation of the computer program for application to the DPC design and contents under consideration has to be demonstrated (Section 2.1.2(c)).

The validation for source term calculations may be based on the SFCOMPO database [61] or as approved by the national competent authority.

References [62, 63] provide additional activity release guidance.

2.4.4. Activity release calculations

2.4.4.1. Containment system of a DPC

The closure system, which is part of the containment boundary of most DPCs, is comparable: two flanges with inserted bolts and a metallic or elastomeric seal in between (for one lid flange). An additional metallic or elastomeric seal is required to create the necessary volume for leak tests via test ports. For example, the double jacket metal seals used for the DPC designs in Germany consist of a circular spiral spring encased in two jackets; the inner layer is made of stainless steel, the outer of aluminium or silver. Material for elastomeric seals usually used is fluorocarbon rubber (FKM) or ethylene propylene diene monomer (EPDM) rubber.

2.4.4.2. Leakage mechanism and mode of calculation

Direct measurements of radioactive releases from a DPC package are not feasible. Therefore, the common method for the specification of leaktightness is to relate the admissible limits of activity release to equivalent standardized leakage rates.

Releasable radioactive material might be in the form of gas, liquid, solid particles, or a combination of these, and can be released through leaks or, in case of DPC with elastomeric seals, by permeation. Miscellaneous models are available for different leak designs and types of fluid. The ‘one capillary leak model’ has become accepted in the field of package design testing [64]. The maximum permissible activity release rate can be expressed in terms of a maximum permissible capillary leak diameter. The following equations describe the flow rates through a capillary.

(1) Gas flow

The modified Knudsen equation is valid for the whole range of molecular, transitional, and viscous laminar gas flow.

$$Q = \frac{\pi}{128} \cdot \frac{D^4}{\mu \cdot a} \cdot \frac{(p_u^2 - p_d^2)}{2} + \frac{\sqrt{2\pi}}{6} \cdot \sqrt{\frac{R \cdot T}{M}} \cdot \frac{D^3}{a}$$

where
Q *is leakage rate [Pa m³ s-1];*
a is capillary length [m];
D is capillary diameter [m];
M is relative molecular mass [kg mol^{-1}];
p_d is downstream pressure [Pa];

p_u is upstream pressure [Pa];
R is universal gas constant [$8.31 \cdot mol^{-1} K^{-1}$];
T is temperature [K] (fluid);
μ is dynamic viscosity of the fluid [Pa s].

In addition to gas, particles could be released, but below a standardized leakage rate of $Q_{SLR} < 10^{-4}$ Pa m^3 s^{-1} the release of fuel or crud particles is negligible due to a choking of the capillary [65].

(2) Liquid flow

Poiseuille's law is applied for the flow of liquids through a capillary:

$$L = \frac{\pi}{128} \cdot \frac{D^4}{\mu \cdot a} \left(p_u - p_d\right)$$

where
L is liquid leakage rate [m^3 s^{-1}].

A DPC design at conventional temperature and pressure conditions is considered to be liquid-tight below a standardized leakage rate of $Q_{SLR} = 10^{-5}$ Pa m^3 s^{-1} [66].

(3) Permeation

Permeation of radioactive gases through metals is negligible for release calculation [67]. If elastomeric seals are used, gas permeation is an additional release pathway:

$$Q_P = P \cdot \frac{A}{l} \cdot \Delta p$$

where
Q_P is permeation rate [Pa m^3 s^{-1}];
P is coefficient of permeation [m^2 s^{-1}];
Δp is partial pressure difference [Pa];
l is thickness of the permeable material [m];
A is area of the permeable material normal to the gasflow [m^3].

The DPC designer has to demonstrate that the design leakage rates specified for the miscellaneous conditions do not exceed the maximum permissible standardized leakage rates. References [, 69] provide the basis for the calculation.

There are seven substantial steps to determine:

1. Total releasable activity;
2. Equivalent A_2;
3. Permissible activity release rate;

4. Activity release due to permeation;
5. Maximum permissible volumetric leakage rate;
6. Maximum permissible equivalent capillary leak diameter;
7. Permissible standardized leakage rate.

2.4.4.3. Design leakage rates

Design leakage rates identify the efficiency limits of the containment system under NCT and ACT and normal, off-normal, and accident conditions of storage, and are deduced from tests with real DPC packages, DPC models, or DPC components (e.g. flange assemblies). Component tests are important for the demonstration of the worst case conditions and for statistical validation.

Impact loads (see Table 6 for off-site transport resulting from the regulatory mechanical and thermal tests) can result in deformations, displacements or degradation (or combination of these) of DPC components involving an unloading and/or a movement of the lids and/or seals as a result of rotation or lateral sliding. The leakage rate can increase as a consequence.

TABLE 6. EXAMPLE OF IMPACTS TO BE CONSIDERED FOR OFF-SITE TRANSPORT THAT CAN INFLUENCE THE LEAKTIGHTNESS OF THE CONTAINMENT SYSTEM

IAEA Transport Regulations SSR-6 (Rev. 1) [1]	**Loadings to be Considered**
RCT Paras 613 and 616	• Acceleration in radial, axial, and vertical directions; • Operational temperature and pressure.
NCT Paras 722 to 724	RCT and • Free drop from a height of 0.3 m (mass ≥15 t); • Five times the maximum weight (during 24 hours); • 6 kg steel bar drop from the height of 1 m; • Maximal normal operating pressure and temperature.
ACT Paras 726 to 730	RCT, NCT and combination of: • Free drop from a height of 9 m; • 1 m puncture test; • 800°C, 30 min thermal test separately; • Water immersion test (including 200 m).

(1) Metallic seals

A specific leakage rate (depending on the type of metallic seal) that attests the regular assembly status (leaktightness) has to be demonstrated by a leakage test after assembling of the closure system after loading and before any transport, or the containment function has to be demonstrated by other means (e.g. taking into account monitoring).

This specified leakage rate has to be accepted for normal operation during storage and RCT.

Off-normal operation, storage related accidents / NCT and ACT: For NCT and ACT the design leakage rates depend on the test safety assessment results.

The vertical 0.3 m drop (package mass ≥15 t) under NCT can cause short term elastic deformation of the bolts that can lead to a short time relaxation of the lid flange. Component tests have shown that after a repeated compression, provided that no seal dislocation occurs, the specified leakage rate is achievable again [70].

Leakage rates measured after a repeated compression including a seal displacement (rotation) are considerably higher [70]. For implementing the specified leakage rate as design leakage rate for NCT, DPC designers need to demonstrate that there is a sufficient compression load on the seal at any time during the drop event to prevent a movement of the seal. Otherwise the higher values have to be used.

The design leakage rates for ACT for DPC designs need to be deduced using, for example, measurements after drop tests with DPC models, numerical analyses of influences of thermal impacts, component tests simulating a lateral and a radial seal displacement, or other similar methods.

Mechanical and thermal safety analyses have to be used to determine the maximum widening between the flange surfaces of the sealing system which can be caused, for example, by deformation of bolts, bending of the lid and/or the DPC body flange, or by dissimilar thermal expansion of lid and DPC body material (due to different coefficients of thermal expansion or inhomogeneous heating under thermal impact). For RCT it is important that such widening does not exceed the useful elastic recovery of the seal, called r_u, because the efficiency of the seal is exhausted above this range. A gap greater than r_u will cause the standardized leakage rate to exceed specifications.

Specified NCT and ACT design leakage rates can only be accepted if the possible widening after impact loading is smaller than r_u (a short-term decompression above r_u is possible). Figure 6 illustrates the useful elastic recovery of r_u.

DPC designers are required to consider the influence of temperature and time to justify conservative r_u values.

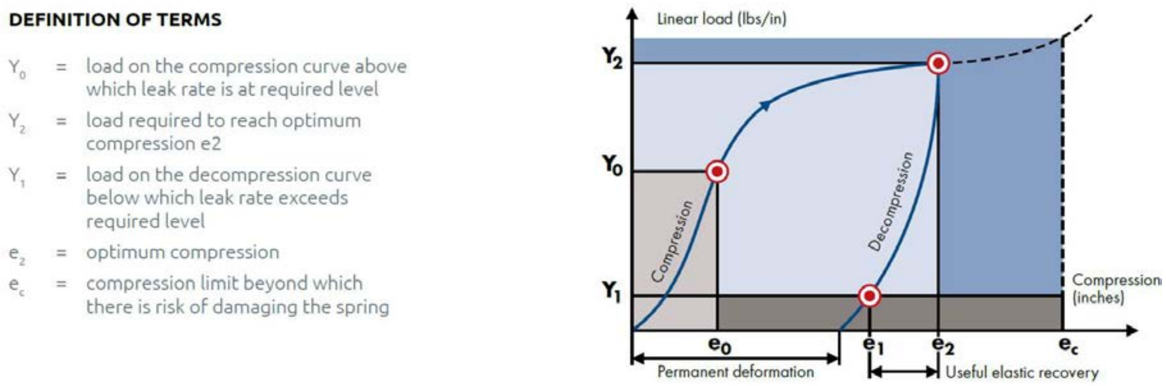

FIG. 6. Compression and decompression cycle of the Helicoflex seal for illustration of the useful elastic recovery ($r_u = e_2$-e_1). Reproduced courtesy of Technetics Group [71].

(2) Elastomeric seals

Elastomeric seals show a very advantageous behaviour under mechanical stresses and are able to compensate for flange dislocations over a wide range of deformations. The design leakage rate when using elastomeric seals is mainly limited by permeation.

A critical point for these seal materials is their behaviour at low temperatures and the limited lifetime at high temperatures (see also Section 1.7). DPC designers have to justify the critical low temperature for failure and lifetime at high temperature when using new mixtures of elastomeric materials.

2.4.4.4. Source term

Spent fuel rods contain radionuclides in the form of gas, volatiles, and fuel particles, which are only releasable through a breach in the cladding. Additional particles known as Chalk River Unidentified Deposit (CRUD), on rods surfaces can contribute to the releasable content.

The activities of the radionuclides, which have to be considered for release calculation, can be calculated by using a computer program, such as ORIGEN [72] or ORIGEN-ARP from the Scale code package [73]. The calculations of the activities of the radionuclides need to lead to the maximum quantities of releasable radionuclides (in terms of A_2). The calculation case to determine the source term for the release analysis could thus be different from the case to determine the source term for the external dose rate calculation.

The release of activity from the fuel rods into the DPC internal cavity depends on the chemical and physical properties of the radionuclides, the fuel characteristics, the conditions of the cladding tubes and on the amount and properties of CRUD.

Based on experiments and examinations, conservative values for the prediction of the source term for leakage rate calculation were deduced in Ref. [74] (Table 7).

TABLE 7. RELEASE FRACTIONS USED TO PREDICT THE SOURCE TERM FOR RELEASE CALCULATIONS FROM SPENT FUEL TRANSPORT PACKAGES [74]

Release fractions		**NCT**	**ACT**
Fraction of gases released due to a cladding breach	f_G	0.3	0.3
Fraction of volatiles released due to a cladding breach	f_V	2×10^{-4}	2×10^{-4}
Fraction of fuel fines released due to a cladding breach	f_F	3×10^{-5}	3×10^{-5}
Fraction of CRUD that spalls off of rods	f_C	0.15	1.0
Fraction of rods developing cladding breaches	f_B	0.03	1.0

These values are determined for burnups of 33 to 38 GWd/tHM. In recent years, fuel is being driven to burnups of 65 GWd/tHM or higher. DPC designers are requested to investigate the possible influence of a higher burnup and other parameters on the release fractions and to justify the release fraction used for their specific cases.

(1) Release fraction of gases and volatiles

The generation of ^{85}Kr and ^{3}H dominates the gas release and is proportional to the burnup. The release of fission gases from fuel occurs through grain boundaries and depends on temperature and fuel microstructure. The release fraction increases disproportionally with a higher burnup. Measurements have shown that a fraction of 30% is still a conservative value up to a burnup of 100 GWd/tHM. For a burnup of 80 GWd/tHM, a release fraction of 15% is justifiable [75].

For volatiles, dominated by ^{137}Cs, ^{134}Cs, ^{106}Ru, and ^{90}Sr, a release fraction of 0.02% is acceptable as conservative estimate even for higher burnup considering the very low vapour pressures of the relevant isotopes.

(2) Release fraction of particles

Changes in the fuel characteristics after a higher burnup can affect the particle size distribution. Also the amount and the characteristics of CRUD fines are impacted by higher burnups. Design leakage rates of spent fuel transport and storage casks equipped with metal seals are, in most cases, small enough to prevent particle release.

(3) Fraction of rods developing cladding breaches

The number of rods developing cladding breaches is a very important parameter for the release calculation. Such breaches enable not only the release of gas, volatiles, and fuel particles into the DPC interior, but also an increase of the internal cavity pressure. In this context, cladding breaches imply only fine cracks, in contrast to the criticality assessment domain where more extensive damages such as fuel rod ruptures are of main interest.

Higher burnups cause a higher cladding material embrittlement due to the uptake of hydrogen and a higher tendency for hydride reorientation, as well as a growing oxide layer and coalescences of fuel and cladding material.

Due to the lack of experimental results, the failure rate of fuel rods cladding under ACT for the containment assessment is assumed to be 100%. Until now there was no need for a more detailed examination with reduction of the failure fraction for ACT in mind because the release calculations for most of the DPC designs show a sufficient margin to the required level. The influence of the degraded rods properties due to higher burnups on the failure probability of the cladding under NCT, for example after a 0.3 m drop, is still an open question.

DPC designers are requested to present additional evidence supporting a conservative value of the fraction of rods developing cladding breaches under NCT. In case of a lack of additional analysis, the number of higher burnup spent fuel assemblies permitted for one loading has to be limited to ensure a sufficient safety margin in calculation. For very high burnups an encapsulation of the fuel rods could be requested.

The assessment for storage may be based partially on assessment for transport, but the following also need to be considered:

(a) Components of the containment system may be different (e.g. two lids).

(b) Normal conditions (e.g. temperature, pressure) may be different for storage.

(c) Accident conditions depend on the storage facility and DPC configuration (aircraft crash, no shock absorbers, etc.) and are different from transport conditions.

(d) Permanent monitoring takes place for many designs, and there is equipment and instructions for the case of leakage (using this methodology could be an additional option to limit the activity release under normal conditions).

(e) Ageing of DPC components (Section 1.7).

(f) Changes of the fuel assembly characteristics (radionuclides composition, cladding, release of activity) during storage.

(g) Pressure increase and radiolysis in the DPC during storage.

2.4.4.5. Other guidance

References [68, 69], and Ref. [5], paras 657.5 to 657.13 provide additional activity release calculation and leakage rate measurement guidance.

2.5. EXTERNAL DOSE RATES ANALYSIS

2.5.1. Reference to DPC design for dose rates analysis

DPC designers have to reference according to Section 2.1.1 the DPC design and a description of its contents.

2.5.2. Assumptions for dose rates analysis

The external dose rates have to be calculated for normal operation, off-normal operation, and accidents. Reference [1] provides the required off-site transport conditions to be analysed. According to SSR-6 (Rev. 1), analysis is required for RCT (incident free), NCT (including minor mishaps), and ACT, each defined by testing conditions. For on-site transport and storage, the conditions to be addressed have to be taken from the analysis of the operational conditions, incidents, and accidents that must be considered for these activities as described in Section 1.5.2.

The basic condition of the DPC package for the given step in the operational scenario needs to be taken from the history of the fuel and the DPC as described in Section 1.5.1 including irradiation of the fuel and all ageing processes of the DPC, its inserts, and the fuel after loading (Section 1.7). Then, based on this state for the assessment conditions given above, the influence on the properties of the DPC, the inserts, and the fuel elements has to be determined (refer to Sections 2.2 and 2.3). The mechanical and thermal impact conditions (DPC package orientation during testing, temperatures, etc.) have to be selected to lead to the worst configuration (highest dose rates). These conditions may differ from those leading to the most severe situation regarding activity release or criticality safety; therefore, these conditions have to be carefully selected and justified in the DPCSC.

Basic information for the assessment of the external dose rates is the:

(1) Source term of the DPC contents taking into account the integrity of the spent fuel (including cladding) and internal components (basket, inner container, etc.);

(2) DPC shielding components integrity.

External dose rates limits have to be taken from international or national regulations or acceptance criteria given by the competent authorities.

Reference [1] defines off-site transport criteria, including dose rate limits for a single DPC package, as well as dose rate limits for the surface and the surrounding area of the conveyance. As it is usually difficult to meet the limits for the conveyance later by additional shielding (need for heat transfer) or distances (conveyance size limits) DPC designers are recommended to take into account the conveyance limits in the DPC design phase. The assessment of the dose rate and dose rate increase ratio for RCT, NCT, and ACT need to assume a radioactive content that would create the maximum dose rate at the surface of the DPC at distances defined in the regulations.

For on-site transport and storage, the dose rate criteria have to be derived according to national regulations specifically applied for the storage site for the public and workers (Section 1.6).

2.5.3. Description and validation of calculation method for dose rates analysis

Dose rates have to be calculated for RCT, NCT, and ACT and normal operation, off-normal operation, and accident conditions of storage.

The selection or calculation of the radiation source term for a DPC package has to be based on a bounding case of the radioactive inventory of the spent fuel assemblies (including structural materials) and the activated materials of the DPC.

A computer program usually calculates external dose rates. The computer program used has to be suitable and accurately specified. The main features of the program have to be described.

Dose rate calculation methods have to be qualified and validated for the specific conditions of the DPC package to which they are applied (Section 2.1.2). One possible method of validation is to compare dose rate calculations against DPC package measurements.

Dose rate calculations have to take into account current ICRP recommendations [76].

2.5.4. Dose rate calculations

The assessment of the dose rate and dose rate increase ratio have to assume a radioactive content that would create the maximum dose rate at the surface of the DPC and at distances defined in the regulations.

The modelling of the shielding components and sources has to be fully described in the DPCSC for all cases analysed.

Dose rate analyses have to take into account:

(1) Dose rate analysis has to be performed in such a way that specific DPC surface areas with maximum dose rates are identified and analysed (e.g. trunnion areas, areas containing gaps that give rise to radiation streaming, areas adjacent to reduced shielding, and other areas with the potential of increased dose rates due to DPC design).

(2) Based on dose rate analysis, the maximum radioactive contents of the DPC have to be justified (or limited) by various methods and parameters (e.g. nuclide specific activity values, nuclide specific source terms for gamma and neutron emitters, minimal cooling time, and others), as appropriate.

(3) Burnup axial profile has to be conservatively taken into account for neutron and gamma sources along the shielding model, as applicable.

(4) Geometry of the modelled source term of the DPC contents has to take into account a structural integrity assessment of the spent fuel (including cladding) and internal components (basket, inner container, etc.). Based on this assessment, possible relocation of the contents has to also been taken into account.

(5) DPCSC has to correctly include the secondary gamma radiation from neutron sources in the dose rate analysis.

(6) Radiation from activated materials from fuel assembly components (e.g. top and bottom nozzles) and from inserts (e.g. control rods, thimble plugs) has to be taken into account and appropriately modelled.

(7) If measurements are applied to demonstrate compliance with the dose rate limits, then representative radiation sources have to be selected, as well as appropriately calibrated dose rate measuring techniques used for gamma and neutron radiation.

(8) The expected areas for peak dose rates to be checked before shipment (Section 1.9) have to be derived from the results of dose rate calculation to ensure compliance with transport regulations.

(9) The integrity of the DPC shielding components and their behaviour under normal and accident conditions have to account for the structural, thermal, and ageing analyses. For example, if applicable:

    (a) Consider thermal response of materials providing radiation protection under fire conditions;

    (b) Provide the possible effects due to lead slump after mechanical impact, taking into account the temperature of the lead.

For storage, the following would also be considered:

(1) Degradation of the shielding components with time (e.g. ageing of neutron shielding material; Section 1.7);

(2) The storage configuration may differ from transport configuration (e.g. additional shielding);

(3) The modelled source term depends on time in storage.

2.6. CRITICALITY SAFETY ANALYSIS

2.6.1. Reference to DPC design for criticality safety analysis

The design of the DPC and the description of the contents need to be referenced according to Section 2.1.1. If burnup credit is used in the demonstration of criticality safety, all necessary information about the irradiation conditions has to be included as mentioned in Section 2.1.1.

2.6.2. Assumptions for criticality safety analysis

The criticality safety has to be demonstrated for RCT, NCT, and ACT and normal operation, off-normal operation, and accidents during storage. For off-site transport, the conditions to be analysed are given in Ref. [1]. According to Ref. [1], analysis is required for RCT (incident free), NCT (including minor mishaps), and ACT, each defined by testing conditions. For on-site transport and storage, the conditions to be addressed have to be taken from the analysis of the operational conditions, incidents, and accidents that must be considered for these activities as described in Section 1.5.2.

The basic condition of the DPC package for the given operation has to be taken from the history of the fuel and the DPC as described in Section 1.5.1, including irradiation of the fuel and all ageing processes of the DPC, its inserts, and the fuel after loading (Section 1.7). Based on this state, DPC designers have to determine the influence of the assessment conditions given above on the properties of the DPC, the inserts, and the spent fuel (Sections 2.2 and 2.3). The mechanical and thermal impact conditions (DPC package orientation during testing, temperatures, etc.) have to be selected to lead to the most reactive configuration. These conditions may differ from those leading to the most severe situation regarding activity release or dose rate calculation; therefore, these conditions need to be carefully selected and justified in the DPCSC.

It is very important to determine the amount of water that can leak into the DPC and be accumulated in its void spaces. As an example, Ref. [1] requires such assumption in assessment of an individual package in isolation for off-site transport. Avoidance of water leakage into the DPC, i.e. water exclusion, can only be assumed when:

(1) The design incorporates at least two high standard water barriers (which remain watertight during the tests for NCT, followed by the tests for ACT and including an immersion under 0.9 m of water for 8 hours) to prevent such leakage, even as a result of error.

(2) A high degree of quality control in the manufacture, maintenance, and repair of the DPC and its inserts is demonstrated.

(3) Tests to demonstrate the closure of each DPC package before each shipment are specified.

According to Ref. [5], para. 680.2, leakage criteria for 'water tightness' need to be set in the DPCSC, and accepted by the competent authority. These criteria have to be demonstrated to be achieved in the tests, and achievable in the production models.

For on-site transport and storage, the moderation conditions to be taken into account have to be derived from national regulations and the analysis of the operational conditions, incidents, and accidents.

As unmoderated low-enriched uranium is always subcritical, the presence or absence of water in the cavity of a DPC has an extremely high impact on criticality safety. A failure in the design phase to determine the most severe accident conditions leading to water ingress into the cavity may result in unacceptably strong neutron multiplication in case of an accident (e.g. if the criticality safety assessment assumed water exclusion, and neutron absorbers or other features for preventing criticality were not included in the design). It is therefore recommended to assume water ingress in the criticality safety demonstration for all cases, even if not required by the regulations.

If more than several grams of water are to be assumed in the DPC cavity, the behaviour of the inserts (for instance, degradation of neutron absorbers) and the fuel are very important for the criticality safety assessment. If water in-leakage is not to be taken into account, it may be possible to demonstrate criticality safety independently from the condition of the inserts and fuel. This may be a solution for cases where it is difficult to describe the behaviour of the fuel in accident conditions due to ageing.

Criticality safety for DPC packages needs to be demonstrated by calculating the effective neutron multiplication factor (k_{eff}) of a single DPC package and arrays of DPC packages in the conditions defined above. Criteria for k_{eff} limits have to be taken from national regulations or acceptance criteria given by the competent authorities and have to consider uncertainties, conservatism, and margin of safety. Reference [5], paras. VI.35–VI.38 and Ref. [14] provide k_{eff} acceptance criteria guidance.

2.6.3. Description and validation of the calculation method for criticality safety analysis

DPC package criticality safety has to be demonstrated by calculating the effective neutron multiplication factor for a single DPC package and arrays of DPC packages for RCT, NCT, and ACT and normal operation, off-normal operation, and accident conditions of storage. Such calculations are usually done using computer programs.

The computer programs used have to be accurately specified (including the cross section data library used and, for example, the modules used for the calculations). The main features of the program need to be described.

The validation of the computer program for application to the DPC design under consideration has to be demonstrated. The validation has to be based on calculations for a sufficiently large database of critical and subcritical experiments. The experiments need to be similar to the DPC design parameters, materials (fuel composition, DPC insert materials, DPC materials, etc.), and neutron spectra (taking into account the moderation ratios of the different configurations of the DPC and its contents). The validation has to lead to the calculation of an upper safety limit for k_{eff}. Reference [5], paras. VI.22 – VI.29, and Ref. [77], Chapter 4 provide advice regarding the validation. Reference [78] collects a large database of critical and subcritical experiments. Reference [79] provides advice on how to select suitable experiments and how to check their similarity.

For situations when the qualification database is not applicable (due to missing or insufficient data) DPC designers may have to use conservative calculation methods and assumptions to provide margins of safety to compensate for the lack of data.

2.6.4. Criticality safety calculations

Criticality safety has to be demonstrated for all operational scenarios planned for the DPC package (Section 1.5.1). The criticality safety demonstration needs to consider the conditions described in Sections 2.6.1 to 2.6.3.

The criticality safety demonstration must analyse (according to Ref. [1], para. 688) a single DPC package reflected by at least 20 cm of water, as well as arrangements of several DPC packages. Reference [1] specifies the hypothetical arrays of (identical) DPCs to be considered by the DPC designer for off-site transport. For storage, the arrangements to be considered would be taken from applicable regulations and the layout of the storage site including the analysis of the operational conditions, incidents, and accidents. If different DPC designs or contents are present at the storage site, their possible interaction needs to be analysed (for DPC packages with thick walls made from iron or steel, the interaction between different DPC packages can usually be neglected, but nevertheless this case needs to be analysed). The arrangements to be taken into account for on-site transport are site specific and need to adhere to the regulations for such operations.

Moderation conditions play an important function in the criticality analysis and unless moderator exclusion is assumed (Section 2.6.2), the DPC designer has to consider optimum moderation in each calculation, including complete, partial, and preferential (limited to the conditions possible during credible accident scenarios) flooding of the DPC.

For some specific DPC designs, if the interaction between DPC packages close to each other cannot be neglected, the optimum moderation conditions of an array of DPC packages could be different from the optimum moderation conditions for the single DPC package. Moderation conditions between DPC packages and within the DPC packages have to be analyzed.

It is important to verify that storage and transport criticality safety assessments are based on the correct configurations, which are usually different for the different operations and scenarios (aircraft impact, shock absorbers, etc.).

The following typical items, if applicable, would be considered in the criticality analysis (however, this list is not exhaustive — see also Ref. [5], Appendix VI):

(1) Justification of the criticality analysis needs to account for all possible physical and geometric configurations (dimensional tolerances, positions of the components, etc.).

(2) Usually k_{eff} increases in cases of fuel rod lattice expansion and may increase by axial shifting of fuel rods and collection of fuel released from broken fuel rods in free space in the DPC cavity. Such configurations need to be carefully considered.

(3) If natural or depleted uranium could be present in the fuel elements, it needs to be taken into account in the criticality safety justification with appropriate assumptions relative to quantities and location of the uranium within the DPC.

(4) For DPC packages for which subcriticality is demonstrated without considering the ingress of water into the cavity under ACT and accident conditions of storage, the criticality safety of a single DPC package under RCT, NCT, and normal operation conditions of storage with water ingress needs to be demonstrated to cover possible situations (including human error).

(5) Consequences of human error/accidents during loading on conditions of the DPC and its contents need to be considered (for example, an erroneously loaded assembly with higher enrichment or lower burnup if burnup credit is taken into account).

(6) All structural materials that could increase the neutron multiplication need to be taken into account.

(7) Rearrangement, degradation, loss of efficiency, and depletion of neutron absorber material need to be taken into account (see also ageing in Section 1.7).

In contrast to the classic approach to criticality demonstration assuming unirradiated fuel, a second approach (burnup credit) may be used when considering a more realistic fuel reactivity under certain conditions, including the selection of nuclides and burnup conditions, computer programs, and isotopic validations.

Information on the use of burnup credit in criticality safety assessments of spent fuel can be found in publications from the NEA WPNCS Expert Group on Burnup Credit Criticality Safety (see the list of references including IAEA meetings on this topic at http://www.nea.fr/html/science/wpncs/buc/index.htm)

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DEFINITIONS

Definitions specific to this publication are listed below:

(1) *Acceptance criteria*: Specified bounds on the value of a functional indicator or condition indicator used to assess the ability of a structure, system, or component to perform its design function. All the measures for assessing the ability of the DPC to perform its functions, which consist of quantitative regulatory limits of the functional performance criteria, fuel acceptance criteria and requirements from the facility design.

(2) *Ageing management programme (AMP)*: A programme conducted by the DPC storage operator for addressing ageing effects that may include prevention, mitigation, condition monitoring, and performance monitoring.

(3) *Controlled document*: A document that is approved and maintained. It has to be signed, dated, and has to include the revision state. The numbers of pages and annexes have to be identified. Changes between document revisions need to be clearly marked.

(4) *Design drawing*: A controlled engineering drawing that indicates geometrical or other parameters of the packaging components that have an effect upon the package design safety assessment.

(5) *Dual purpose cask (DPC)*: The assembly of components (packaging) necessary to fulfill the safety functions for transport and storage of spent fuel.

    (a) 'Dual purpose' means the purposes for transport and storage, but not for disposal (i.e. 'multipurpose' is out of scope of this report).

    (b) Configurations of the DPC for transport and for storage may differ. For example, a DPC for transport may be fitted with impact limiters, while a DPC for storage may be fitted with an additional lid or a monitoring system.

    (c) 'DPC package' means DPC with its contents.

(6) *DPC designer*: The person or organization responsible for the design of the DPC; each DPC design would have only one DPC designer.

(7) *DPC safety case (DPCSC)*: A collection of arguments and evidence in support of the safety of the DPC.

    (a) The scope of the dual purpose cask safety case (DPCSC) is limited to the DPC.

    (b) A safety case for the DPC storage system consists of the DPCSC and distinct safety case for the storage facility.

(8) *Gap analysis*: A gap analysis for a DPCSC is an assessment of the state of technical knowledge, standards, and regulations regarding safety functions of structures, systems and components. A gap analysis i) lists characteristic factors, such as the state of technical knowledge, regulations, and standards, of the safety case, ii) evaluates the effect of changes

of technical knowledge, standards, and regulations on the safety of the DPC package, and then iii) highlights the existing gaps that need to be filled.

(9) *Long term storage*: This definition follows SSG-15, Annex I (i.e. storage beyond approximately fifty years and up to approximately one hundred years).

(10) *Normal, off-normal, and accident conditions of storage or handling*: Conditions during storage or handling in the nuclear facilities to which the DPC is designed.

(a) *Normal conditions of storage/handling*: The maximum level of an event or condition expected to routinely occur.

(b) *Off-normal conditions of storage/handling*: The maximum level of an event that, although not occurring regularly, can be expected to occur with moderate frequency and for which there is a corresponding maximum specified resistance, limit of response, or requirement for a given level of continuing capability.

(c) *Accident conditions of storage/handling*: The extreme level of condition, which has a specified resistance, limit of response, and requirement for a given level of continuing capability, which exceeds off-normal conditions.

Relations among the operational and accident states of transport and storage are illustrated as follows:

Conditions of transport		
Routine conditions	Normal conditions	Accident conditions
Conditions of storage or handling		
Normal operation	Off-normal operation	Accident conditions

(11) *Routine, normal, and accident conditions of transport*: Conditions specified in IAEA Regulations for the Safe Transport of Radioactive Material, SSR-6 (Rev. 1) to apply a graded approach by which to specify the performance standards, and are characterized in terms of three general security levels:

(a) Routine conditions of transport (incident free);

(b) Normal conditions of transport (minor mishaps);

(c) Accident conditions of transport.

(12) *Short term storage*: This definition follows SSG-15, Appendix I (i.e. storage up to approximately fifty years).

(13) *Storage period*:

For the DPC package, a period designed to store spent fuel.

For the storage facility, a period designed to store DPC packages.

(a) In these guidelines the term ‘storage period’ is commonly used for the storage facility and for the DPC package.

(b) When distinction is needed, the terms ‘the storage period for facility’ or ‘the storage period for DPC’ may be used.

(c) For the DPC, the storage period starts when the spent fuel is first loaded.

(d) The termination of the operation of the DPC package generally means the unloading of spent fuel from the DPC package.

(e) For the storage facility, the storage period starts when the first DPC package is received, and ends when the last DPC package is transported from the facility.

ABBREVIATIONS

ACT	-	accident conditions of transport
AMA	-	ageing management activity
AMP	-	ageing management programme
CRUD	-	Chalk River unidentified deposit
DPC	-	dual purpose cask
DPCSC	-	dual purpose cask safety case
GALL	-	generic ageing lessons learned
k_{eff}	-	effective neutron multiplication factor
LMP	-	Larson-Miller parameters
NCT	-	normal conditions of transport
NUSSC	-	Nuclear Safety Standards Committee
RASSC	-	Radiation Safety Standards Committee
RCT	-	routine conditions of transport
SCC	-	stress corrosion cracking
SSC	-	structure, system, or component
TLAA	-	time-limited ageing analysis
TRANSSC	-	Transport Safety Standards Committee
WASSC	-	Waste Safety Standards Committee

ANNEX

EXAMPLE FOR THE HOLISTIC APPROACH OF A DPCSC FOR AN OPERATIONAL SCENARIO

This example is based on the Japanese holistic approach of combining package design approval renewal, storage license for a storage period of up to 50 years, and inspections before shipments to storage, during storage, and prior to shipment after storage.

This example describes the complete operational scenario from loading the DPC inside nuclear power plant up to transport from an off-site storage facility without a spent fuel retrieval facility.

The sequence of operational steps for the scenario is as follows:

(1) DPC preparation for off-site transport;

(2) Off-site transport (before storage);

(3) Handling at storage facility (before storage);

(4) Storage (off-site);

(5) Handling at storage facility (after storage);

(6) Off-site transport (after storage);

(7) DPC unloading.

A proposed holistic approach to guarantee the safety of transport after storage creates such an operational scenario [A–1–A-3] consists of the following concepts.

(1) The safety of storage (item (4) relies on the proper preparation of the DPC and safe transport of the DPC to the storage facility, as well as maintenance of the DPCSC and inspections of the DPC safety functions during storage.

  (a) The continued integrity of spent fuel contained into the DPC is ensured by confirming its initial integrity at the nuclear power station before loading, its proper loading into the DPC, and its safe transport to the storage facility.

  (b) To do so, the nuclear power plant operator is required to properly prepare the DPC (including proper loading of the spent fuel), to provide the record of the operation (specification of the spent fuel loaded including irradiation conditions and records of the loading process and the record of the inspection before shipment), and to provide the record to the storage facility operator.

  (c) During storage the DPCSC is updated by gap analyses when regulations or technical knowledge change, and the DPC safety functions are verified by inspections.

(2) Maintenance and update of the transport package design approval of the DPC during storage relies on maintaining the DPC safety functions during storage, and on performing gap analyses on the DPCSC when regulations or technical knowledge change.

    (a) The transport package design approval has to be maintained and updated (renewed) during the storage period.

    (b) Safety functions of the DPC as a transport package rely on the safe storage and inspections related with ageing.

    (c) To ensure this, the storage facility operator is required to conduct proper monitoring and inspection of safety functions of the DPC over the storage period and to maintain proper records including the records provided by the nuclear power plant operator.

    (d) Compliance with the regulatory requirements for transport is maintained by gap analyses when regulations or technical knowledge including standards change.

(3) The safety of off-site transport after the storage (item (6) above) relies on the safe storage in the storage facility.

    (a) Though all of DPC safety functions and integrity of spent fuel cannot be inspected directly by visual inspection when initiating transport, these inspections can be supplemented by confirming records from a well-organized inspection programme.

    (b) The transport operator who owns the transport package design approval for the DPC can substitute periodic inspections of transport packaging with records provided and confirmed by the storage facility operator.

    (c) Therefore, the safety of transport after storage can be guaranteed without direct inspection and confirmation of DPC internals and spent fuel integrity (by opening lids) by delivering and maintaining DPC fabrication and inspection records for the proper preparation at the nuclear power plant, safe transport from nuclear power plant to the storage facility, and safe storage at the facility.

(4) The consistent safety of the DPC storage system, from DPC fabrication to its transport after storage, is secured by holistic regulatory control by concerned competent authorities.

    (a) The competent authority has to review the application for transport package design approval to ensure safety considering not only to the transport from the nuclear power plant to the storage facility, but also to the transport after storage, and to confirm that the DPC maintains its safety functions for transport as stipulated by regulations. The DPCSC described in this guidance serves as a sound basis for such regulatory approval because it follows the full operational scenario, including all dependencies between the steps regarding the safety functions.

    (b) Nuclear power plant operator, storage facility operator, and transport operator responsibilities for DPC shipment and receipt are required to be defined.

Figure A-1 illustrates the regulatory control and inspections framework for spent fuel transport and storage. Table A-1 lists and Figure A-2 provide examples of inspection items and methods necessary to maintain transport functions during storage [A-4].

Conventionally, transport package design approvals and licenses for storage are issued separately under independent review of independent safety analyses and for different licensing periods. The new approach described in this guidance, however, enables licensing of all operational steps, including off-site transport after storage by activities of competent authorities based on a single combined safety case.

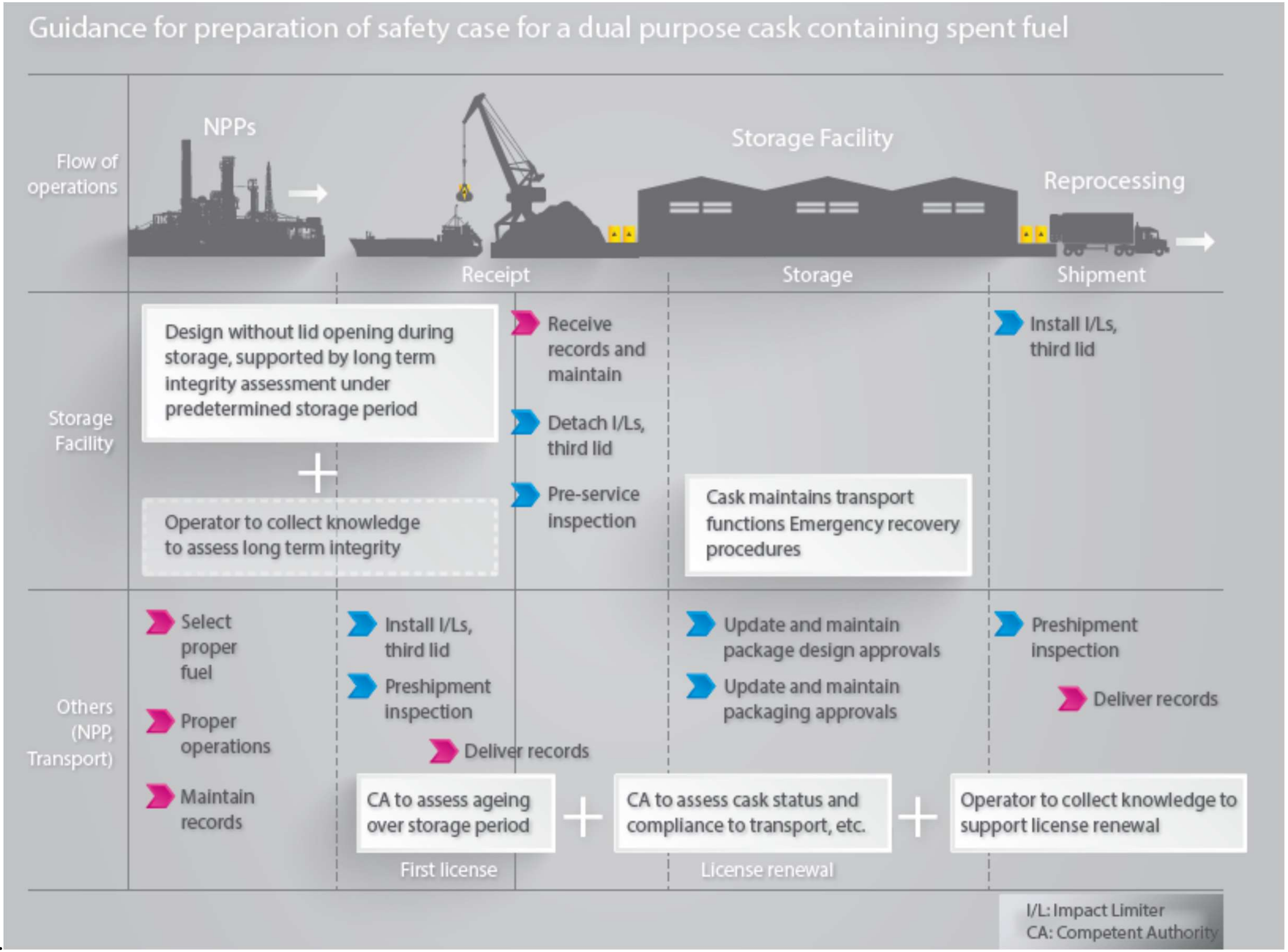

FIG. A-1. Example of management of licensing and inspections in spent fuel transport and storage.

TABLE A-1. EXAMPLE OF INVESTIGATION ITEMS TO BE CONDUCTED AT THE INSPECTION BEFORE TRANSPORT

Inspection Items	Inspection Method	
	Transport before Storage	**Transport after Storage**
1. External Appearance	Visually inspect the packaging containing spent fuel for anomalies.	
2. Leaktightness	Test the double sealing systems of second and third lids for leak rate.	
3. Pressure Retaining	1) Investigate the amount of residual water in the packaging; 2) Record the amount of inert gas; 3) Measure the initial pressure of the gas introduced into the packaging.	1) Investigate the amount of residual water in the packaging; 2) Record the amount of inert gas; 3) Measure the initial pressure of the gas introduced into the packaging.
4. Dose Rate	Measure the packaging containing the spent fuel for gamma dose rate and neutron dose rate using survey meters.	
5. Subcriticality	Visually inspect the basket installed in the DPC for anomalies.	Visually inspect the basket installed in the DPC for anomalies.
6. Temperature Measurement	Measure the readily accessible packaging external surface temperature.	
7. Lifting	Visually inspect the trunnions and the adjacent areas for anomalies after lifting the packaging.	
8. Weight	Calculate the total weight of the packaging and the contents from the manufacturing and loading records.	
9. Content	1) Visually inspect the content for anomalies.	1) Visually inspect the content for anomalies.
	2) Review documents to check for the data of the fuel contained in the packaging.	
10. Surface Contamination	Inspect the package surface contamination density using the smear method.	

* Records include monitoring data of pressure between lids, DPC surface and storage facility building temperature, dose rate near DPC, and external appearance inspection records of DPC.

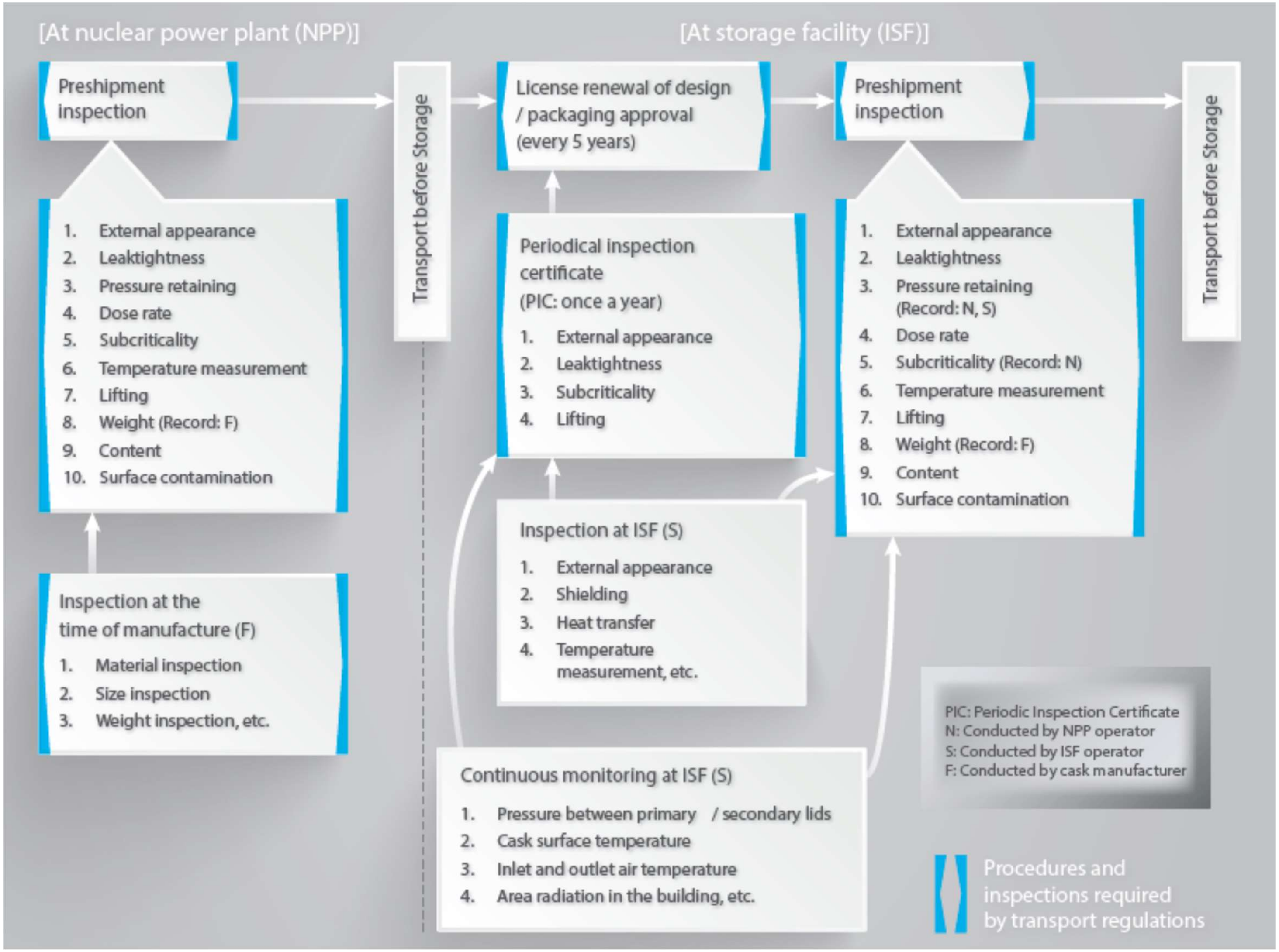

FIG. A-2. Schematic diagram of a series of investigations required for dual purpose casks prior to transport. Reproduced courtesy of T. TAKAHASHI [A-4].

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