GERMAN APPROACH FOR THE TRANSPORT OF SPENT FUEL PACKAGES AFTER INTERIM STORAGE

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Abstract

In Germany the concept of dry interim storage of spent nuclear fuel in dual purpose metal casks is implemented, currently for periods of up to 40 years. The casks being used have an approved package design in accordance with the international transport regulations. The license for dry storage is granted on the German Atomic Energy Act with respect to the recently (in 2012) revised "Guidelines for dry cask storage of spent nuclear fuel and heat-generating waste" by the German Waste management Commission (ESK) which are very similar to the former RSK (reactor safety commission) guidelines.For transport on public routes between or after long term interim storage periods, it has to be ensured that the transport and storage casks fulfil the specifications of the transport approval or other sufficient properties which satisfy the proofs for the compliance of the safety objectives at that time. In recent years the validation period of transport approval certificates for manufactured, loaded and stored packages were discussed among authorities and applicants. A case dependant system of 3, 5 and 10 years was established. There are consequences for the safety cases in the Package Design Safety Report including evaluation of long term behavior of components and specific operating procedures of the package.

Present research and knowledge concerning the long term behavior of transport and storage cask components have to be consulted as well as experiences from interim cask storage operations. Challenges in the safety assessment are e.g. the behavior of aged metal and elastomeric seals under IAEA test conditions to ensure that the results of drop tests can be transferred to the compliance of the safety objectives at the time of transport after the interim storage period (aged package). Assessment methods for the material compatibility, the behavior of fuel assemblies and the aging behavior of shielding parts are issues as well.

This paper describes the state-of-the-art technology in Germany, explains recent experience on transport preparation after interim storage and points out arising prospective challenges.

1. Introduction

The use of metallic transport casks for dry interim storage of spent nuclear fuel (SNF) can be designated as a German invention. In 1978 the company GNS started the approved application for the first CASTOR® cask (CASTOR® Ia) with a monolithic cask body made of ductile cast iron (DCI), closed by a bolted double lid system with metallic seals. A first CASTOR® Ic-Diorit cask was loaded and put to interim storage in Switzerland in 1983; in 1986 spent fuel storage in CASTOR® V/21 casks began in Surry, VA, USA. After implementation of two central storage facilities (Gorleben, Ahaus), the German decommissioning policy switched over to spent fuel storage in CASTOR® V casks on at-reactor storage sites since 2000. The central storage facility at Gorleben is mainly used now for interim storage of vitrified

high-level waste (HLW) in dual purpose casks. The storage facility at Lubmin (Interim Storage North, ZLN) is used for all spent fuel of the decommissioned eastern German NPPs of the VVER type and various German research reactor fuel.

The paper describes the German approval procedure for transport licensing including requirements regarding documents for application. Details about safety case requirements based on international and national regulations are given. Furthermore requirements concerning interim storage and related licensing procedures are explained. Finally, BAM research activities concerning long term behavior of components and materials are explained and references are given.

2. Approval of Transport Package Design

In Germany casks for interim storage are dual purpose casks. Every storage cask has to have a transport approval certificate at time of storage placement and over the storage time as well. Usually a Type B(U) approval (accident resistance package according to IAEA transport regulations TS-R-1 [1]) with Germany as country of origin is necessary [12, 14]. In accordance to German guideline R003 [2] the package design assessment and the approval procedure are conducted by the Federal Office for Radiation Protection (BfS) and the Federal Institute for Materials Research and Testing (BAM). The assessment has to base on a Safety Analysis Report, provided by the applicant.

Requirements on Application Documents

The application documents must include at least the information required by the applicable paragraphs of TS-R-1 [1]. Compliance with all applicable requirements for the requested design approval shall be demonstrated by providing a Safety Analysis Report. The Safety Analysis Report must include in particular:

a) the modes of transport for which a design approval is requested together with the relevant dangerous goods transport regulations;

b) a detailed description of the proposed radioactive contents including the following information, as applicable: nuclides/nuclide composition, activity and mass, physical and chemical state, geometric shape, arrangement, irradiation parameters, materials of manufacture, nature and characteristics of the radiation emitted, heat capacity to be dissipated and mass of fissile material;

c) a reproducible illustration, showing the make-up of the package, including impact limiters, devices for thermal insulation and packaging inserts, if applicable;

d) a detailed description of the design and its components, i.e. the complete drawings, parts lists, material specifications etc.

e) the safety demonstration showing plausibly that the design meets all the requirements of the applicable regulations according to (a) above. The demonstration has to cover in particular:

- demonstration of mechanical stability for routine, normal and accident conditions of transport for the components of the containment system, the components of the shielding, the components of the confinement system for ensuring subcriticality and the attachments for lifting by crane and for transport on public traffic routes [13],

- demonstration of thermal behavior for routine, normal and accident conditions of transport including an evaluation of thermal stresses and the thermal behavior of the components of the

containment system, the components of shielding and the components for ensuring subcriticality,

- demonstration that the limits for the release of radioactive material for normal and
- accident conditions of transport are met [14],
- demonstration that for the maximum radioactive contents the dose rate limits for normal and accident conditions of transport are met,
- for fissile material, demonstration of subcriticality for routine, normal and accident conditions of transport;

f) the quality assurance and monitoring programme for design, manufacturing, documentation and use including all instructions necessary for use (including special stowage provisions or other instructions, e.g. for safe heat dissipation or for ensuring criticality safety), maintenance and re-testing/reinspection as well as for operations during transport and in-transit storage. The experiences and involvement of the competent authority in this field in Germany are described by Wille [14].
All specifications must be considered by the user of the package to ensure the loading, the transport, the operation and the periodic inspections according to regulatory requirements. Up to now the design assessment was determined by the evaluation of the materials used with regard to their properties and compatibilities for short periods (transport periods). This suitability evaluation is supplemented by the specification of a system of periodic inspections (after 15 transports but not later than 3 years, after 60 transports but not later than 6 years, before one-time transport after interim storage), which should guarantee that the package complies the specifications before transport on public routes [14].

The safety demonstration of a design can be accomplished by using the results of tests performed with prototypes or models of appropriate scale, by reference to previous satisfactory demonstrations of a sufficiently similar nature, by calculation, when the calculation procedures are generally agreed to be suitable and conservative or by a combination of these test methods.

Reference to test results of designs similar to the design for which approval is requested is permissible if the similarity can be demonstrated sufficiently by justification and validation.

If computer codes are used for safety demonstration it is up to BfS and BAM to require additional documents to show suitability and appropriate validation of these codes, such as:

documents to show the extent and results of verification/validation of the code including the determination and justification of safety factors, if appropriate (conservatism),

documents to show the verification of these codes on the basis of comparisons of calculations and other investigations (e.g. measurements), examples are explained by Wille [12],

justification for the applicability of these codes including a statement of possible sources of errors, particularly for conditions for which sufficient verification has not yet been provided,

assessment of the effects of modelling assumptions and simplifications as well as any other calculational parameter with influence on the analysis results, particularly on safety margins against the limits for safety related parameters and

justification of input parameters.

Furthermore, the competent authorities may require proofs of qualification for staff members performing the calculations [11].

Design Assessment

BfS and BAM carry out the comprehensive safety assessment of the design (design assessment). They assess the safety demonstration of a design with respect to compliance with the regulations. In detail, BAM carries out the safety assessment with respect to the mechanical and thermal design, the release of radioactive material and quality assurance. Required tests with prototypes, models or single components are performed by BAM.

BfS carries out the safety assessment with respect to shielding, criticality safety and compliance with the activity limits concerning the radiological properties.

BfS summarizes the results of the complete procedure and issues the design approval certificate.

Design Approval

Design approval is granted if the design assessment has been concluded with positive results. The approval certificate is generally issued for a validity period of three (1985 Edition of the regulations) and five years (1996 Edition of the regulations). The competent authority may consider a deviation from this validity period if the applicant requests any other validity period and substantiates such request. In Germany it is possible for package designs which are compliant to the current regulations [1] (1996 Edition of the regulations) to get a 10 year approval certificate. The hereby associated requirement is an exclusion of a further manufacturing of the particular package design. For example, this procedure can be used for package designs whose loaded casks are stored in an interim storage site and a new manufacturing is not planned or impossible. Depending on the cask design, particular time intervals of maintenance and updating of the Safety Analysis Report are determined.

The validity of the approval certificate will be extended upon application if the legal regulations have not changed materially and safety related objections against an extension of the validity period can not be raised, either. Such application shall include documents to show that all applicable requirements continue to be met. This includes, e.g., an assessment of the influence of advanced technical standards on the design as well as the practical experience feedback from using the design, particularly concerning the quality assurance and monitoring programme.

Except as required in the design approval certificate and subject to legal regulations (e.g., legal changes, transitional periods), a valid design approval certificate authorizes the manufacture of an unlimited number of packagings. Subject to other required approvals (e.g., shipment approval), any package may be transported if at the time of transport the following documents are available: a valid design approval certificate, a certificate of the inspections carried out before commencement of operation (certificate of acceptance) and the certificates of re-testing/reinspection as required.

3. Licensing for Dry Storage

Spent fuel and vitrified high active wastes from reprocessing are stored in interim storage facilities which are licensed on the basis of § 6 of the German Atomic Energy Act [8] and taking into consideration the “Guidelines for dry cask storage of spent fuel and heat-generating waste” [9]. The storage facility contains all technical and security infrastructure for operation, casks with the radioactive contents under dry and inert conditions and a building containing the casks and all handling, maintenance and monitoring equipment. Interim storage sites have been licensed as centralized facilities like Ahaus or Gorleben at first in the 1980’s and later on – mainly after 2001 – due to changes of the German Atomic Act as at-site

facilities at all German NPP locations. The storage period was generally limited to 40 years for administrative reasons because it was expected to have a final repository available after that time. In the meantime major delays in the repository siting and exploration procedure occurred and therefore extended storage periods may become relevant in the future.

Safety goals for dry interim storage casks are the same as for transport packages: Safe enclosure of the radioactive inventory, subcriticality, shielding, and decay heat removal in a way that safe enclosure, subcriticality and shielding are not affected. The main safety goals are guaranteed by the dual purpose casks and only shielding is additionally supported by the storage building which also protects casks from environmental conditions. Furthermore, the storage license holders have to demonstrate spent fuel element integrity before loading and fuel rod integrity during interim storage (no systematic fuel rod failure). The casks are thick-walled and made of forged steel or ductile cast iron containing a permanently monitored double barrier lid system with long term resistant metal seals. The cask inventory is carefully vacuum dried and filled with inert gas after loading to avoid corrosion effects and ensure effective heat removal. As a basic requirement each cask design for dry interim storage has to be transportable to and from the storage site at any time and for that reason it needs a valid Type B transport license. Because accident safe Type B casks have demonstrated their safety level within the transport licensing procedure all these safety assessments can be used by applicants for storage licenses as well if appropriate. Additionally, different operation conditions inside the storage facility require adapted or additional safety assessments. Especially mechanical accident scenarios are significant different in comparison to Type B(U) test conditions due to cask handling without impact limiters and different drop orientations, drop heights and target stiffness. Another difference is the long term performance of all cask components which has to be assessed and evaluated for the applied storage period. Because of the dry and inert storage conditions and the only use of passive safety relevant systems maintenance and inspections procedures are very limited during storage operation which is under permanent supervision by the operator, responsible state authorities and their technical experts. Furthermore, a formal periodic safety inspection procedure including aging management is in a two year test phase and is expected to be implemented to all interim storage facilities subsequently. This systematic approach allows to summarise lessons learned, technical changes and optimization measures and to share the experience with other facilities and licensing authorities. Finally, such an information pool might be a good basis for possible future lifetime extension applications.

Storage licenses are issued by BfS on basis of safety assessments by the applicants which are usually the utilities of the NPPs and not the transport license holder. The safety assessment evaluation is performed by technical experts on behalf of BfS like BAM for all cask specific issues including quality assurance and the TÜV for facility and inventory specific issues.

As mentioned before, transportation after storage is essential to all casks stored in interim storage facilities whether they are centralized or on-site. Permanent demonstration of transportability is required by all issued licenses for all casks being in storage. So far it is common understanding of all stakeholders in German interim storage business that valid Type B approvals for all cask designs during storage and not only at the beginning is a necessary prerequisite. On the other hand any individual cask has to demonstrate compliance with the transport license prior to transportation as it is discussed later in this paper.

4. Long Term Behavior of Components and Materials

During long term interim storage the main driving forces of aging effects are:

Gamma radiation,

Neutron radiation,

Decay heat,

Outer corrosion effects (e. g. moisture, and air pollution),

Relaxation, creeping, corrosion of screwed and sealed lid systems, basket, and fuel rods.

Degradation effects strongly depend on the type of material. All main cask components responsible for the safe enclosure are usually made of metal like cask body, lids, barrier seals, and bolts. Additionally, polymers are used for supplementary neutron shielding components, auxiliary seals and decontamination coatings. In general, damaging effects by radiation depend on dose rates, type of radiation and material structure. Metals are generally more resistant than polymers. Degradation effects may result in quantitative changes of specific material properties or modifications in material structure which may decrease the effectiveness of cask components.

Current investigations performed by BAM focus on the long term behavior of metal seals as the essential component for the safe enclosure, on the long term behavior of polymer materials as components for neutron shielding and on the aging mechanisms and low temperature behavior of elastomeric auxiliary seals. These investigations shall generate a better data base for understanding and quantification of aging effects and have been summarized before by Völzke [3]. More details with respect to aging management fundamentals and the investigation programs performed by BAM have been published during the PATRAM conference 2010 by Erhard [4], Jaunich [5], and Wolff [6]. Specific results from the BAM metal seal investigation program were published by Völzke [7]. These include extrapolation of seal pressure force decrease and decrease of elastic seal recovery depending on the temperature level and with respect to seal performance evaluation under normal operation and accident conditions during and after long term storage. More investigations including inspection programs will be necessary in the future to answer arising questions concerning safety functions during transport after long term storage or with respect to extended storage periods.

5. Tests and Checks for Transport Ability after Storage

In principle, it has to be ensured before transport that the package complies with the specifications of the approval certificate. This also applies when transport is performed after interim storage. Until now, the evaluation of the long term behavior (stability) was not an explicit part of the design assessment while the approval procedure according to the transport regulations.

The transport regulations assume casks which are only for transport. In this case the whole package is completely accessible before loading and again after transportation and unloading. For this reason periodic inspections can be provided for all essential components and sections. Periodic inspections are required after 3 respectively 6 years or 15 respectively 60 shipments.

During and after interim storage the packaging is not accessible for complete periodic cask inspections in sense of the approval certificate. The specifications in the test-plan for the periodic inspections after interim storage should cover the sections accessible from the outside, ensure the leak-tightness according to the specifications and where appropriate provide measurements which allow conclusion to the inaccessible sections.

Examples are:

Accessible Sections

Visual inspection of surfaces (e.g. decontamination coatings), visual but also surface crack inspection, load testing of the attachment system, , replacement of components (when necessary)

Compliance of the containment system with specifications

Inspection of the pressure monitoring device and inspection of tightening torques of the lid bolts, performance of leak-tightness (e.g. leakage rate measurements)

Measurements (conclusion to inaccessible sections)

Verification of the shielding effectiveness, e.g. regarding the effectiveness of neutron radiation shielding material in the shell of the packaging, the bottom of the packaging or between the lids.

Following the described measures in accordance with the current approach and the derived questions it appears to be reasonable to expand the considerations with respect to long term behavior as part of the approval procedure for transport and storage casks.

6. Quo vadis – Challenges and Prospective Work

Work on Characteristics of Long Term Behavior of Materials and Components

Until now the plans for periodic inspection contain restrictive determinations of inspection steps for an one-time transport after 40 years. According to the understanding of the state-of-the-art of technology there are steps such as a load test of the complete load attachment system and the complete inspection of the tightening torque of the screws as a part of the containment system implemented. However, these determinations do not cover all questions concerning the properties of components respectively material after interim storage of many years. Various questions on long term behavior of components and materials resulting from the particular operation state (storage) of the transport package arise.

In the following several points relating long term behavior and the fulfillment of IAEA requirements (e.g. test conditions) are named for future discussion.

behavior of aged metallic and elastomeric seals as a part of the containment system

transferability of drop test results (e.g. tightness, mechanical material behavior, deformations) regarding the compliance of the safety objectives before a transport after interim storage (aged package)

transport of defect spent fuel assemblies/rods – warranty of leak-tightness of enclosures such as quivers for defect spent fuel rods under accident conditions of transport

behavior of aged spent fuel assemblies/rods

behavior of aged impact limiters

change of material properties of shielding components (e.g. influence of radiation)

Basically it is to be ensured that during and after the interim storage period the package fulfills the requirements of the IAEA transport regulations, means the package has to meet the specifications of the approval certificate. It could also mean the package has to have sufficient properties to fulfill the appropriate safety cases.

Regulatory Work

Since many countries operate interim spent fuel storage in dual-purpose casks, the integrated safety assessment and a harmonized approved/licensing approach became evident at an international level,

organized by IAEA in joint WASSC/TRANSSC (Waste Safety Standards Committee/Transport Safety Standards Committee) activities. Between April 2011 and April 2013 three meetings of a "Joint Working Group on Guidance for an Integrated Transport and Storage Safety Case for Dual-Purpose Casks for Spent Nuclear Fuel" took place. A "Guidance for preparation of a safety case for a dual purpose cask containing spent fuel" was developed on basis of the European Guide for Package Design Safety Analysis Report [10]. This IAEA-TECDOC shall be published until end of 2013, and shall contain guidance in dual purpose cask safety assessment criteria and methods for on-site transport, interim storage and post-storage off-side transport. An important issue is the introduction of periodic "gap analyses" to react on changes of regulations, standards and technical knowledge in order to update safety cases during long storage periods. The working group also elaborated recommendations to TRANSSC to consider these categories of packages in the transport regulations (SSR-6, SSG-26) in a proper manner concerning maximum transport period clarification, transitional arrangements and introduction of ageing considerations. Recommendations to WASSC are to extend Safety Guide "Storage of Spent Fuel" (SSG-15) with the guidance document section on ageing management, and to support member states in developing methods to investigate on-site transport and handling drop accidents. Current information on the IAEA activities can be taken from a specific website [15].

7. Conclusions

Safety assessment of spent nuclear fuel transport casks, as well as of dual purpose casks for spent nuclear fuel storage is based on well established methods. For future applications a better harmonization of both licensing (transport and storage) areas appears reasonable. In any case specific considerations of transport safety aspects after interim storage should be followed. For that purpose research on aging mechanisms, incorporation of storage related property changes into the transport safety case, and regulatory developments are necessary.

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German Approach for the Transport of Spent Fuel Packages after Interim Storage

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Outline

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Introduction

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Concept of Dry Interim Storage for SNF and HLW in Germany

- according to German Reactor Safety Commission (RSK) guidelines 2012
- accident resistance dual purpose metal casks with
  - Transport Approval Certificate
  - two independent sealed barriere lids
  - permanent monitoring of cask tightness
- storage period up to 40 years
- storage building for weather protection and additional shielding

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Introduction

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Main Design Features of current Transport and Storage Casks

- Monolithic cask body made of *DCI* or *forged steel*/shell with welded bottom
- Dimensions:
  - Length: *4.0* to *6.0 m*
  - Diameter: *1.5* to *2.5 m*
  - Wall thickness: *0.25* to *0.45 m*
- Storage: *Double lid closure system* with metal seals and permanently monitored pressure between bolted lids
- Vacuum dried and Helium filled cask interior

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History of Storage in Germany

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CASTOR® THTR/AVR	⇨	Ahaus since 1992 Jülich since 1993
CASTOR® IIa, TS 28V, CASTOR® V/19 CASTOR® Ic, CASTOR® HAW 20/28, TN85	⇨	Gorleben beginning 1995

Experience on Cask Storage up to 21 years in Germany

Current German interim storage licenses ending

Gorleben	2034
Ahaus	2036 (CASTOR® THTR/AVR: 2032)
at-site facilities	2042/43

Interim storage periods may need to be extended in future

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Design Approval Certificate (Transport)

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Approval Certificate	⇨	for transport on public routes ⇨ at time of storage placement ⇨ *over storage time (up to now)*
Type B(U) Certificate	⇨	Germany as country of origin
Approval Procedure	⇨	according IAEA Regulations (TS-R-1) and German Guideline R003, PDSR Guide

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Design Approval Certificate

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Certificate Validity Period ⇨ 1985 & 1996 Edition of the IAEA Regulations ⇨ up to 5 years

"Loaded and Stored" ⇨ 10 years
- ✓ exclusion of further manufacturing
- ✓ cask loaded and placed in storage
- ✓ intervals of maintenance and updating the SAR determined

⇨ **Advantage:** *Transport Package design well known* over storage period
- ✓ *constantly care* of the safety cases incl. documents concerning compliance to the regulations
- ✓ reasonable expense over storage period

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Package Design Safety (Transport)

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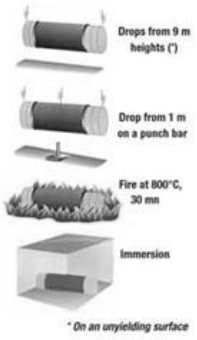
Safety Demonstration
- ✓ *mechanical stability*
- ✓ *shielding*
- ✓ *criticality safety*
- ✓ *thermal design*
- ✓ *attachments for lifting*
- ✓ *activity release*
- ✓ *dose rate*

Quality assurance and monitoring program
- ✓ *design, manufacturing, documentation*
- ✓ *operation*
- ✓ *maintenance & re-inspection*



test scenarios according to IAEA TS-R-1 (SSR-6)

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Drop Test Program

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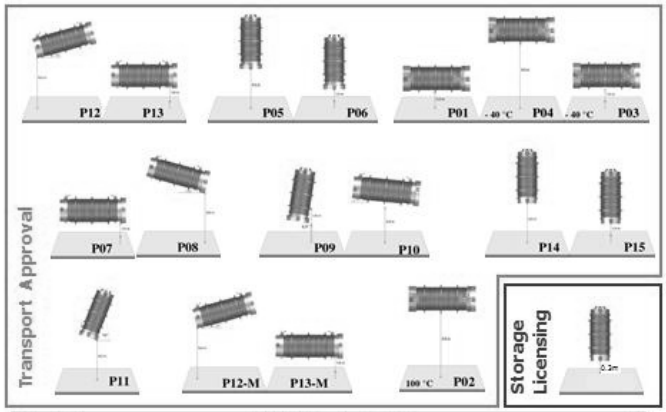
Example of drop test sequences of a HLW CASTOR® cask performed at BAM



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Licensing for Dry Interim Storage

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According to §6 of the *German Atomic Energy Act*

- license issued by Federal Office for Radiation Protection
- technical assessment by different expert organizations (BAM, TÜV etc.)

According to Safety Guidelines for *Dry Interim Storage of Irradiated Fuel Assemblies* by the German Reactor Safety Commission

- stored casks have to be *transportable at any time* during storage
- consideration of storage operation condition
- *mechanical accident scenarios* different to transport conditions (handling without impact limiters)
- *long term performance* of all components
- periodic safety inspection and aging management procedure is going to be implemented

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Long Term Behavior of Components and Material

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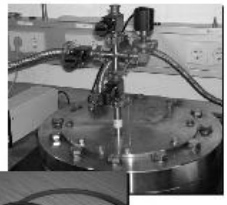
Activities by BAM

Investigation of Metal Seal Resistance

- Long term behavior
- Corrosion Tests (water in the gap between inner and outer seal jacket)



Ageing Effects of Storage Cask Polymer Components

- Neutron shielding components (high temperature, radiation etc.)
- Elastomeric auxiliary seals (low temperature, long term behavior)

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Tests and Inspections for Transport after Storage

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'Pure' Transport Packaging: after unloading, all sections accessible

➡ **system of periodic inspections**

Transport after Storage: **system of specific tests and inspections**

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➡ accessible package sections
- visual inspections,
- load testing,
- replacement of components

➡ check of the containment system
- check of the pressure monitoring system,
- lid screws (tightening torque),
- leak-tightness

➡ measurements
- verification of the shielding effectiveness

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Experience in Transport Preparation after Storage

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CASTOR® THTR/AVR

Transport FZ Jülich ⇨ Storage Facility Ahaus ?

Transport FZ Jülich ⇨ USA

Transport preparation of 152 casks is running

Example
Leak-Tightness Test

Example
Repair & Testing
of Trunnions

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Quo Vadis – Challenges and Perspectives

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R&D according characteristics of long term behavior of material and components

- aged metallic and elastomeric seals (containment system)
- aged package under regulatory tests
- aged Spent Fuel Assemblies
- ...

⇨ Package has to fulfill the requirements of the transport regulations & the approval certificate **after storage period**

⇨ appropriate (conservative) assumptions for safety cases

Regulatory Work

IAEA Working Group – Safety Case for Dual Purpose Casks

⇨ guideline and recommendations are developed

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