Gap Analysis Examples from Periodical Reviews of Transport Package Design Safety Reports of SNF/HLW Dual Purpose Casks

Steffen Komann[a*], Frank Wille[a], Bernhard Droste[a]
[a] Federal Institute for Materials Research and Testing (BAM), Berlin, Germany

Abstract: Storage of spent nuclear fuel and high-level waste in dual purpose casks (DPC) is related with the challenge of maintaining safety for transportation over several decades of storage. Beside consideration of aging mechanisms by appropriate design, material selection and operational controls to assure technical reliability by aging management measures, an essential issue is the continuous control and update of the DPC safety case. Not only the technical objects are subject of aging but also the safety demonstration basis is subject of "aging" due to possible changes of regulations, standards and scientific/technical knowledge. The basic document, defining the transport safety conditions, is the package design safety report (PDSR) for the transport version of the DPC. To ensure a safe transport in future to a destination which is not known yet (because of not yet existing repository sites) periodical reviews of the PDSR, in connection with periodic renewals of package design approval certificates, have to be carried out. The main reviewing tool is a gap analysis. A gap analysis for a PDSR is the assessment of the state of technical knowledge, standards and regulations regarding safety functions of structures, systems and components.

Keywords: Dual Purpose Casks, Aging, Transportation, Periodical Review.

1. INTRODUCTION

For interim storage of spent fuel or HLW in many countries transport casks are used. The design of these "dual purpose casks" (DPC) has to be assessed and approved according to transport regulations (based on IAEA SSR-6), and to be assessed within the storage facility licensing procedure. Although the transport cask design differs from the storage cask design, e.g. by use of impact limiters, the majority of cask components is identical for both.

Differences occur also in the acceptance criteria; these are for the transport case defined in IAEA SSR-6 [1], and have to be developed for the storage case based on the storage facility requirements [11]. Considering transport after several decades of storage requires the implementation of ageing behavior into the transport safety case. Additionally the transport package design safety case has to be maintained in an up-to-date state, considering potential regulatory changes and development of scientific and technical knowledge. The review of a transport package design safety case has to be done periodically, implemented in periodic re-assessment for renewal of the package design approval certificate. The review process (as a kind of "intellectual periodic inspection") should be part of the approved applicant's management system and part of the administrative competent authority system.

From experience we have seen that stability of regulatory requirements for Type B(U) packages was not a major problem, but consideration of ageing and developments regarding the state-of-the-art technology can cause necessary adjustments of specific technical evaluation, with the result of confirmation of package safety, or with the development of appropriate compensatory measures to reach the required level of safety.

2. BACKGROUND OF DPC STORAGE IN GERMANY

Casks for interim storage are dual purpose casks in Germany, it means the casks are used not only for transportation but also for interim storage of spent nuclear fuel or radioactive waste inside an interim storage facility. A DPCs in an interim storage facility are shown in figure 1.

Figure 1: DPCs in an Interim Storage Facility Gorleben (Photo: GNS)

Decommissioning of spent nuclear fuel (SNF) requires several decades of storage before direct disposal. In case of reprocessing the fission products are transferred to vitrified high level waste (HLW) which has to be stored also over several decades before it can be disposed in a repository.

Most of the spent fuel produced in Germany until 2005 went to reprocessing in La Hague, France and Sellafield, UK. Since July 2005 German utilities are forced by law to store spent fuel in storage facilities located at the NPP sites. Before that decision, the old decommissioning policy was based on two central storage facilities in Ahaus and Gorleben. Since 1979 it was decided in Germany to store SNF and HLW under dry conditions in transport casks.

This concept of Dual Purpose Casks (DPC) was at the first time developed with the types of CASTOR® casks by GNS (Gesellschaft fuer Nuklear-Service GmbH, Essen, Germany). The central transport cask storage facility Ahaus was mainly used for the storage of 305 CASTOR® THTR/AVR casks with the complete inventory of the Thorium-High-Temperature-Reactor (THTR) after its decommissioning in 1994. The central transport cask storage facility Gorleben was mainly used to store 108 casks (CASTOR® HAW 20/28CG, TS 28 V, TN85, CASTOR® HAW 28M) with vitrified HLW received back from France. Besides 12 transport cask storage sites at NPPs (there were stored 332 CASTOR® V/19 and V/52 SNF casks at the end of December 2013), there are additionally two storage sites at Research Centre Jülich (for 152 CASTOR® THTR/AVR casks with the complete inventory of the research reactor AVR) and in Lubmin the ZLN storage site at the decommissioned former GDR NPPs with 65 CASTOR® 440/84 casks.

All these several hundred SNF and HLW transport and storage casks have to be transported in future after a storage period which is currently per license limited to 40 years, but which is expected to be some decades longer due to outstanding evaluation, selection and licensing of a high active waste repository. Responsibility for future generations requires from the beginning that there will be a safe transfer of the existing DPC to their currently unknown destination.

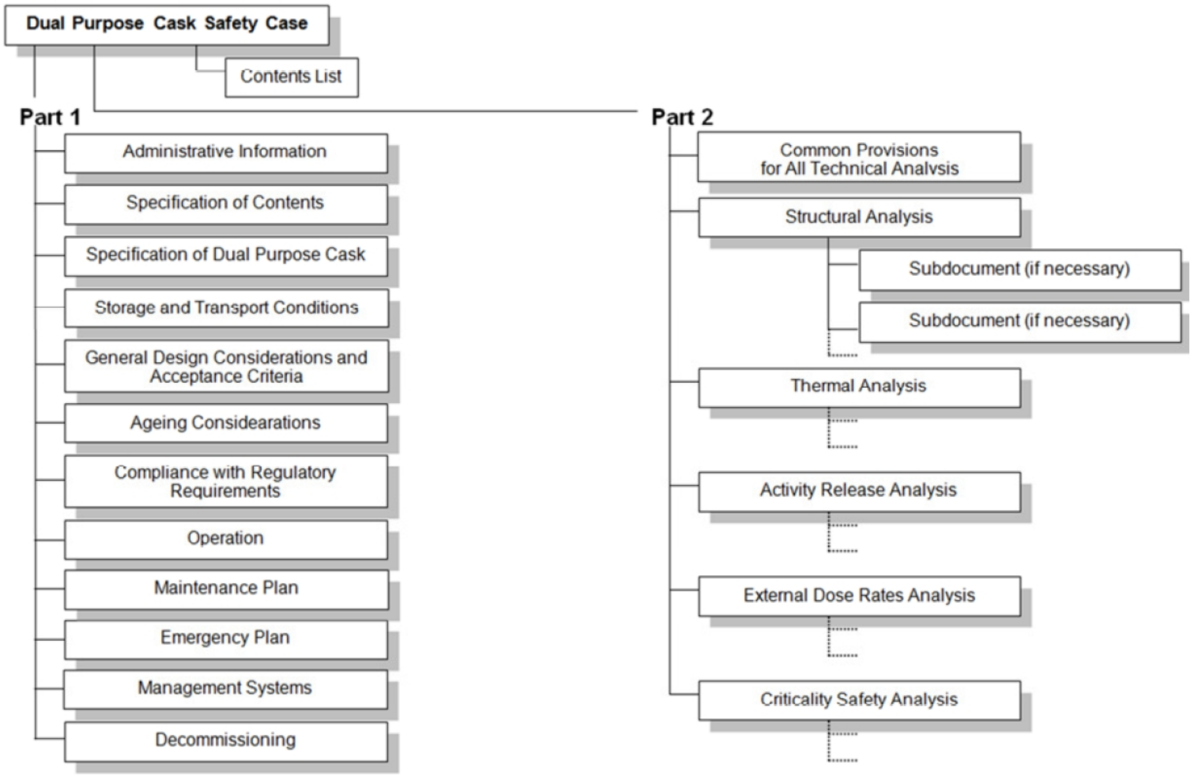
All stakeholders (vendors, transport and storage operators, authorities, regulators, technical experts) involved in that process need to follow a strict course of keeping the foundation for transport safety, the transport package safety report (safety case) effective through the entire lifetime of these objects.

3. DPC TRANSPORT PACKAGE DESIGN APPROVAL

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 revised “Guidelines for dry interim storage of irradiated fuel assemblies and heat-generating radioactive waste in casks” by the German Waste Management Commission (ESK) [11].

Every storage cask has to have a transport approval certificate at time of storage placement. Usually a Type B(U) approval (accident resistance package according to IAEA transport regulations [1]) is necessary. 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 Case, provided by the applicant.

Figure 2: Structure of a PDSR; here for a SNF Dual Purpose Cask [3]



The Package Design Safety Report (PDSR) is a collection of scientific and technical arguments, including safety assessment and package design, manufacturing and operation specifications required to demonstrate compliance with the applicable transport regulations.

The “European Association of Competent Authorities for the Safe Transport of Radioactive Materials” issued the “Technical Guide – Package Design Safety Report for the Transport of Radioactive Materials” [3]. This “European PDSR Guide” is a useful guidance for structure and safety assessment details of a package design safety report. Based upon the same structure an IAEA working group developed the document “Guidance for preparation of a safety case for a dual purpose cask containing spent fuel” [4].
Figure 2 shows the structure of a Dual Purpose Cask Safety Case (DPCSC). Important for the long-term safety preservation of dual purpose casks are the requirements for ageing considerations in the safety case, ageing management during storage and inspection programs before transport after storage.

The DPCSC document also addresses problems of adjusting the differences between licensing types of storage and transport package design approval. A storage license is issued for a storage period of several decades. A transport package design approval is normally issued for a period of a few to several (between 3 and 10) years in Germany. Before the end of the approval period the certificate needs to be extended for the next period by a demonstration of compliance with the current transport regulations.

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, creep, corrosion of bolted 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, main seals, and bolts. Additionally, polymer components are used for supplementary neutron shielding components, auxiliary seals and decontamination coatings. In general, damaging effects of 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 by Wolff et al. [5]. More details with respect to aging management fundamentals and the investigation programs performed by BAM were published by Erhard et al. [6], and Jaunich et al. [8]. Latest results from the BAM metal seal investigation program are published by Völzke et al. [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. The influence of aging mechanisms on the DPC transport safety is discussed in Droste et al. [12].

5. PERIODIC REVIEW AND GAP ANALYSES EXAMPLES

5.1 General

Not only DPC components and materials are subject to aging, this is also the case for regulations, standards, technical and scientific knowledge. Their aging mechanism is the change. Therefore, it is essential, for keeping a PDSR up-to-date for periodic package design approval renewal, to evaluate in a periodic review the impacts of these changes onto package safety. The method for that is a gap analysis. In [4] gap analysis is defined: “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. Gap analysis consists of

i) listing of characteristic factors, such as the state of technical knowledge, regulations, and standards of the safety case,
ii) evaluation of the effect of changes of technical knowledge, and standards on the safety of the DPC package, and then
iii) high-lighting the gaps that exist and need to be filled.”

Periodic safety reviews and gap analyses are to be performed to keep a DPCSC up-to-date. Those periodical reviews are an important part of knowledge management, and force DPC designers, storage operators and regulators to keep knowledge on DPC safety present to all relevant stakeholders during the several decades lasting operation period. Periodic reviews are the only method which allows the tracking of safety knowledge, independently from institutional and personnel changes too.

Nitsche et al. [9] and Wille et al. [10] describe the German regulatory concept of transport package design approval for DPCs during interim storage period in detail. If manufacturing and loading of the casks are not done anymore and no transports are planned, BfS and BAM allow application of package design certificate with a validity period of 10 years.

A step wise procedure of evaluation of documents of the PDSR over the validity period is defined. This procedure includes the evaluation of consequences at enactment of new regulations over the entire validity period of the certificate. Beyond that after 5 years the certificate holder has to provide an evaluation that all safety related technical standards and codes, and safety demonstrations of the PDSR are valid.

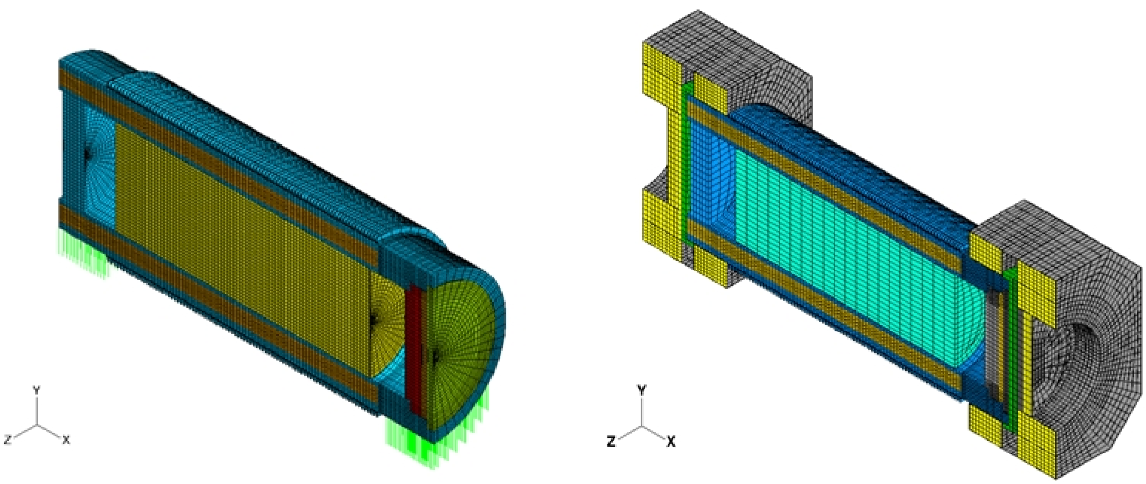
After 10 years an extension of the package design certificate is necessary. The complete evaluation regarding state-of-the art technology of all parts of the PDSR has to be done. The consequence could be that e. g. new analysis methods for safety demonstration have to be applied. The advantage of this substantial work is the reflection of the knowledge about the package design and the concept of safety demonstration. We understand this procedure as the aging management concerning knowledge of the PDSR and the safety concept behind.

5.2 Examples of Safety Case Gap Analyses

Important for the periodical review of the package design safety report are both the experience and feedback out of manufacturing and the state-of-the art of safety analyses. This includes not only the analyses methods but also the validity of the applicable standards.

This periodically report has to contain an assessment of all components of the packaging including radioactive inventory regarding their condition and ageing influences and the comparison with the package design safety report based on the valid approval certificate.

Figure 3: Static and Dynamic Numerical Model of Cask Body

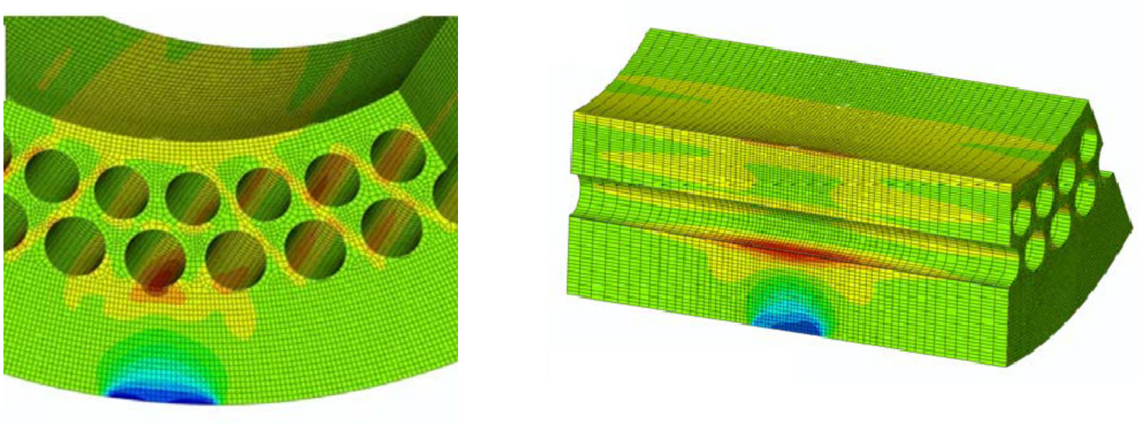


Cask Body Structural Analysis

It is to check, if the analyses methods are still valid for the assessment of the cask body. So it could be possible, that a actualized numerical analysis replace the analytical analysis for the cask body made in the past. In this case the influence of a numerical analysis of the package design safety has to be assessed. If during the licensing procedure a static numerical model was used and the state-of-the-art analysis shows the application of a dynamic numerical model is necessary, this influence on the safety report has to be checked. In figure 3 a static and dynamic Finite-Element-Model are presented. In Komann et al. [13] the approach of comparing static and dynamic Finite-Element-Analysis described in more detail.

Usually by using numerical models the local stresses has to be assessed (figure 4). If an analytical approach within the primary licensing procedure was applied, the influence of these local stresses compared with global loading scenarios has to be investigated. For this case additionally investigations regarding the material behavior could be needed. Furthermore the validity of the applied boundary conditions of the loading scenarios according to the regulations must be checked (e.g. temperature, pressure).

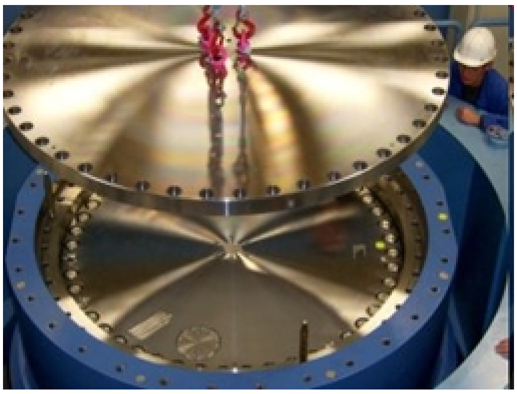
Figure 4: Local Stress Distribution in a Cask Body (1-m-Puncture Bar Drop)



Lid System Structural Analysis

In Germany a DPC is normally equipped with a double barrier closure system consisting of a primary lid and a secondary lid (figure 5). This requirement results from the boundary conditions of the storage facility to ensure the monitoring of the DPC during the storage time. The lid system consists of the lid, normally made of stainless steel, the lid screws and the metallic or elastomerical seals.

Figure 5: Lid System of a Cask (Photo: GNS)



During the drop tests according to the regulations several loading conditions arise in the components of the lid system. For the determination of the activity release, respectively the leakage rate of the lid system, it is necessary to know the loading conditions in the components exactly. It means here for instance the screw pretension or the pressure in the cask flange, where the seals are applied. To assess the activity release after interim storage period the loading conditions must be checked regarding these mentioned aspects.

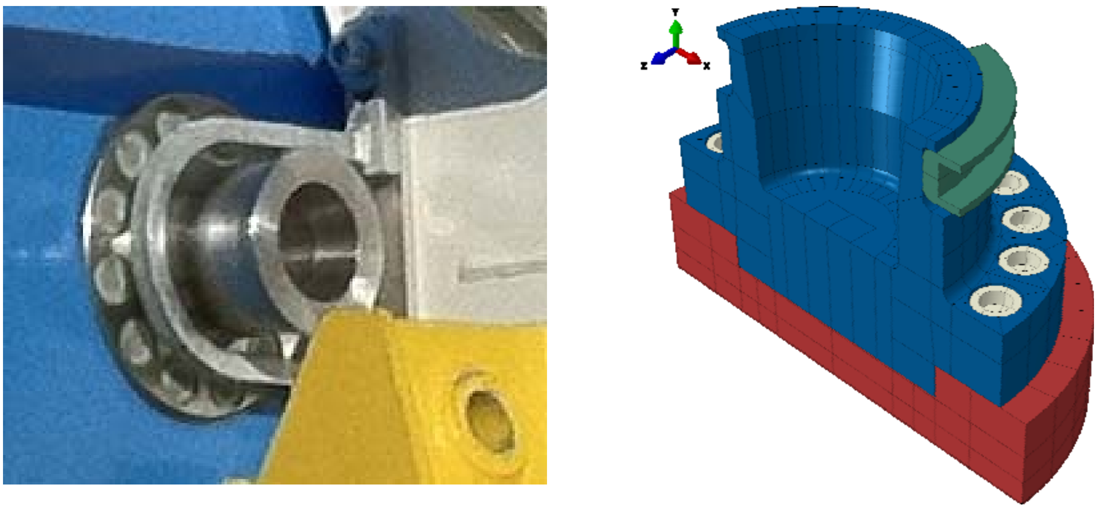
Impact Limiter Design Assessment

Impact limiters are necessary to decrease the impact loads resulting from drop test scenarios onto the packaging and the radioactive inventory. The construction of these components is therefore essential for the assessment of the package. The impact limiters are only part of the transport design approval of the package in Germany. Inside the interim storage facilities the impact limiters are not part of the cask storage design. To ensure the transportability during the interim storage period the impact limiters must be assessed periodically as well. The main materials of such impact limiters in Germany are wood and steel. The development in the knowledge in the field of the characteristic material behavior, e.g. stress-strain curves of timber regarding several temperatures, and the material condition is needed for the periodically assessment of the impact limiters. If the periodic structural assessment of the packaging results in phenomena like e.g. higher local stresses that could not have been identified by former calculations, compensatory measures could be a new impact limiter design leading to lower loads on the structure.

Load Attachment System

The purpose of the trunnions (figure 6) is the handling of the package inside a nuclear facility. Sometimes the trunnions will be used to store the package in a transport frame during transport over public traffic routes. Thus it is needed to assess these components for loading conditions resulting from regular handling procedures and transport conditions as well. The trunnions, often made of stainless steel, are robust against several loading conditions. But the conditions inside the trunnion screws are important for the safety assessment. The screw pretension depends amongst others on the decay heat of the package and the environmental temperature. So a change of the screw pretension can occur. This effect has an influence of the safety assessment of the trunnion system and the ability for handling and transportation.

Figure 6: Trunnion (Left: Real, Right: Numerical Model)



6. CONCLUSION

Safety assessment of spent nuclear fuel transport casks, as well as casks for spent nuclear fuel storage as dual-purpose casks is based on well established methods. For future applications a better harmonization of both licensing (transport and storage) areas is recommended.

The basic document, defining the transport safety conditions, is the package design safety report (PDSR) for the transport version of the DPC. To ensure a safe transport after interim storage period periodical reviews of the PDSR, in connection with periodic renewals of package design approval certificates, have to be carried out. The main reviewing tool is a gap analysis. A gap analysis for a PDSR is an assessment of the state of technical knowledge, standards and regulations regarding safety functions of structures, systems and components.

Furthermore the periodic review and update of the safety case and the package design approval is an important element of knowledge management.

References

[1] International Atomic Energy Agency (IAEA). Regulations for the Safe Transport of Radioactive Material, 2012 Edition, Specific Safety Requirements No. SSR-6, Vienna, 2012

[2] Guideline for the design approval procedure of packages for the transport of radioactive material, of special form radioactive material and low dispersible radioactive material (R003), Verkehrsblatt No. 23, 2004 December 15, p. 594.

[3] European PDSR Guide, ISSUE 2 (September 2012) http://www.bfs.de/de/transport/zulassung_behaelter/grundlagen_zulassungsverfahren/European_PDSR_Guide_Issue_2_Sept12.pdf

[4] IAEA-TECDOC-DRAFT “Guidance for preparation of a safety case for a dual purpose cask containing spent fuel”. Draft TM-44985, IAEA. Vienna, Austria, 2013 (to be published)

[5] D. Wolff, H. Völzke, F. Wille, and B. Droste „Extended Storage after Long-Term Storage“, 17th International Symposium on the Packaging and Transport of Radioactive Materials (PATRAM 2013), San Francisco, CA, USA, (August 18-23, 2013).

[6] A. Erhard, H. Völzke, U. Probst, and D. Wolff, “Ageing Management for Long Term Interim Storage Casks”, Paper#61, 16th International Symposium on the Packaging and Transport of Radioactive Materials (PATRAM 2010), London, UK (Oct. 03-08, 2010).

[7] H. Völzke, D. Wolff, U. Probst, S. Nagelschmidt, S. Schulz, „Long-term Performance of Metal Seals for Transport and Storage Casks “, 17th International Symposium on the Packaging and Transport of Radioactive Materials (PATRAM 2013), San Francisco, CA, USA, (August 18-23, 2013)

[8] M. Jaunich, W. Stark, D. Wolff, and H. Völzke, “Investigation of Elastomer Seal Behavior for Transport and Storage Packages”, 17th International Symposium on the Packaging and Transport of Radioactive Materials (PATRAM 2013), San Francisco, CA, USA, (August 18-23, 2013)

[9] F. Nitsche, F.-M. Börst, I. Reiche: The German Regulatory Concept of Transport Package Design Approval for Dual Purpose Casks during Interim Storage. 17th International Symposium on the Packaging and Transport of Radioactive Materials (PATRAM 2013), San Francisco, CA, USA, (August 18-23, 2013)

[10] F. Wille et al.: German Approach and Experience Feedback of Transport Ability of SNF Packages after Interim Storage. 17th International Symposium on the Packaging and Transport of Radioactive Materials (PATRAM 2013), San Francisco, CA, USA, (August 18-23, 2013)

[11] RECOMMENDATION of the Nuclear Waste Management Commission (ESK) - Guidelines for dry cask storage of spent fuel and heat-generating waste (revised version of 10.06.2013), (in German), http://www.entsorgungskommission.de/englisch/statements---recommendations--letters/index.htm

[12] B. Droste, S. Komann, F. Wille, A. Rolle, U. Probst, S. Schubert: Considerations of Aging Mechanisms Influence on Transport Safety and Reliability of Dual Purpose Casks for Spent

Fuel Nuclear Fuel or HLW, PSAM12, Probabilistic Safety Assessment and Management, Honolulu, Hawaii, USA (June 22-27, 2014)

[13] S. Komann, M. Neumann, V. Ballheimer, F. Wille, M. Weber, L. Qiao, B. Droste: Mechanical assessment within type B packages approval: applications of static and dynamic calculations approaches, In: Packaging, Transport, Storage & Security of Radioactive Material, 2011, Vol. 22, No. 4, p. 179-183