Safety Aspects of Long-term Dry Interim Storage of Type-B Spent Fuel and HLW Transport Casks

Dietmar Wolff, Ulrich Probst, Holger Völzke, Bernhard Droste, Roland Rödel

Bundesanstalt für Materialforschung und –prüfung (BAM), 12200 Berlin, Germany

Abstract / Introduction

Based on the German decision to minimise transports of spent fuel casks between nuclear power plants, reprocessing plants and central storage facilities several on-site storage facilities have been licensed till the end of 2003. Because of the large amount of type-B transport casks which are going to be used for long-term interim storage the question of time limited type-B license maintenance during the storage period of up to 40 years has been discussed under different aspects. This paper describes present technical aspects of the discussion.

A main aspect of transport cask qualification for interim storage is the long-term behaviour of the metallic seal lid system. Concerning this results from current experimental long-term tests with metallic “Helicoflex”-seals in which pool water is enclosed are presented. The test series has been performed by the Federal Institute for Materials Research and Testing (BAM) on behalf of the Federal Office for Radiation Protection (BfS) since 2001.

Finally, the paper presents a German concept for an authorities’ and technical experts’ exchange of experience, know-how and state of the art referring to cask dispatch in nuclear facilities. BAM has taken over a central role in this so-called “co-ordinating institution for cask dispatching information” (“KOBAF”) which contains an online data base and a technical working group meeting twice a year. The goal is to keep comparable technical standards for all nuclear sites and storage facilities which are going to load and dispatch casks of the same or similar types under the responsibility of different German state governments for the next decades.

1. The use of transport casks for interim storage

In recent years dry interim storage has been developed worldwide as an alternative decommissioning strategy to the reprocessing of spent fuel from commercial nuclear power plants (NPP). In those cases the spent fuel is stored in transport casks that have to be additionally qualified for long-term interim storage, and after a storage period of some decades these casks are to be shipped to a conditioning facility where the spent fuel has to be put into casks suited for final disposal. Hence, the use of transport casks for dry interim storage minimizes transport operations today, but will result in transport operations after a long-term storage period. This requires specific considerations of the durability of safety relevant cask properties, and preservation of the package design approval. Fore instance these so called dual-purpose metal casks, which are designed to be used for both transportation and long term storage, have to fulfil the radioactive material transport regulation requirements not only today but in addition in future (after some decade storage) to ensure the same level of safety as at the time of cask loading. But, with respect to the conformity of these dual-purpose casks to the future transport regulations, it has to be taken into account that the transport regulations could have been changed in the mean time.

<u>The German concept of decentralized interim storage:</u>

In 1998 the German government decided to phase out of commercial nuclear energy utilization. In context with this change in energy policy, a waste management program was developed including a new concept of dry on-site interim storage instead of centralized interim storage. In order to minimize transports of spent fuel casks between nuclear power plants, reprocessing plants and central storage facilities, the operators of NPP have to erect and to use interim storage facilities for spent nuclear fuel on the site or in the vicinity of nuclear power plants. With one exception, the on-site interim storage facilities are limited to the storage of spent fuel elements from the neighboring nuclear power plant. Up to now, 11 on-site interim storage buildings, one storage tunnel and 4 out of 5 on-site interim storage areas (preliminary cask storage till the on-site interim storage building is completed) have been licensed at 12 nuclear power plant sites in five federal states (for an actual overview see the homepage of BfS [1]). Inside the interim storage buildings the casks are kept in upright position, whereas at the preliminary interim storage areas horizontal storage of the casks on concrete slabs is used and for gamma and neutron radiation shielding and as weather protection, each cask is covered by concrete elements.

Already in operation are the 4 interim storage areas and one interim storage building at NPP Emsland (Lingen). With an assumed construction period for the storage buildings of about two years, all on-site interim storage facilities may possibly be available around 2005 and shall operate for about 40 years. The storage areas, which are necessary for power plants with limited fuel pool capacity, are licensed for about 5 years and are supposed to operate until the on-site storage buildings are in operation.

In addition to the new on-site interim storage facilities, two central interim storage facilities located in Gorleben and Ahaus and one interim storage facility for spent fuel elements from the decommissioned experimental high temperature reactor AVR at Jülich as well as the Interim Storage Facility North (ZLN) at Rubenow near Greifswald for spent fuel elements from the decommissioned nuclear power plants at Greifswald and Rheinsberg are in operation. The interim storage building at Gorleben is the only one in Germany that has a license for the storage of vitrified high level radioactive waste (HLW) from reprocessing of German fuel rods abroad.

Licensing procedure:

The approval procedures for Type B(U) packages designs applied in Germany are in compliance with the provisions of the IAEA Regulations for the Safe Transport of Radioactive Material TS-R-1 [2]. The competent authority for the approval of such packages is the Federal Office for Radiation Protection (BfS). The Federal Institute for Materials Research and Testing (BAM) is the responsible German authority for safety assessment and comprehensive design testing of Type B(U) packages for the transportation of spent fuel assemblies. Basis for the package design approval procedure in Germany is the Guideline R 003 [3] issued by the Federal Ministry of Transport, Building and Housing (BMVBW) in 1991 (see also [12]). BAM deals especially with mechanical, thermal and release behavior under normal transport conditions and accident situations as well as quality-assurance measures for construction, manufacturing and use of Type B(U) packages.

Responsible for the licensing of interim storage facilities pursuant to § 6 of the German Atomic Energy Act is the Federal Office for Radiation Protection. BfS has involved experts and has ordered expert opinions with regard to safety of the facility, safety of the storage casks and environmental impact assessment. The licensing authority has to examine if the required protection is guaranteed. Responsible for the supervision during operation is the supervisory authority of the respective federal states. Both, BfS and the supervisory authority of the respective federal states have involved BAM as an technical expert organization in the field of thermal and mechanical safety as well as quality assurance in terms of storage of dual-purpose casks.

Technical aspects:

In Germany, for transport of spent fuel assemblies and subsequent dry interim storage massive, monolithic dual-purpose casks of the CASTOR® type made of ductile cast iron with spheroidal graphite are applied. Such casks for transport and dry interim storage have to fulfill the same basic requirements under accident conditions, which are safe enclosure of the radioactive inventory, subcriticality, sufficient dissipation of decay heat and shielding. Therefore, the assessment methods which are described by the IAEA transport regulations (tests with prototype casks, tests with scaled models, reference to previous safety demonstrations, calculations) are also valid for safety assessment under the storage site specific accident conditions. But the level of acceptable values differs depending on the storage site specific safety requirements. For instance, the transport regulations require a 9 m drop test onto an unyielding target. Consequently, the casks for transportation are equipped with impact limiters which lead to acceptable mechanical stresses of the cask structure under the 9 m drop. On the other hand, there are the storage site specific accident conditions which are the results of the respective safety analysis.

One of the most important differences is the seal performance. For dual-purpose casks not only the requirements for transport casks but also the seal performance for long-term storage has to be satisfied. For that purpose, the metal seals and double-lid structure are adopted to the cask design. In addition, the pressure between double lids is monitored. In the case of pure transport casks the use of only one sealed lid is licensed. Also corrosion behaviour and relaxation processes of all cask components taking into account the duration of interim storage have to be discussed. Another criterion that has to be taken into account is ageing of cask components due to radioactive irradiation, but the required performance after interim storage may be less stringent due to the decay of spent fuel activity. Detailed information on results of BAM investigation of thermal and mechanical behaviour especially of dual-purpose metal casks of the CASTOR® type can be found elsewhere [4] to [11].

For the safety analysis in the course of the licensing procedure of interim storage facilities the applicants often refer to the results of the safety analysis of Type B(U) licensing procedure. It is shown that the safety-relevant requirements of dual-purpose casks for dry interim storage are covered to a large extent by the Type B(U) licensing requirements especially quality assurance measures for cask manufacturing. Therefore the storage licenses demand valid Type B(U) licenses for all casks at least when they are shipped to the interim storage facility even if there is no transport on public routes.

But there is a controversial discussion about the necessity of the maintenance of Type B(U) licenses during the whole storage period. On one hand it is argued that caused by changing requirements of the regularly updated Type B(U) license casks may have to be handled and modified without any relevance to storage safety. On the other hand it is argued that such operations don't need to be performed before the final cask transport from the storage facility. However, it should not be forgotten that at the latest for the purpose of final disposal a transport on public routes is necessary and regaining a Type B(U) license will be - if possible at all - very complicated after several decades because the whole documentation of the casks including safety assessment reports will not be up to date then.

From the technical point of view it would be reasonable if a compromise could be found for dual-purpose casks used as transport cask only for shipping to an interim storage facility after loading and for shipping to a disposal facility after the interim storage period. A solution which is under discussion now is to extend the validity period of the Type B(U) license to 10 years if all casks of the design are loaded. Additionally every two years e.g. the transport license holder examines whether changed national regulations due to changes in IAEA regulations are relevant for the Type B(U) licenses. The result of this examination will be evaluated by the national competent authorities BfS and BAM. In addition, every five years BfS and BAM verify the cask design with respect to national regulations which are relevant for cask safety and for the Type B(U) license. If required the license holder has to create supporting documents. Every ten years the license holder applies for an extension of the Type B(U) license. For this purpose a revision of the security bulletin considering the current state-of-the-art of cask-specific technical aspects is necessary.

2. Influence of potential damages of metal seals on leak tightness

Experimental background:

A main aspect of transport cask qualification for interim storage is the long-term behaviour of the metallic seal lid system. Concerning this the influence of potential damages of metal seals used in dual-purpose casks of the CASTOR® type on leak tightness is investigated. The structural principle of such a metal seal of "Helicoflex" type, which are located in a groove at the bottom side of the primary and the secondary lid, is shown in Fig. 1. In Germany for spent fuel interim storage CASTOR® casks a leakage rate of $< 10^{-8}$ Pa·m^3/s (standard helium leakage rate) for each barrier (primary as well as secondary lid system) is required.

Fig. 1: General structure of "Helicoflex" type metal seals (German nomenclature of material numbers)

Since casks have been loaded under water in spent fuel storage pools of the NPP, in case of final pressing of the primary lid metallic seal before the drying procedure pool water can possibly remain in the gap between inner and outer jacket of this seal (see Fig. 2). For such a situation it has to be discussed the possibility of opening the outer

aluminium jacket by corrosion which would increase the number of possible leak path's from two (between outer jacket and lid/cask body) to four (in addition between inner and outer jackets). In order to investigate such potential effects of that humidity on the stability of the seal especially on leak tightness two types of experiments were performed.

In 2001 a test series has been started by BAM on behalf of the BfS to study corrosion effects possibly originated by the water in the jacket gap. Therefore in March 2001 four metal seals were filled with boronated water (concentration of 2040 ppm boron), which is also used in storage pools of German pressure water reactors, and installed in a flange system as shown in Fig. 3. The flange upper part is manufactured as a ring. Therefore, visual inspection of installed seals at any time during the test period is possible by simply removing the cover lid. Two seals are stored at room temperature and two seals are annealed at 80° C in a heating chamber. In addition, to stimulate corrosive damages in relative short time four seals were filled with water containing 10^{-3} mol of sodium chloride and installed in the flange system in October 2001. Two of these seals are stored at room temperature and two are annealed at 80° C in a heating chamber. Leakage rate measurements at all eight flanges are performed every six month using a helium mass spectrometer. Before the start of the test series one additional seal was filled with water containing 10^{-3} mol of sodium chloride and annealed at 80° C for three month. After that period the seal was removed and opened to inspect the inside of the outer aluminium jacket. This was performed to check the suitability of the water quality for the following long-term test series as described above.

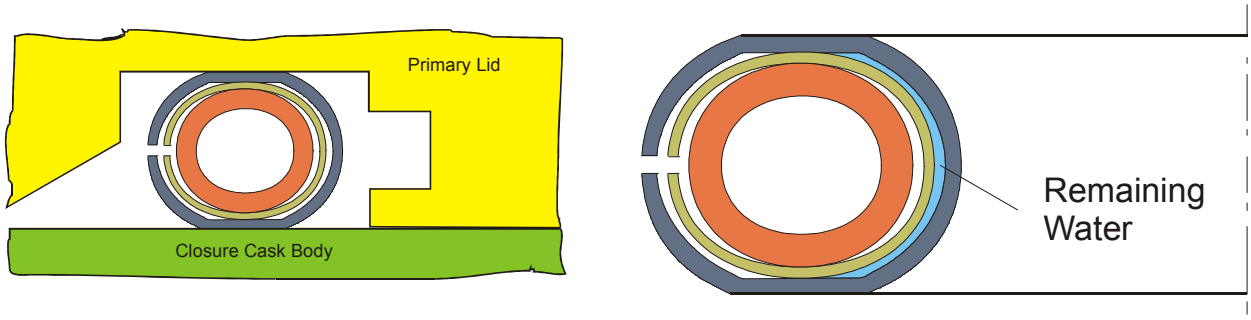

Fig. 2: Location of the seal in a dual-purpose CASTOR® cask (right), remaining water in the seal after final pressing of the seal before drying procedure (left)

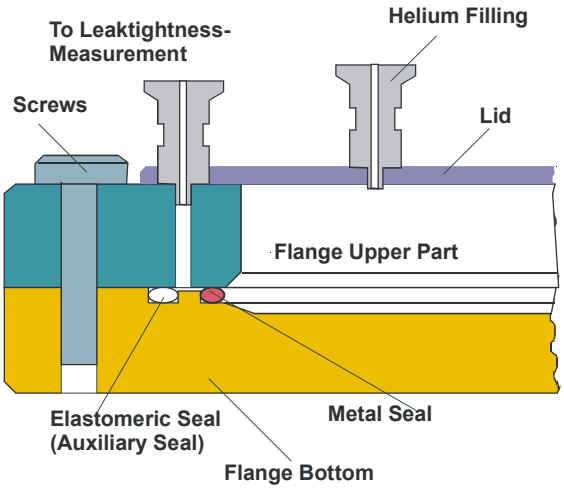

Fig. 3: Test flange system

Fig. 4: Seal with 16 points of defects, dimensions: slotted hole appr. 1,5 x 15 mm

Another investigation was separately performed to simulate a damage of the outer jacket due to corrosion. For that reason the outer aluminium jacket of a metallic seal was opened mechanically. Another seal prepared with 16 of such defects (see Fig. 4) was installed in the flange and subjected to leakage rate measurement, too. Moreover, the construction of the flange system as shown in Fig. 3 allows the mechanical treatment of the outer jacket of an al-

ready installed seal. Hence, it is possible to compare results of leakage tests before and after damaging of the outer jacket.

Experimental results:

For the seal which was annealed for three month and prepared with water containing 10^{-3} mol of sodium chloride no change of leakage rate (< 10^{-10} Pa·m^3/s, which is better than equipment sensitivity) was observed, although the inspection of the inside of the outer aluminium jacket by scanning electron microscopy displayed partial attacks of corrosion as can be seen in Fig. 5 and the water had completely disappeared. Hence, the observed partial corrosion damages of the aluminium jacket took place with less penetration depth.

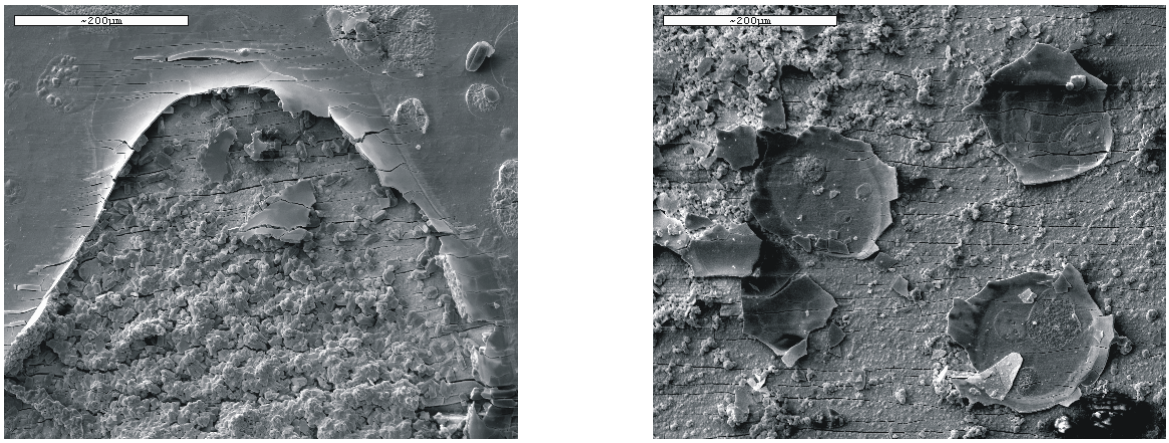

Fig. 5: Partial attacks of corrosion due to sodium chloride containing water after three months at 80 °C.

Leakage rate measurements of the mechanically damaged seals resulted in values < 10^{-10} Pa·m^3/s just before and after the damages were applied. With that it can be concluded that an open outer jacket does not influence the sealing quality. Therefore the same high sealing quality is realized by both the contact of inner and outer jacket as well as the contact of outer jacket and lid/cask body.

For all water filled seals leakage rate measurements have been performing every six month since preparation in March and September 2001. Up to now no increase of the initially determined leakage rate (< 10^{-10} Pa·m^3/s) has been observed.

Summarizing all results obtained so far by leakage rate measurements, no influence of partial mechanically destroyed outer aluminium jacket or of corrosion caused by water that may remain between inner and outer seal jackets on the initially high tightness quality was observed. The long-term tests will be continued during the next years.

3. "KOBAF" - a German concept for an authorities' and technical experts' information exchange system

As described in this paper, in the next few years several interim storage facilities for dual-purpose casks will be in operation on the sites of nuclear power plants in addition to the already existing central interim storage facilities in Germany. An important precondition for the storage of loaded dual-purpose casks in interim storage facilities is to fulfil numerous technical requirements with respect to safe enclosure of the radioactive inventory, subcriticality, sufficient dissipation of decay heat and shielding. These requirements are fixed for instance in the respective site-specific "technical conditions for acceptance". Responsible for the supervision during operation is the supervisory authority of the respective federal state. This also includes the proofs of quality assurance of the production of each individual container and all of its components up to the regulations for the assembly of the cover sealing systems after cask loading inside the NPP.

In order to keep comparable technical standards for all nuclear sites and storage facilities which are going to load and dispatch casks of the same or similar types under the responsibility of different supervisory authorities, in November 2002 German federal state governments decided to realize an authorities' and technical experts' exchange of experience, know-how and state of the art referring to cask dispatch in nuclear facilities - a so-called "co-

ordinating institution for cask dispatching information" (in German "KOBAF"). BAM has taken over a central role in KOBAF which contains an online data base of cask specific documents and a technical working group meeting twice a year.

The substantial component of KOBAF is the collection and supply of all information of cask construction, which are of importance for cask dispatching with respect to interim storage. Documents with relevance only for nuclear power plants or interim storage buildings are not considered. The operators of the interim storage facilities and cask suppliers were involved in the discussion for document selection. In principle four classes of documents are of interest:

- regulations for cask handling independent of interim storage facility e.g. working instructions, test regulations, assembly instructions,
- cask construction / cask type specific documents e.g. parts lists, assembly drawings and so called master flow diagrams
- storage facility dependent and cask related documents e.g. technical conditions for acceptance and experience reports with respect to cask dispatch and storage
- current information related to casks e.g. customer information of the cask manufacturer

According to these four groups of information and in order to create an easy-to-use and self-describing online data base (which is called "BIBO" and is managed by TUEVNord EnSys Hannover GmbH & Co. KG), the data base consists of the four linked general modules "regulations and instructions", "casks", "interim storage site" and "news".

With KOBAF the following advantages can be achieved:

- The information of the on-line data base are available at any time, whereas a high safety standard is assured by personal access authorization.
- The examination of the current state-of-the-art of cask-specific technical aspects can be done easily on the part of the licensing and supervisory authorities and expert organizations due to direct insight into required documents. Hence, fewer inquiries at operators, other authorities, consultants or experts and therefore less correspondence are necessary.
- It is possible to use already available inspection results from other supervision procedures, if they are of importance for the procedure which has to be examined. This should minimize the inspection expenditure and multiple checks of same circumstances in different supervision procedures can be avoided.
- By short-term information on experiences of cask dispatch in one interim storage facility, technical problems or additional effort during cask dispatch may be avoided in other interim storage facilities.
- Consistent surveyor's estimation of same technical criteria should be attained by regular technical discussions in the expert working group of KOBAF.

4. Summary

A large amount of type-B transport casks are going to be used for long-term dry interim storage in Germany. The question of time limited type-B license maintenance during the storage period of up to 40 years is currently discussed under technical and administrative aspects. As a first step a concept for the application of a 10 years duration of a Type B(U) license has now been developed in case that all casks of the design are loaded.

As a main aspect of transport cask qualification for interim storage results from current experimental long-term tests with metallic "Helicoflex"-seals with enclosed pool water were presented. At present, by leakage rate measurements no influence of partial mechanically destroyed outer aluminium jacket or of corrosion caused by water that may remain between inner and outer seal jackets on the initially high tightness quality was observed. The long term tests will be continued during the next years.

Finally, the paper presented a German concept for an authorities' and technical experts' exchange of experience, know-how and state of the art referring to cask dispatch in nuclear facilities. This so-called "co-ordinating institution for cask dispatching information" ("KOBAF") contains an online data base and a technical working group meeting twice a year. The goal is to keep comparable technical standards for all nuclear sites and storage facilities which are going to load and dispatch casks of the same or similar types under the responsibility of different German state governments for the next decades.

References

[1] Bundesamt für Strahlenschutz (BfS)
http://www.bfs.de/transport/gv/dezentrale_zl/karte.html

[2] International Atomic Energy Agency (IAEA)
TS-R-1, Regulations for the Safe Transport of Radioactive Materials 1996 Edition (as amended 2003), (Vienna; Austria: IAEA).

[3] Bundesministerium für Verkehr, Bau- und Wohnungswesen (BMVBW)
Richtlinien für das Verfahren der Bauartzulassung von Versandstücken zur Beförderung radioaktiver Stoffe - R 003 - vom 20. 02.1991
Verkehrsblatt, Heft 4, 1991, S. 231.

[4] Droste, B.
Bauartprüfung, Qualitssicherung und Sonderversuche mit CASTOR-Behältern.
Fachtagung Standortnahe Zwischenlager, Bonn, Germany, 14.-15.03.2004.

[5] Völzke, H., Droste, B. and Rödel, R.
Experiences and Status in Safety Assessment Methods within the Scope of Licensing Procedures for Multi-Purpose Flasks in Germany.
RAMTRANS, **11**(1-2), 39-43 (2000).

[6] Droste, B., Quercetti, T. and Gogolin, B.
Test Facilities for Radioactive Materials Transport Packagings (BAM, Germany).
RAMTRANS, **12**(3-4), 105-113 (2001).

[7] Droste, B., Völzke, H., Wieser, G. and Qiao, L.
Safety Margins of Spent Fuel Transport and Storage Casks Considering Aircraft Crash Impacts.
RAMTRANS, **13**(3-4), 313-316 (2002).

[8] Völzke, H., Wieser, G., Zencker, U., and Ballheimer, V.
German Cometent Authority Guidance in FE Methods Applications for Package Design Assessment.
14th Int. Symp. on the Packaging and Transportation of Radioactive Materials (PATRAM),
Berlin, Germany, September 20.-24.09.2004.

[9] Wieser, G. , Qiao, L., Völzke, H., Wolff, D. and Droste, B.
Safety Analysis of Casks under Extreme Impact Conditions.
14th Int. Symp. on the Packaging and Transportation of Radioactive Materials (PATRAM),
Berlin, Germany, September 20.-24.09.2004.

[10] Wieser, G., Qiao, L., Eberle, A. and Völzke, H.
Thermo-Mechanical Finite Element Analyses of Screwed Cask Lid Structures.
14th Int. Symp. on the Packaging and Transportation of Radioactive Materials (PATRAM),
Berlin, Germany, September 20.-24.09.2004.

[11] Droste, B., Ballheimer, V., Wieser, G. and Qiao, L.
Spent fuel Transport Associated with other Dangerous Goods in Regular Train Unit
- Assessment of Hypothetical Explosion Impacts-.
14th Int. Symp. on the Packaging and Transportation of Radioactive Materials (PATRAM),
Berlin, Germany, September 20.-24.09.2004.

[12] Nitsche, F. and Rödel, R.
Revised Guidelines for the Approval Procedure of Package Designs in Germany.
14th Int. Symp. on the Packaging and Transportation of Radioactive Materials (PATRAM),
Berlin, Germany, September 20.-24.09.2004.