Aging Management of Dual-Purpose Casks on the Example of CASTOR® KNK

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Abstract: In 2010 the spent fuel of the German prototype fast breeder reactor KNK was returned from France to Germany. For the return and the interim storage 4 transport and storage casks of the type CASTOR® KNK were designed and fabricated by GNS Gesellschaft für Nuklear-Service mbH. The casks were transported to Germany in December 2010 and stored in the interim storage facility ZLN operated by Energiewerke Nord GmbH (EWN). Due to there dual-purpose all CASTOR® casks have to fulfill the requirements of both fields of operation – transport and storage. After a minimum storage period of 40 years, a last transport to the final repository has to be carried out with the same requirements as for new casks. To be sure that the cask can be transported after the storage period the authorities require the renewal of the package design approval, normally each 5 or 10 years. In case of CASTOR® KNK the approval expires at October 2014. EWN and GNS are planning an extension of the validity period of the package design approval to 10 years. For this purpose an aging management report is necessary considering all stress factors, which are crucial for the rate of aging: Radiation, thermal and mechanical loads and corrosion.

Keywords: CASTOR, Dual-purpose cask, KNK, aging management, Germany

1. INTRODUCTION

In Germany there is so far no repository for high active waste, such as spent fuel assemblies or vitrified waste from reprocessing plants. That is why such waste is loaded into casks which may be used both for transport and for storage over a period of several decades. For this purpose, the German Company GNS Gesellschaft für Nuklearservice GmbH has developed the special CASTOR® type cask since the 1970es. The development of this cask type continued during the following years, being adapted to the specific cases. In the mean time, there are more than 20 different types of casks, which differ both in geometry (height, diameter, wall thickness) and in basket design, according to the specification of different plants and types of fuel.

Before loading the CASTOR® casks, a multitude of verifications are required to prove that the casks fulfill both the regulations of international requirements for legal transport regulations, for Type B(U) packagings, in agreement with the IAEA regulations, and also with national storage regulations according to the Atomic Law, requiring at least 40 years of interim storage. The license as transport cask is independent from concrete utilizations; license as storage cask is always granted for a specific storage purpose. For this, a storage license application is filed according to the Atomic Law, for storing the concerned CASTOR® casks in a specific interim storage facility. Fulfillment of the requirements for a storage period of 40 years must be proven within the scope of this application, that is, all aging factors which may occur during the interim storage period must be taken into account. Once it has been granted, the license for storage is valid during the whole interim storage period.

Due to the fact that the validity of the package design approval according to transport regulations is limited in time as opposed to the former, a renewal of the approval requires that it must be verified every 5 years that cask complies with the actualized transport regulations in every case. This also will

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be true when the concerned casks are not being transported during the considered period. This is based on the fact that the storage authorization according to the Atomic Law requires that it must be possible to transport casks for removal at any time.

Interim storage of the casks is decentralized in Germany. The used fuel assemblies are stored in interim storage facilities at the nuclear power plants, in so called on-site interim storage facilities. The only type of storage which was carried out centrally so far was that of waste returning from reprocessing in France. As soon as a repository is available, all casks must be transported there.

Till mid 2013 it was planned to construct a repository in a salt stock near Gorleben, in the North of Germany. This boundary condition was basically changed through the Repository Site Selection Act, which came into force in mid 2013. The repository searching process was initiated anew according to a transparent procedure, on a “blank” map of Germany, involving the public. The repository site shall be found till 2031. The approval and construction of the repository will follow. Final construction of the repository is not expected before 2050.

Due to the increased period of interim storage which will follow as a result of this, the question of aging management is being considered with increasing intensity by the authorities responsible for interim storage. In Germany, a periodic safety inspection which must take place every 10 years, as is required for nuclear power plants, is now being required for interim storage facilities. This must include a control of aging management.

Independently from the relevance of the increased interim storage period for the storage facilities themselves, the question is arising as to what the behavior of casks will be under normal conditions of transport and due to hypothetical incidents during transport, after 50 to 70 years of interim storage. Presently, the competent German Authorities are requiring detailed information concerning aging management, in order to take this question into account and to establish a base for significantly increased periods of approval.

2. BACKROUND KNK

The Compact Sodium-Cooled Nuclear Reactor Facility KNK II, located at the Karlsruhe Institute for Technology (KIT), the former Research Center Karlsruhe, has been operated from 1977 to 1991 as a prototype Fast Breeder Reactor facility. The fuel of the KNK II consisted of fuel assemblies (FA) with highly enriched Uranium-/Plutonium-MOX fuel (up to 93 % 235U enrichment and up to 35 % plutonium in the heavy metal).

The fuel rods were transported to C.E.A. (France) in 1993 for reprocessing. However, due to the low solubility of the MOX fuel 2413 fuel rods from 27 FA could not be reprocessed. They were encapsulated and stored in a pool of the French research centre Cadarache operated by the Commisariat à l'énergie atomique (C.E.A.).

In a German-French fuel return project these fuel rods was returned to Germany to be stored for long time storage in the interim storage facility ZLN operated by state-owned company Energiewerke Nord GmbH (EWN).

The project started in September 2001 and ended with the transport in December 2010 [1].

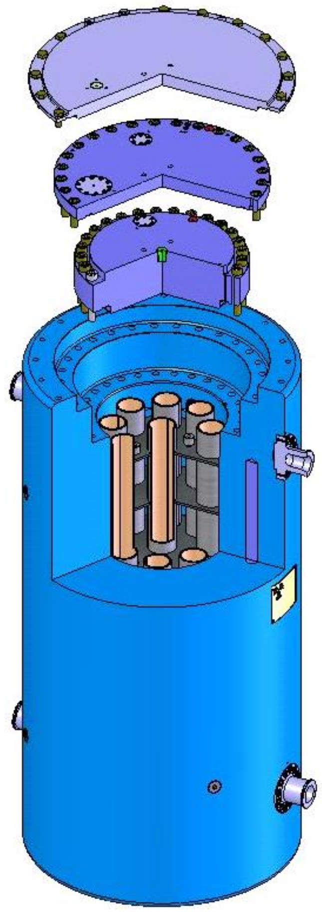
For the return and the interim storage of the fuel, 4 transport and storage casks of the type CASTOR® KNK were designed and fabricated by GNS Gesellschaft für Nuklear-Service mbH especially for this project.
The license for storage was granted in 2010 by Bundesamt für Strahlenschutz (BfS), valid for 40 years. The package design approval for transport was granted in 2009 by BfS, but only valid for 5 years.

3. CASK DESIGN

The transport and storage cask CASTOR® KNK consists of a thick-walled cylindrical cask body, which contains a basket for holding nine cans with the inventory, and is closed with a primary and a secondary lid with the associated bolts and seals. Figure 1 shows a 3D-model of the cask.

The cask body is made of ductile cast iron, the two lids are made of stainless steel. Above the secondary lid a protection plate of unalloyed structural steel is arranged to protect the lid system from external influences. For the crane handling, two trunnions each are arranged diametrically on the lid side and on the bottom side of the cask wall. As a transport package the cask equipped with lid side and bottom side shock absorbers. On the means of transport, the cask is covered by a transport hood that constitutes the readily accessible surface in the sense of the transport regulations.

Figure 1.
3D-Model of CASTOR® KNK



The main dimensions of the cask are approx.:
- outer diameter (without shock absorbers): 1380 mm
- width (with shock absorbers): 2090 mm
- height (without shock absorbers): 2784 mm
- height (with shock absorbers): 3906 mm
- inner diameter (cask body): 640 mm
- height of cask cavity: 2014 mm

The maximum mass (loaded, with shock absorbers) is approx. 32,500 kg, the mass without shock absorbers (loaded) is approx. 26,300 kg.

The inventory data of one cask are
- decay heat: 570 W
- total activity: 4.7×10^{15} Bq
- inventory mass: 500 kg
- heavy metal mass: 210 kg
- total mass U-235: 67 kg
- total mass Pu: 32 kg

4. REQUIREMENTS FOR RENEWAL OF PACKAGE DESIGN APPROVAL

The package design approval according to transport regulations for the CASTOR® KNK cask type expired in October 2014. The competent Authority is willing to grant a 10 years prolongation of the approval, provided the following conditions are fulfilled:
- the cask type is no longer being manufactured,
- all casks are loaded and stored in the interim storage facility,
- no transports are planned in the near future.

These boundary conditions are fulfilled for the CASTOR® KNK, so that it is endeavored to obtain a 10 years extension of the approval according to transport regulations.

For renewal of the package design approval it has to be demonstrated, that the Safety Analysis Report of the dual-purpose cask meets the state of the art. The state of the art permanently progresses. But new analysis methods require specific material parameters which often cannot be determined afterwards on the basis of available data. Due to this fact, the progression of the state of the art is one of the most challenging aspect in the long-term storage.
Active measures can be taken to increase the existing safety margins. Direct measures could be the re-design of the shock absorber or the introduction of an additional over-pack.
Indirect measures could be the mitigation of accident scenarios by new handling equipment/procedures or structural strengthening of the facility against outside impacts.

As mentioned in the beginning, the verification of the Safety Report has to be completed with an aging management report. The report has to reflect operation factors like handling and storage conditions and the experience during life time.

5. STORAGE

5.1 Actual storage situation

The interim storage facility ZLN is located near Greifswald at the Baltic Sea and is owned and operated by EWN GmbH, which is a 100 % daughter of the German Federal Ministry of Finance. As the KNK fuel is also owned by the German government and the Karlsruhe site has no storage facility for fuel any more, ZLN was chosen as interim storage. Figure 2 und 3 shows pictures of the premises, the ZLN facility and the storage hall.

Figure 2. Premises of EWN GmbH and Interim storage facility ZLN


Premises of Energiewerke Nord GmbH at the Baltic Sea


ZLN facility (red circle = storage hall 8)

Figure 3. 4 CASTOR® KNK casks between their “big brothers” in hall 8

The ZLN is a dry storage facility consisting of 8 storage halls. Halls 1-7 are used for non heat producing waste. CASTOR® casks may only be stored in hall 8. While air is being dried and heated by means of a ventilating system in halls 1-7, there is no supplementary ventilation system in hall 8. The heat from the casks is removed through natural convection. Special venting orifices in the walls and in the roof are provided for this purpose.

5.2 Possible Maintenance Actions to Control Aging

As a consequence of the storage requirements dual-purpose casks must have a double lid system, which is permanently monitored. Due to the double-lid design, the outer barrier (consisting of the secondary lid system and associated bolts and gaskets) can completely be removed without opening the inner containment of the radioactive material.

If the outer barrier would show any sign of intolerable aging effects, there is the opportunity to change or rework the affected components. Moreover, also the bolting of the primary lid system is completely accessible to test or to apply the specified torque of the bolting. The loss of pre-stress due to relaxation can be easily compensated.

For removable parts of the transport package aging effect can be eliminated by maintenance measures in advance. Only for the cask body, the basket and the primary lid system the influence of aging on specified characteristics must be ruled-out.

Some of the main components (cask body, basket, primary lid with bolts and metallic gasket and of course the fuel) cannot be substituted after the storage period and thus at least for those components aging management is already necessary in the casks design phase to avoid later interventions. Here the term aging means changes of characteristics of the cask, its components or the inventory with time or use. It is the task of the designer and user to take engineering, operation and maintenance actions to control the aging effects of the cask and its components within acceptable limits in order to ensure the specified characteristics and functionality over the complete lifetime cycle.

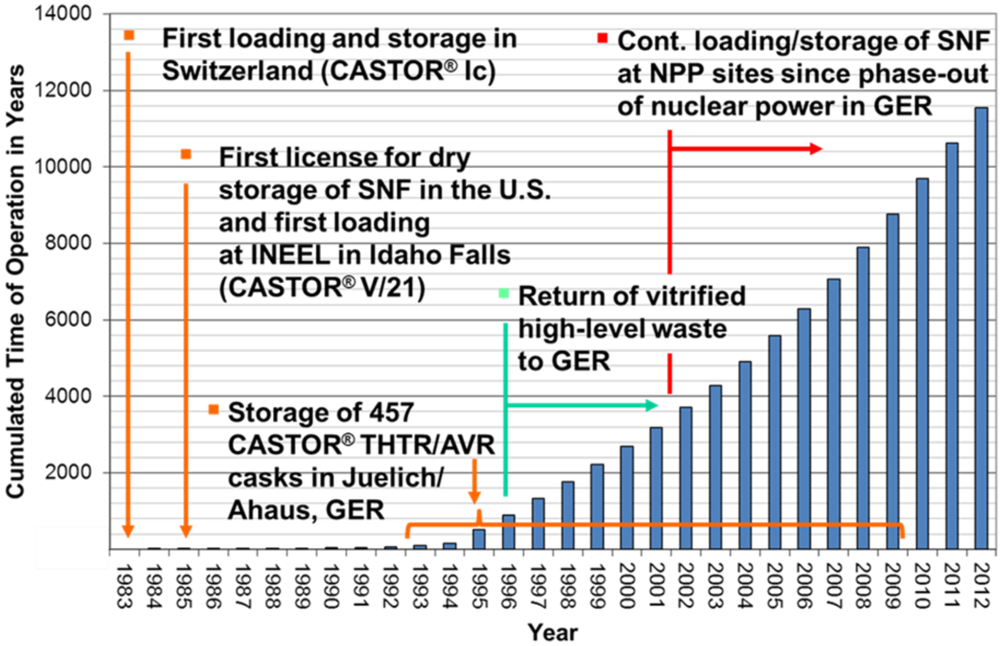
6. EVALUATION OF AGING INFLUENCES

6.1 Experiences by GNS

By now, more than 1,000 CASTOR® casks are in operation, about half of them in storage facilities operated by GNS. The overall storage time of CASTOR® casks worldwide sums up to more than 10,000 years (see Figure 4), while the storage period of single casks reaches up to 30 years. With this huge operational experience the CASTOR® design has got an in-service proof of its long-term operational reliability. [2]

On the basis of the operational experiences it can be concluded, that design and operation of CASTOR® casks is appropriate to keep the effects of aging within acceptable limits and to ensure the required functionality over the complete life cycle.

Figure 4. Cumulated time of operation of CASTOR® casks worldwide



6.2 Operational influence factors

The following influences are investigated within the scope of the evaluation of aging effects:

Environmental and handling influences

The following environmental and handling influences are being evaluated in relation to the interim storage facility:

- environmental temperature and change of temperature
- humidity
- aggressive media
- UV radiation
- mechanical stresses (dynamic and static stresses)

Inventory influences

The radioactive material in the casks has gone through a multitude of nuclear reactions and activation processes during reactor operation. Accordingly, during the following radioactive decay or during the cooling time, all types of radioactive radiation are being emitted by the inventory. As alpha and beta radiation merely have a short range, only neutron and gamma radiation are taken into account when considering the interactions with cask components. Due their long range, both types of radiation reach all cask components. Furthermore, the kinetic energy released during the radioactive decay of the inventory (especially beta minus decays and gamma radiation), the so-called decay heat must be removed passively over the cask components and transferred to the environment. The component and inventory temperatures during the corresponding operating phases are significant when evaluating material behavior.

The following parameters are taken into account:

- decay thermal power
- radioactive radiation
- residual humidity
- nuclides due to nuclear reactions

Influences due to design

Those influences resulting from the design and the dispatching of the casks are considered as influences due to design. These include on the one hand mechanical stresses resulting from the tightening torques of screwed connections, the compression of gaskets and pressurizations, and on the other, materials mating due to design.

Consequential influences

The above mentioned influences due to operation and inventory will cause effects which themselves may cause the release of materials, which in turn may influence the materials. Thus, different mechanisms may be the cause of hydrogen release, of hydrogen peroxide and of other aggressive media generation.

6.3 Aging effects

During storage, the casks are subject to effects which may modify their structural material characteristics. Possible effects and their consequences on the cask components shall now be explained. It will furthermore be explained which effects resulting from these influences will cause no impairments, so that they must not be evaluated in the following chapter.

Structural changes

Temperature effects and/or neutron irradiation may cause changes of the crystalline structure and of the microstructure of the materials. No structural changes of the metallic and inorganic materials caused as a consequence of thermal effects must be expected at the temperatures considered here. However, in principle, structural changes due to irradiation are possible.

Creeping/relaxation

When materials are submitted to mechanical stress, this will cause a diffusion of vacancies, to displacements of dislocations and/or to gliding processes along gliding planes. Due to this, plastic deformations may occur already below the apparent yielding point. Different effects may result from these creeping effects.
Screws may be subject to extension of length due to these creeping processes. This means a loss of the adjusted preliminary strain. This effect is called relaxation, and must only be considered for screws.
As only metallic gaskets and screws are subject to mechanical stress, the evaluation of creeping processes will remain limited to these two components.

Chemical reactions

Chemical reactions will cause changes of the electron shell of the participating atoms, resulting in changes of the linking conditions within the molecules. This may cause the breaking of bonds and the formation of new ones. The different reactions which may result are:

- solid state reactions
- gaseous phase reactions
- reactions in solutions

Anodic and cathodic partial reactions may occur separately on a surface or on different surfaces. This will lead to different mechanisms and corrosion effects, such as

- surface corrosion
  both the GGG material used as cask body material, as also the unalloyed and low-alloyed steels and zinc will present a tendency to surface corrosion under the boundary conditions considered here.
  As most of the used structural materials consist of these, the cask components must be evaluated for uniform corrosion.

- Galvanic corrosion (contact corrosion)
  The casks which must be evaluated are made of a multitude of different materials which are in contact with one another. Thus, galvanic corrosion must be evaluated.

- Pitting
  Pitting occurs in metals which may form a passive surface layer. Components made of stainless steel, of aluminum and aluminium alloys, are used in the casks. These materials generate native passive layers. However, as no aggressive media will be used, or be generated during interim storage, no pitting is expected.

7. EVALUATING OPERATING EXPERIENCE WITH CASTOR® KNK

The following operating phases are taken into account for evaluation:

- loading,
- transport to the interim storage facility,
- long term interim storage,
- transport to a nuclear facility after interim storage.

Before loading, it is assured by means of examinations that the cask is in the conditions required by specifications. The unloaded casks will be submitted neither to radiation nor to decay heat before being loaded, so that aging effects dating from the time before loading may be excluded.

7.1 Loading

Place and date of loading
The casks were loaded mid 2010 at Cadarache, in France. Nothing noteworthiness was observed during loading. Figure 5 shows the interior of a loaded CASTOR® KNK, and the exterior lid (protection plate) after lead sealing.

Figure 5. Pictures of CASTOR® KNK, basket with 9 cans and lid with seal

Inventory

- Specifying inventory.
  Due to the high enrichment of MOX fuel, criticality design of the cask was carried out using actual fuel data, that is, each of the four casks has its own inventory data sheet. During loading, it was controlled and recorded that the fuel rods cans mentioned in the inventory data sheet are putted into the correct casks.

- Thermal power at the time of loading, and comparison with design data.
  Layout values according to the maximum admissible decay power amounted to 567 W for CASTOR® KNK; the real decay powers of the 4 casks were below the layout value (max. 422 W) at the time of loading.

- Dose rate at the time of loading, and comparison with calculations / limit values.
  At the time of loading, the measured real values were lower than the layout values and the transport limit values.

- Temperature at the time of loading, and comparison with calculations / limit values.
  At the time of loading, the measured real temperatures were lower than the layout values or respectively the maximum admissible temperatures.

7.2 Public transports

Date, duration, beginning, destination, means of conveyance
Transport was carried out as a road transport from C.E.A. Cadarache to the transshipment station of Les Milles, followed by rail transport from Les Milles to Lubmin ZLN (Figure 6)

Departure Cadarache:	Dec. 13, 2010
Transfer at Les Milles:	Dec. 14, 2010
Arrival at ZLN:	Dec. 16, 2010, 23.35 hours

Figure 6. Transport on rail from Les Milles , Southern France, to Lubmin, Northern Germany

Transport configuration
Transport configuration for road and rail, consisting of vehicle, adapter plates, holding down clamp, transport frame, cask, transport hood (Figure 7). The trunnions do not interfere with the transport frame.

Figure 7. Cask on the transport frame

7.3 Storage

<u>Bringing into storage</u>
The casks are raised to vertical position after arrival (Figure 8), and transported to the place of intervention, where necessary dose rate, neutron radiation and contamination measurements, as well as tightness tests of the protection plate (Figure 9) were carried out. The casks were then sealed and brought to their storage positions.

Figure 8. Cask handling at ZLN with horizontal and vertical lifting beam

Figure 9. Neutron Measurement and leak test

Position of the cask and of the surrounding casks
The casks were brought into storage according to the authorized storage position configuration. In 2011, the latter was changed, due to increased safety requirements. Neighboring casks are documented.

Temperature and humidity in the storage facility
The parameters temperature, relative ambient humidity, ambient pressure and dew point temperature are measured and recorded once an hour inside and for comparison outside the storage facility.

Exchange of air with environment outside the storage facility
Ventilation in hall 8 is designed as natural ventilation. Venetian shutters are installed in the north wall, to assure regulation of the volume stream. These are automatically opened or closed by means of servo motors, depending on temperature within the hall. The roof of hall 8 has 160 ventilator cowls arrayed in 32 rows, to assure ventilation. The maximum volume stream of this passive ventilating system amounts to 260,000 m^3/h. Heat transfer is assured by convection. Temperature exchange over walls, roof and floor is insignificant.

Particular events during storage

- Failing pressure switch
  The pressure switch was replaced after the failure was identified. The failing pressure switch was sent to GNS for examination.

- Penetration of water into hall 8
  Due to unfavorable weather conditions, snow penetrated into hall 8 in March of 2013, through the ventilation cowls on the roof. Melting water covered the floor of hall 8, and the bottoms of some of the transport and storage casks. Water also was found under the 4 CASTOR® KNK casks. The cask bottoms however were not wet, because the casks stand on pads.

7.4 Findings resulting from storage to this day

Aging effects / corrosion
So far, CASTOR® KNK casks have been stored for 3 years. No aging effects or corrosion were found during this period.

Required conservation measures
Storage experience revealed that no supplementary conservation measures are necessary.

7.5 Repairs / Maintenance

Repair measures
No repairs were required during the storage period.

Maintenance
- Replacement of the pressure switch
- Changing the storage position of 2 casks due to operating conditions. The bottoms of the casks were examined visually during this procedure.

7.6 Periodic inspections carried out

So far, no periodic inspection was required for CASTOR® KNK.

8. CONCLUSION

Experience obtained during operation and storage showed that the conditions of transport and storage cask CASTOR® KNK fulfills the requirements of transport regulations, and that it may continue to be manufactured as planned, thanks to well defined and authorized measures.

Sufficient conservation measures were carried out for all casks, to assure protection against corrosive influences.

So far, no safety relevant aging effects were found for casks according to CASTOR® KNK design. Protection objectives were continuously assured during the total storage period.

Summarizing, it may be stated that the regulations and verification measures on which the safety technological layout of design package CASTOR® KNK as based on the safety report continue to be valid.

Evaluation of the operating experience shows that the design of package design CASTOR® KNK is sufficiently robust as far as storage and transport regulation requirements are concerned.

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