CASTOR® HAW28M - a high heat load cask for transport and storage of vitrified high level waste containers

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1. Introduction

Within the German return programme for vitrified high level waste (HLW) from reprocessing at COGEMA and BNFL up to now 39 casks loaded with 28 containers each were transported back to Germany and are stored in the Interim Storage Facility Gorleben (TBL-G) for up to 40 years. For transport and storage in all but one case the GNB casks CASTOR® HAW 20/28 CG have been used. This cask type is designed to accommodate 20 or 28 HLW containers with a total thermal power of 45 kW maximum.

In the near future, among the high level waste, which has to be returned to Germany, there will be an increasing number of containers of which the heat capacity and radioactive inventory will exceed the technical limits of the CASTOR® HAW 20/28 CG. Therefore GNB has started the development of a new cask generation, named CASTOR® HAW28M, meeting these future requirements.

The CASTOR® HAW28M is especially developed for the transport of vitrified residues from France [1] and Great Britain [2] to Germany. It complies with the international regulations for type B packages according to IAEA (International Atomic Energy Agency) [3]. It is thus guaranteed that even in case of any accident the cask body and the lid system remain functional and the safe confinement of the radioactive contents remains intact during transport.

The CASTOR® HAW28M fulfills not only the requirements for transport but also the acceptance criteria of interim storage: radiation shielding, heat dissipation, safe confinement under both normal and hypothetical accident conditions. Storage buildings such as the TBL-G simply support the safety functions of the cask.

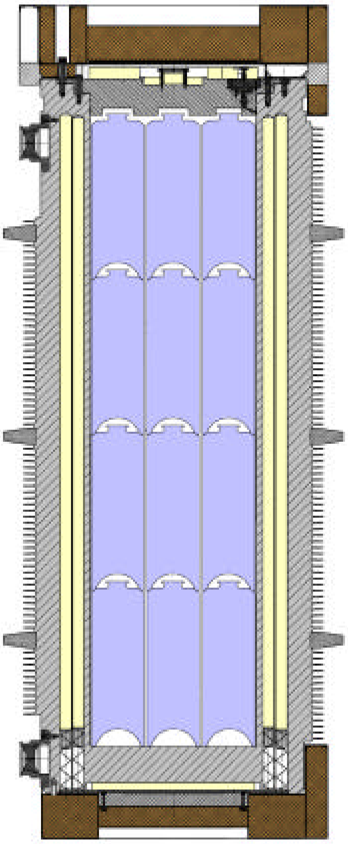
The challenge for the development results from higher requirements of the technical specification, particularly related to fuel which is reprocessed. As a consequence of the reprocessing of fuel with increased enrichment and burn up, higher heat capacity and sophisticated shielding measures have to be considered. For the CASTOR® HAW28M new materials and new design methodologies have been developed and applied.

The following sections give an overview on the design characteristics, the cask materials developed and the safety analyses performed.

2. Design Characteristics of the CASTOR® HAW28M

The CASTOR® HAW28M is designed to accommodate 28 containers with vitrified high level waste with a total thermal power of maximal 56 kW and a total activity of maximal 1270 PBq. The HLW containers consist of stainless steel cans filled with glass, containing highly radioactive fission products. The glass filled cans are tightly welded with a lid. The maximum thermal power of a single glass container to be loaded can reach 2 kW.

Figure 1 gives an overview of design characteristics, main dimensions and masses of the CASTOR® HAW28M.



Technical Data:

Length	6765 mm 1) 6122 mm 2)
Outer Diameter	2750 mm 1) 2430 mm 2)
Cavity Height	5180 mm
Cavity Diameter	1350 mm
Weight Empty	101,6 t 1) 99, 6 t 2)
Weight Loaded	116,4 t 1) 114,4 t 2)

1) Transport Configuration
2) Storage Configuration

Figure 1 Design Characteristics and Technical Data of the CASTOR® HAW28M

The cask consists of the thick-walled cylindrical cask body made of ductile cast iron. In order to best secure the neutron moderation axial boreholes are drilled into the cask wall which contain moderator rods. In the bottom area a cylindrical moderator plate is inserted and sealed with a bolted sealing plate. In addition, a multi part moderator plate is placed and attached on the top side of the primary lid.

On the outside wall of the cask, radial cooling fins are machined to improve the heat transfer from the cask to the environment. The outer surface is protected by a coat of paint.

The glass containers are positioned in seven stacks consisting of four containers each. In order to keep the glass containers in position and to guarantee sufficient heat removal to the cask body, a basket is installed in the cylindrical cavity. The basket also includes shielding elements consisting of encapsulated graphite, which are arranged between the outer stacks of containers and the cavity wall.

The cavity of the cask is closed by a primary lid with its bolts and a metal seal. A lifting device which allows attachment of lifting equipment is installed in the primary lid for handling operations. The primary lid has a handling connection which leads into the cavity and is required for the evacuation and filling of the cavity with an inert gas. The handling connection is closed by a closure lid sealed with a metal seal.

On the outside of the cask body, there are 2 trunnions at both the bottom and lid side ends arranged diametrically in pairs. During the handling in vertical position, the package is fixed to the lid side trunnions, in the horizontal position it is fixed to all four trunnions. During transport, the package is fixed to all four trunnions in a special transport frame and secured.

During transport on public routes, the cask is equipped with shock absorbers as parts of the package.

Prior to interim storage, the shock absorbers are removed and a secondary lid with metal seals is bolted onto the cask body above the primary lid and, additionally, a protection lid is installed above the secondary lid.
The space between primary and secondary lid is filled by helium under overpressure; the permanent control of this pressure delivers the tightness information during the long-term storage.

3. Cask Materials

As a base material for the cask body, ductile cast iron (DCI) was chosen, which has sufficient ductility, is good shielding, easy to machine, relatively inexpensive, and has been developed to a reproducible superior quality in co-operation with renowned foundries. Extensive mechanical test programmes for licensing were performed with numerous model test casks and prototypes under extreme conditions representing severe accident scenarios. The tests were the basis for the licensing of the CASTOR®-family as a type B (U) transport cask design and for the long-term interim storage.

The CASTOR HAW28M is a high heat load cask for transport and storage of vitrified high level waste containers. Therefore, even new materials and designs have been developed and applied for that cask. Among others, neutron shielding parts made of polyethylene have been designed. Because of the high decay heat of the radioactive content, special investigations have been done by GNB for special mixtures of polyethylene at temperatures up to a value of 160 °C, and new criteria for the assessment of the behaviour of polyethylene in amorphic conditions have been developed by the Federal Institute of Material Research and Testing (BAM). Some results of special investigations and appropriated assessments are given in [4].

In addition to the above mentioned materials, shielding parts made of graphite mixtures have been designed for the use within the cavity of the cask and aluminium alloys were investigated during the development of additional shock absorbing devices.

4. Safety Analyses

The analyses of shielding and thermal behaviour as well as of cask strength according to IAEA Type B test-requirements (9m drop, 1m pin drop, 800 °C fire test) and of the cask behaviour during accident scenarios at the storage site (drop, fire, gas cloud explosion, collision of casks) were carried out by means of qualified calculation methods and programmes, which are well established and accepted by the competent authorities.

The mechanical analysis under hypothetical accident conditions for different loading cases (drop in different impact orientations of the cask) were performed with numerical methods, like Finite-Element-calculations (FEM) with ANSYS. The used calculation model consists of lower bound material properties, 3-dimensional simulation of the cask geometry, reasonable assumptions and clearly defined boundary conditions. As a result of the calculation the local distribution of all stress tensors inside the cask body is known (see example in Figure 2).

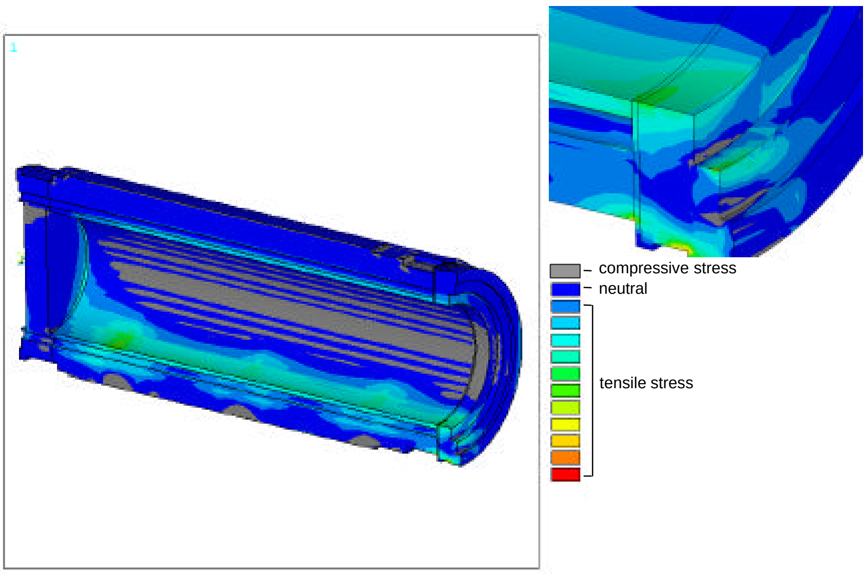


Figure 2 Quasi-Statically Calculations of the Stresses during the 9-m- Drop (ANSYS)

In the framework of the safety assessment stress limitation criteria were defined in order to assure a sufficient margin against plastic deformation and brittle failure (see detailed description in [5]). These criteria consider the behavior of ductile cast iron as well as the applied method for stress calculation. The strength analysis has shown that the mechanical stresses under both normal operational and test/accidental conditions are below the respective allowable stresses.

The results of the safety analysis after drop tests according to IAEA-regulations will be confirmed by means of a drop test programme using a scaled model. The tests will be performed under supervision of competent authorities and independent experts, such as BAM and German TÜV. For preparation of the drop tests, detailed calculations of the dynamic behaviour with the code LS-DYNA were performed. As an example, Figure 3 shows the result of the deformation during a 9-m drop.

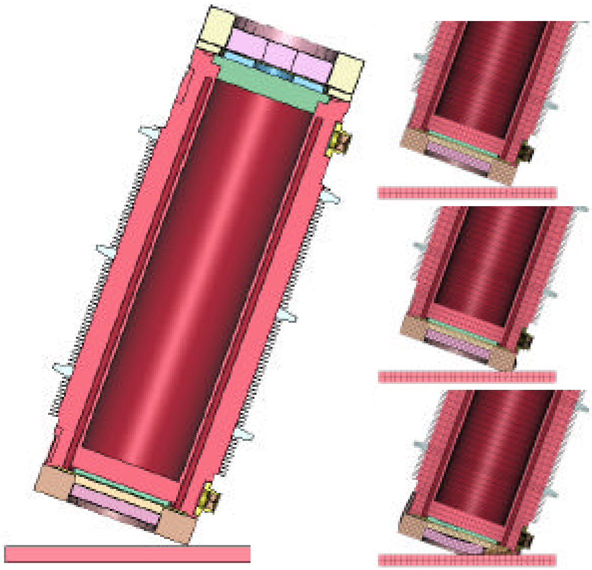


Figure 3 Dynamic Calculations of the deformations during 9-m-Edge Drop (LS-DYNA)

The thermal behaviour of the cask and inventory was analysed for the normal transport conditions and for the IAEA fire test conditions as well as for storage conditions. The respective analyses were performed by means of composed numerical-analytical methods (state thermal condition) and numerical non-steady state methods (cask under fire conditions) using the finite element code ANSYS.

As an example of the ANSYS analysis results, the temperature distributation of the cask and inventory as well as the temperature profile at the cask surface are depicted in Figure 4.

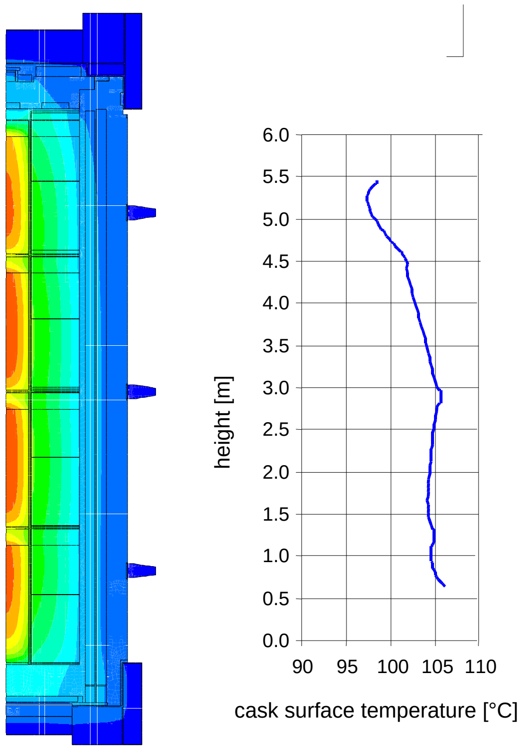


Figure 4 Calculated Temperatures for Normal Conditions (ANSYS)

For the thermal analyses, it has been assumed that the package, consisting of the cask with inventory and impact limiters, is transported horizontally. The decay heat generated within the containers is conveyed by means of thermal radiation and thermal conduction from the surfaces of the containers to the basket and then - predominantly by means of thermal conduction - to the outer surface of the basket. In the gap between the basket and the cavity wall, the heat is conveyed by means of radiation and conduction. In the cask side wall, the heat is conveyed to the surface of the cask mainly by conduction. From the surface of the cask, the heat is dissipated by means of radiation and natural convection to the environment.

The shielding analyses were performed with MCNP, which is a Monte Carlo transport code that offers a three-dimensional combinatorial geometry modelling capability including complex surfaces. For normal transport conditions the cask was modelled with the impact limiters and the transport hood. The hypothetical accident conditions assume the absence of the transport hood, the impact limiters and the neutron moderator. The shielding analysis covers the hypothetical accident conditions in the related regulation in a conservative manner, because in reality the impact limiters remain on the cask and the total loss of the neutron moderator is not possible. Moderator regions in the shielding model are replaced by air.

With the three-dimensional modelling it is possible to model each container. As a result, the local shielding ability of the cask can effectively been used. For each container activity limits are derived for the main neutron an gamma generating nuclides. With these limits it is guaranteed that during transport the dose exposure is always lower than the limits of the IAEA regulations.

As an example of the shielding calculations the contribution of the radionuclides EU-154 (gamma) and Am-241 (neutron) of each canister of one stack to the dose rate (2 m distance to cask surface opposite of the stack) is depicted in figure 5.

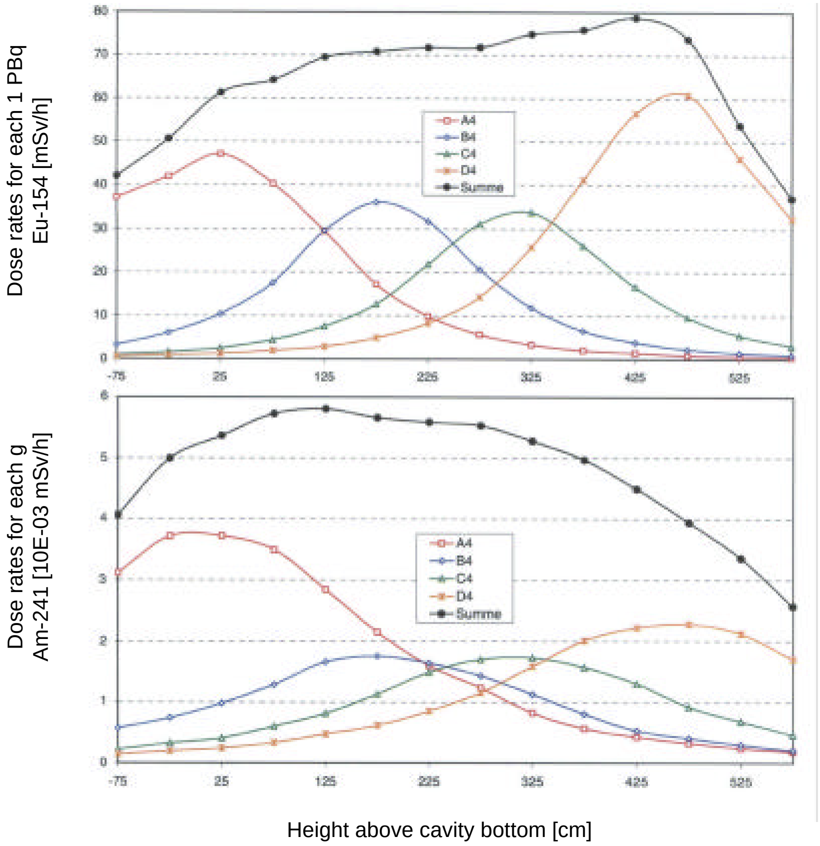


Figure 5 Exemplary dose rate calculations for Eu-154 (gamma) and Am-241 (neutron)

The three-dimensional Monte Carlo code KENO was selected for performing the criticality analysis because it has been extensively used and validated by others and has all the necessary features for this analysis. The criticality calculations were performed with the SCALE program system.

5. Summary and Conclusion

Within the German return programme for vitrified high level waste (HLW) from reprocessing at COGEMA and BNFL, up to now 39 casks loaded with 28 containers each were transported back to Germany and are stored in Gorleben for up to 40 years. For transport and storage in all but one case the GNB casks CASTOR® HAW 20/28 CG have been used. This cask is an approved design for loading, transport and storage of HLW which shows the well-elaborated and extensively applied technology of GNB casks. Nevertheless, modified types with a higher loading capacity are in the development stage to fulfil future requirements.

The challenge for further development results from higher requirements of the technical specification, particularly related to fuel which is reprocessed. As a consequence of the reprocessing of fuel with increase in enrichment and burn up, higher heat capacity and sophisticated shielding measures have to be considered.

Therefore, GNB has performed development of a new cask generation, named CASTOR® HAW28M, meeting these future requirements. It is designed to accommodate 28 containers with vitrified high level waste from the reprocessing plants at COGEMA and BNFL with a total thermal power of 56 kW maximum and a total activity of 1270 PBq maximum.

For the CASTOR® HAW28M new materials and new design methodologies have been developed and applied.
The licensing procedure for the cask has already started. Within this procedure, drop tests will be performed under supervision of the Federal Institute of Material Research and Testing (BAM).

6. References

[1] COGEMA, Specifications of vitrified residues produced from reprocessing at UP 2 or UP 3 - A La Hague plants Second Series, July 1986

[2] British Nuclear Fuels plc (BNFL), Vitrified Residue Specification, March 1990

[3] International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Material, Safety Standards Series no. TS-R-1 (St-1, Revised), 1996 Edition (Revised), IAEA, Vienna (2000) International

[4] T. Krietsch, D. Wolff, U.Knopp, H.-D. Brocke, Behaviour of Neutron Moderator Material at High Temperatures in CASTOR® Casks – Qualification and Assessment, The 14th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2004), Berlin, September 20-24, 2004

[5] R. Hüggenberg, K. Klein, J. Holub, Concept of stress limitation for CASTOR® casks made of ductile cast iron, The 14th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2004), Berlin, September 20-24, 2004