CONSTOR® full-scale prototype drop test and measuring program

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Introduction

The CONSTOR® steel-sandwich cask was developed as a cost-effective design by using conventional mechanical engineering technologies and commonly available materials. The CONSTOR® consists of a cask body with an outer and an inner liner made of steel. At the upper end, the liners are welded to a ring made of forged steel. The space between the two liners is filled with heavy concrete named CONSTORIT for additional gamma and neutron shielding. The CONSTORIT consists of an iron aggregate frame and hardened cement paste. The liners of the cask and the forged head ring form the basis for the structural integrity, the CONSTORIT bears only a menial part of accident loads.

The CONSTOR® concept fulfils both the internationally valid IAEA criteria for transportation and the requirements for long-term intermediate storage in the US and various European countries.

Since the beginning of the development of the CONSTOR® design in the early nineties, two drop test series with half-scale models have already been performed:

In 1997, a drop test program containing 9-meter drops and 1-meter pin-drops was performed with the CONSTOR® VB-1, a 1:2 model of a CONSTOR® RBMK 1500 that was designed for the storage of RBMK fuel in Lithuania. To date, 60 CONSTOR® casks of this type have been delivered to the Ignalina Nuclear Power Plant. They are loaded and in operation on the storage site.

In 2002, another drop test program with an advanced CONSTOR® cask design (CONSTOR® VB-2, see Fig. 1) was performed. The geometry was the same as for the CONSTOR® VB-1. To improve the heat removal properties in comparison with the CONSTOR® VB-1, heat conducting elements were arranged inside the CONSTORIT. The name for the new CONSTOR® cask series is CONSTOR® V.

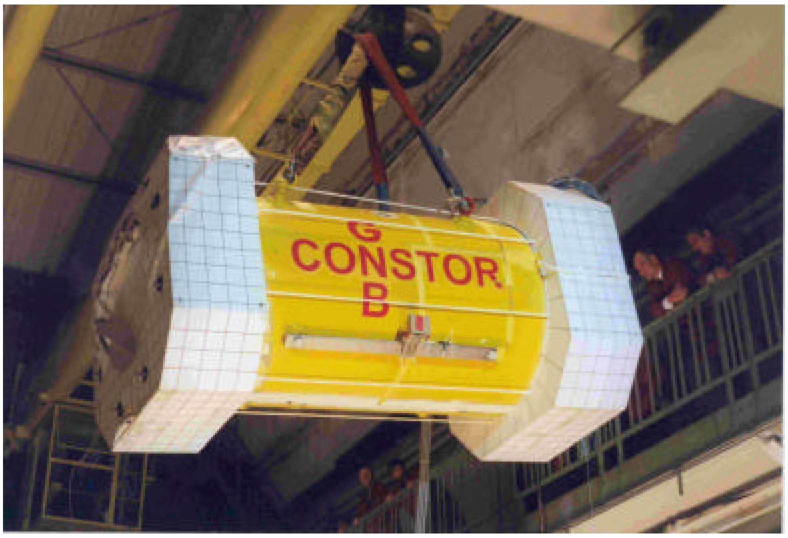

Fig. 1 Test Cask CONSTOR® VB-2 with octogonal impact limiters

The results of the CONSTOR® VB-2 drop test program showed that the integrity and leak tightness of the liner welds were maintained over the whole test series. However, the 1-meter pin-drop test turned out to be the most demanding condition for the cask integrity. To enhance the analytical safety margins for the mechanics during transport accidents, the enlargement of the liner thickness were thoroughly discussed. As a result, the development of the puncture-resistant jacket started: Instead of enlarging the cask walls for the transport, the intended purpose were achieved by an additional steel liner. It provided the opportunity to separate requirements for the storage and the transport application.

By this means, handling procedures at the facilities did not need to be complicated because of the enhanced cask weight. Besides that, the economics of the transport and storage system are less affected because there is only a small number of puncture-resistant jackets needed.

The design of the puncture-resistant jacket was realised for the first time for the CONSTOR® V/TC.

A full-scale model of a CONSTOR® V for BWR inventory has been manufactured for the third drop test program starting in 2004, and will be presented in a first 9-meter drop test on the BAM drop test facility at Horstwalde near Berlin during the PATRAM 2004 Symposium. The transport package consists of a cask with a dummy basket, a puncture-resistant jacket and two impact limiters.

The full-scale model CONSTOR® V/TC

The CONSTOR® V/TC (see Fig. 2) represents a prototype of a CONSTOR® V/69 and is very similar to the CONSTOR® V/32. These casks are designed to store BWR-inventory or PWR inventory, respectively, according to international requirements, the US-NRC among others. These casks are presented in the PATRAM 2004 paper "The use of the CONSTOR® cask concept for light water reactor fuel".

The CONSTOR® V/TC also represents the basic CONSTOR® design. It consists of a cask body with an outer and an inner liner made of steel. At the upper end, the liners are welded to a ring made of forged steel. The space between the two liners is filled with CONSTORIT. Additional to the basic CONSTOR® design, it has the features of the advanced CONSTOR® design for heat loads up to 30 kW, that was firstly realised with the building of the CONSTOR® VB-2: Copper heat conducting elements and CONSTORIT.

The lid system comprises a steel shielding lid which rests on an inclined ring surface in the head ring and is fixed in axial direction by means of form-fit retaining elements in a channel within the head ring, as well as a closure lid with screwed connection and sealed with two metal O-rings.

Thus, the transport containment is constituted by the inner liner, the head ring and the closure lid with the two metal O-rings.

The mass of the basket and the inventory are provided in the form of an inventory dummy (see Fig. 3) consisting of axially arranged steel disk elements, with torsion locks and spacers. The torsion lock device ensures that the instrumentation for strain and acceleration measurements cannot be damaged during the tests. The basket dummy represents the mass of the fuel elements and the basket as well as the load applied to the cask body during the 9-meter drop and the 1-meter pin-drop tests. The total weight of the dummy (~36 t) corresponds to the weight of the basket with fuel elements of the CONSTOR® V/69.

Between the upper end of the inventory dummy and the shielding lid, the largest possible axial distance is selected. This ensures that in case of a secondary impact (drop position on lid system or bottom side) the largest possible load is applied to the shielding lid or the bottom of the cask.

Octagonal impact limiters are used for the tests. Bottom and lid shock absorbers consists of several layers of wood which are encapsulated in steel sheet structures. To resist the puncture during the 1-meter pin drop, the closure lid is protected by a thick steel sheet. To this sheet, a ring is fully welded which is designed to protect the cask during the 1-meter pin drop at its lid and bottom ends. The impact limiters are attached to the CONSTOR® V/TC on the puncture-resistant jacket (see Fig. 4).

In 2004, the prototype of the CONSTOR® V/TC was manufactured and the referring drop test program has been planned.

In Tabs. 1 and 2, the geometrical data and the masses of the cask and its components for the transport configuration are shown.

Fig. 2 CONSTOR® V/TC general view

Fig. 3 CONSTOR® V/TC dummy basket

Fig. 3 CONSTOR® V/TC transport package at GNB in Mülheim

Cask length with impact limiters	7 445 mm
Outer Diameter of the cask	2 332 mm
Outer Diameter of the impact limiters	3 510 mm
Outer Diameter of the puncture-resistant jacket	2 592 mm

Tab. 1 Geometrical Data of the test cask and its components for the transport configuration

Mass of the cask	ca. 110 t
Mass of the impact limiters	ca. 20 t/impact limiter
Mass of the puncture-resistant jacket	ca. 31 t
Mass of the transport package	ca. 181 t

Tab. 2 Masses of the test cask and its components for the transport configuration

The cask body features two passages through the cask wall as cable conduits. The measuring cables of redundant strain gauges can thus be fed out of the cask at different points.

On the inside of the cask, a U-profile welded across the entire axial shaft length is provided to prevent any torsion. This U-profile is at the same time used as a cable duct. The above-mentioned passages in the cask side wall are on the same level as the U-profile in order to provide an easier cable routing.

Surfaces on the external cask side or on the inside of the impact limiters are, as much as required, fitted with cable ducts in order to prevent measuring cables from shearing off. The same measures are taken on the internal liner bottom in order to route the measuring cables to the axial cable duct.

On the inventory dummy, however, recesses are provided to protect the cables on the internal liner of the cask.

Test aims and test program

According to the regulations, the structural evaluation of a transportation package may be performed by analysis, test, or a combination of both. The structural evaluation of the CONSTOR® transportation package is performed by analysis. However, demonstration tests will be performed to show the adequacy of the analytical tools and assumptions used for the structural analysis.

This is achieved through favourable comparisons between measured results from the demonstration drop tests and pre-test predictions made by analysis.

The pre-test predictions for the CONSTOR® V/TC were performed using the same analytical and numerical tools and assumptions that will be used for the safety analysis of the CONSTOR® V/69 and CONSTOR® V/32 package designs.

Pre-test predictions are based on the anticipated test conditions, considering the real specific mass properties and material properties of the test package. Specific items include the dynamic acceleration time-history response of the package at the instrumented locations, dynamic elongation (strain) response at specific locations on the package, and overall damage predictions (i.e., impact limiter deformations and permanent deformation of package components).

All drop tests described below are the subject of preliminary calculations with the code LS-DYNA in order to implement the planned measuring points at the correct places and to establish a suitable selection of sensors, using the extent of the calculated tensions. Also, the data are used to verify the design methods and codes.

The preliminary calculations also analyse further drop positions that are not part of the test program, in order to prove that the positions selected for the tests are comprehensive.

Several drop sequences will be carried out to determine the severest possible damage. Each drop test sequence respectively comprises a 9-meter drop test and a 1-meter pin-drop test. The order of the drop tests is planned as follows:

<u>Sequence 1:</u>
- 9-meter drop on the mantle line
- 1-meter pin-drop test (horizontal) on the bottom end

<u>Sequence 2:</u>
- 9-meter drop (slap down) onto the lid area
- 1-meter pin-drop test (horizontal) onto the lid end

<u>Sequence 3:</u>
- 9-meter drop (vertical) flat onto the lid side
- 1-meter pin-drop test (vertical) onto the lid edge

Sequence 4:
- 9-meter drop (vertical) onto the bottom edge
- 1-meter pin-drop test (vertical) onto the bottom edge

Further drop tests are planned for the examination of individual drop positions and are not planned as a combination:

- 9-meter drop (vertical) flat onto the bottom
- 1-meter pin-drop test (horizontal) onto the undisturbed surface of the puncture-resistant jacket
- 1-meter pin-drop test (horizontal) onto the connection point of both liners of the puncture-resistant jacket

The drop tests in horizontal position are carried out with all components of the complete package design (cask body, lid system, inventory dummy, puncture-resistant jacket, and impact limiter).

For the vertical orientated drop tests onto lid or bottom side, the respective upper impact limiter will be replaced by a construction which allows to handle the transportation package and supports the setting of drop angles that deviate from the vertical alignment of the transportation package.

In all drop tests the transportation package drops onto a rigid foundation.

The drop tests with the CONSTOR® V/TC are carried out at a test cask temperature that corresponds to the ambient temperature on site.

Properties of the drop test target

All drop tests will take place at the BAM drop test facility at Horstwalde, near Berlin.

The foundation for the drop tests is called „unyielding target“ according to the guidelines of the IAEA-regulations. The basic requirements are, that the stiffness and the mass are equal or higher than these of real foundations (for example soil, concrete, rock, etc.). An important criteria is, that the foundation exhibits a mass which is at least 10 times higher than the mass of the transport package specimen. A further advantage is the comparability of the results by performing each drop test on the same target.

Instrumentation of the cask and measuring program

The cask is equipped with strain gauges and acceleration sensors to measure strains and accelerations at pre-selected cask locations during the tests. These measurement points are determined considering the maximum stresses to be expected according to the preliminary calculations.

The inner liner, together with the head ring and the closure lid, forms the leak-tight containment of the cask. Therefore, primarily the weld seams between the inner liner and the bottom as well as between the inner liner and the head ring are instrumented with strain gauges.

With regard to the lid system, the behaviour of the closure lid bolts is of particular interest. Therefore, several bolts are each fitted with three strain gauges at 90° intervals; these should provide information on the bolt strains during the drop tests onto the lid side. As the shielding lid has only a shielding function, no additional measurements are carried out on the same.

In the area of the pin impact point (centre of gravity of the transportation package) a larger number of strain gauges is provided on the inner liner in order to obtain sufficient measuring signals for the different areas of the spike impression (centre, edge, direct environment).

Acceleration measurements are used to verify the shock absorber design with regard to the effective reduction of the deceleration on the cask and the inventory.

The recorded measuring values are subsequently processed (filtering of the time-dependent measuring values, conversion of the strain values into stress values) and then compared with the results from the pre-test calculations. The strain measurements provide the essential component for the verification of the design methods.

For the 9-meter drop test at Horstwalde, the instrumentation plan is shown in Fig. 5.

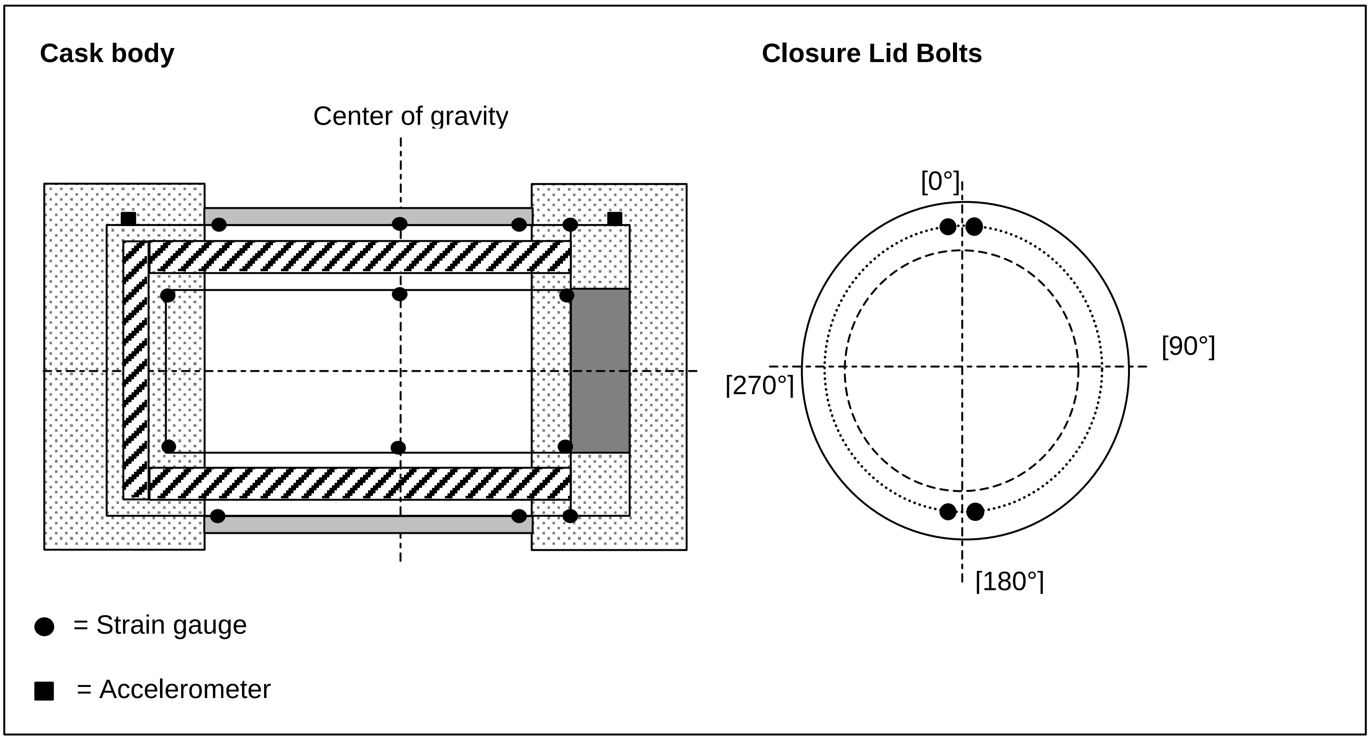

Fig. 5 Instrumentation plan for the 9-meter drop test on the mantle line at Horstwalde

Pre- and post-test inspections

Before the start of the test series, all components of the transport package are measured to be able to exactly evaluate the deformation after the first test (measurement record of the manufacturer). There is also a leak-tightness test performed on the closure lid to make sure that the containment is in the proper condition before the test.

After each test, any deformation of the impact limiters and puncture-resistant jacket is measured. Deformation measurements on the cask body are carried out only after the 1-meter pin-drop tests onto the puncture-resistant jacket or if visible deformation of the cask body has occurred.

Measurements of the leak-tightness on the closure lid are also carried out after each drop test sequence.

After each test, a visual inspection of the entire cask is carried out. Here, all deformations and any damage is comprehensively documented by photographs.

In case of deformations the weld seams are checked with magnetic powder or the dye penetrant technique.

Documentation and evaluation of the test series

A substantial amount of documentation has to be provided for the drop tests. The post-test inspections are accompanied by quality assurance staff members of GNB and independent experts (TÜV) and a record is prepared for each drop test.

The strain and acceleration measurements are summarised in a separate test report. These results are then used for the comparison with the outcomes of the subsequent calculations with the numerical tools.

In total, an exhaustive reporting structure is established to ensure the traceability of all boundary conditions and procedures for the drop tests.

Summary

Using detailed numerical analyses and tests regarding the half-scale test casks CONSTOR® VB-1 and CONSTOR® VB-2, it could be already shown that the CONSTOR® cask concept is able to fulfil all requirements for packages designed for the transport and storage of spent fuel under hypothetical accident conditions.

The presently planned demonstration drop test program with the CONSTOR® V/TC is also expected to confirm the positive results from former tests and calculations. Experience shows, that the combination of numerical calculations and experimental tests is essential for the optimisation of the design on both counts, on the technical as well as on the economical one.