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Half and full scale drop tests for qualification of CONSTOR® casks as type B(U)F packages

Sabine König, Rudolf Diersch

GNS Gesellschaft für Nuklear-Service mbH/GNB, Essen, Germany

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 shell made of steel. At the upper end, the shells are welded to a ring made of forged steel. The space between the two shells is filled with heavy concrete for gamma and neutron shielding. The liner of the casks and the forged head ring form the basis for the structural integrity, the concrete 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, two drop test series have already been performed and a third one is being planned to start in 2004:

1997 A drop test program containing 9m- and 1m-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 have been delivered to the Ignalina Nuclear Power Plant. In 2001, the CONSTOR® received a type B(U)F license in the Czech Republic.

2002 Another drop test program with an advanced CONSTOR® cask design (CONSTOR® VB-2) 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.

2004 A full scale model of a CONSTOR® V for BWR inventory has been manufactured and will be presented in a first 9m drop test at Horstwalde near Berlin during the PATRAM Symposium. The transport package consists of a cask with a dummy basket, a puncture-resistant jacket and two impact limiters. Further 9m- and 1m-pin-drops will be performed there afterwards.

Drop test programs with CONSTOR® VB-1 and CONSTOR® VB-2

The first drop test program with a CONSTOR® cask was performed in 1997 with the CONSTOR® VB-1. The cask was tested as transport configuration, with impact limiters (see Fig. 1).

A 9-meter horizontal drop and several 1-meter pin drops onto the side wall and onto the lid and bottom side were part of the program, as well as two 1-meter drops onto the bottom edge without impact limiters. The two letter drop tests were chosen to simulate drop test accidents at the storage site.

The post-test inspection program of the cask model has shown that the cask integrity and leak tightness were maintained after this series of six drop tests. The stress analysis also confirmed that the mechanical stresses under accidental conditions were below the respective allowable stresses.

These drop tests were needed to confirm the results of the safety analysis report delivered to the nuclear authority of the Czech Republic (SONS) in the context of the transport application for the CONSTOR® RBMK 1500. In 2001, the CONSTOR® received a type B(U)F license in the Czech Republic.

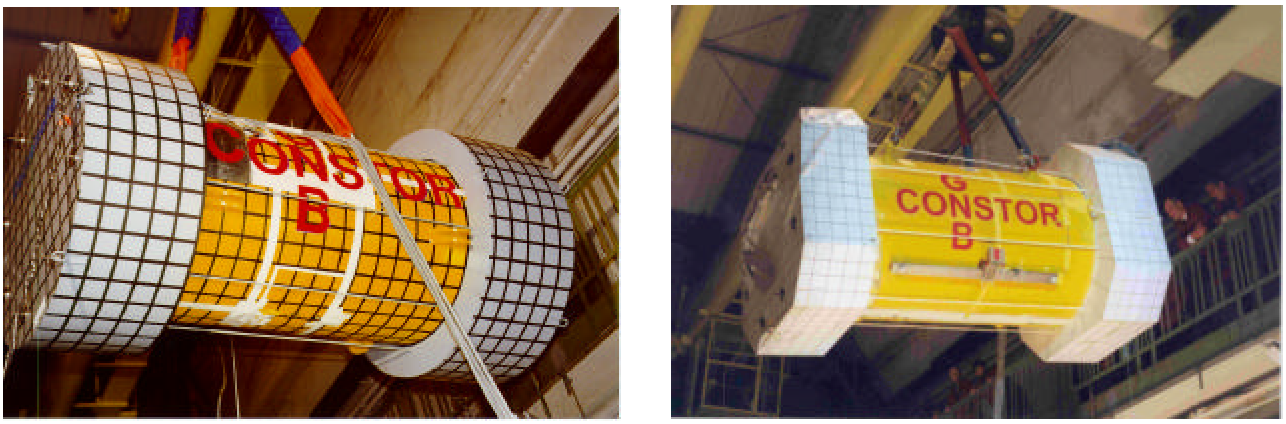

Fig. 1 Test Casks CONSTOR® VB-1 (round impact limiters) and CONSTOR® VB-2 (hexagonal impact limiters)

The second drop test program was performed in 2002 with the advanced CONSTOR® cask design. The geometry was the same as for the CONSTOR® VB-1, but with a different design of the cask wall. Heat conducting elements were arranged inside the CONSTORIT to achieve heat loads up two 30 kW. Beside that, the composition of the concrete filling was modified. It now consists of iron aggregate and cement (CONSTORIT), so that the heat conductivity, as well as the shielding ability were improved. The name for the new CONSTOR® cask series is CONSTOR® V, the corresponding half-scale model is the CONSTOR® VB-2.

With the CONSTOR® VB-2, a very extensive test program took place, including a 9-meter side drop, a 9-meter slap-down and several 1-meter pin drops.

The results showed that the integrity and leak tightness of the liner welds could be maintained until the end of the 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 was achieved by an additional steel shell. 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. Beside that, the economics of the transport and storage system are less affected because there are only a small number of puncture-resistant jackets needed.

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

The full-scale model CONSTOR® V/TC

The CONSTOR® V/TC (see Figs. 2 and 3) represents a prototype of the 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 the requirements of the US-NRC: for on-site storage in accordance with 10 CFR Part 72 and for off-site transportation in accordance with 10 CFR Part 71. The Part 71 regulations include a Normal Condition of Transport (NCT) 0.3-meter free drop test and Hypothetical Accident Condition (HAC) 9-meter free drop and 1-meter puncture tests for which the package must be designed.

The CONSTOR® V/TC also represents the basic CONSTOR® design. It consists of a cask body with an outer and an inner shell made of steel. At the upper end, the shells are welded to a ring made of forged steel. The space between the two shells is filled with heavy concrete for gamma and neutron shielding. Additionally, 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 an austenitic shield plug which rests on an inclined ring surface in the head ring and is fixed in an axial direction by means of form-fit retaining elements in a channel within the head ring, as well as an austenitic closure plate with screwed connection and two metal seals.

Thus, the transport containment is constituted by the inner liner, the head ring and the closure plate with the two metallic seals.

Basket and inventory are provided in the form of an inventory dummy (see Fig. 2) 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 9m and HAC puncture tests. The 36 t total weight of the dummy corresponds to the weight of the basket (including fuel elements) of the CONSTOR® V/69.

The largest possible distance is selected between the inventory dummy and the shield plug. 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 shield plug or the bottom of the cask.

Octagonal impact limiters are used for the tests. Bottom and lid shock absorbers consist of enclosed steel sheet structures filled with several layers of wood. To resist the puncture during the 1-meter pin drop, the main part of the impact limiter consists of a thick steel sheet that protects the closure lid. 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 wood is attached in many layers to reach the maximum absorption ability. The impact limiters are attached to the CONSTOR® V/TC on the puncture-resistant jacket.

In 2004, the prototype of the CONSTOR® V/TC was manufactured and the third drop test program has been planned. The CONSTOR® V/TC package includes the cask body, inventory dummy, closure lid system, bottom-end and lid-end impact limiters as well as the puncture-resistant jacket.

In Tabs. 1 and 2, the geometrical data of the cask and the components for the transport configuration are shown. Fig. 2 shows the cask and the basket dummy 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	approx. 110 t
Mass of the impact limiters	approx. 20 t/piece
Mass of the puncture-resistant jacket	approx. 31 t
Mass of the transport package	approx. 181 t

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

Fig. 2 CONSTOR® V/TC and dummy basket

Test aims

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, confirmatory tests will be performed to demonstrate the adequacy of the analytical tools and assumptions used for the structural analysis.

This is achieved through favourable comparisons between measured results from the confirmatory drop tests and pre-test predictions.

The pre-test predictions were performed using the same analytical 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 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 object of preliminary calculations with 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.

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 sequences will be carried out to determine the severest possible damage. Each drop test sequence respectively comprises an HAC free drop and a following HAC puncture test. The order of the drop tests is planned as follows:

<u>Sequence 1:</u>
- HAC free drop on the mantle line
- HAC puncture test (horizontal) on the bottom end

<u>Sequence 2:</u>
- HAC free drop (slap down) onto the lid area
- HAC puncture test (horizontal) onto the lid end

Sequence 3:
- HAC free drop (vertical) flat onto the lid
- HAC puncture test (vertical) onto one lid end

Sequence 4:
- HAC free drop (vertical) onto the bottom edge
- HAC puncture test (vertical) onto the bottom edge

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

- HAC free drop (vertical) flat onto the bottom
- HAC puncture test (horizontal) onto the undisturbed surface of the puncture-resistant jacket
- HAC puncture test (horizontal) onto the connection point of both shells of the puncture-resistant jacket

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

For the vertical drop tests onto lid or bottom, the respective upper shock absorber 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 are carried out at a test cask temperature that corresponds to the ambient temperature on site.

Properties of the drop test target

The 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“. The design is realised according to the guidelines of the „Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material“. 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

The cask is equipped with strain gauges and acceleration sensors to quantify strains and accelerations at pre-selected cask areas during the tests. 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 preliminary calculations. The strain measurements provide the essential component for the validation of the design methods.

The strains occurring during the tests are measured on the transportation package. After analysis of the drop tests, the measuring results are compared with the preliminary calculation results and evaluated.

The measurement points are determined considering the maximum stresses to be expected according to the preliminary calculations.

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

With regard to the lid system, the behaviour of the closure plate 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 system. As the shield plug 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 measurement points is provided on the internal liner in order to obtain measuring signals for the different areas of the spike impression (centre, edge, direct environment).

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

Post-test inspections

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 HAC puncture tests onto the puncture-resistant jacket or if visible deformation has occurred at accessible places of the cask body.

Tests of the leak-tightness on the closure plate 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 global 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 analytical 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 analyses and tests regarding the test casks CONSTOR® VB-1 and CONSTOR® VB-2, it could be already shown that the CONSTOR® cask concept is designed for the transport and storage of spent fuel.

The presently planned confirmatory drop test program with the CONSTOR® V/TC is also expected to be successful. Experience shows, that the combination of analytical tools and experimental tests is essential for the optimisation of the design on both counts, on the technical as well as on the economical one.