Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2007
October 21-26, 2007, Miami, Florida, USA

DROP TEST RESULTS OF THE FULL-SCALE CONSTOR® V/TC PROTOTYPE

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ABSTRACT

In the context of the research on the mechanical safety of packages for radioactive material, full-scale drop tests with spent fuel and HAW transport and storage casks have been performed by the Federal Institute for Materials Research and Testing (BAM). The research reflects national and international interest in acquiring comparative knowledge of full- and reduced-scale model drop tests as well as in Finite Element (FE) calculations.

This paper presents the experimental, analytical and first numerical results of the full-scale drop test with the full-scale CONSTOR® V/TC prototype, manufactured by GNS, Gesellschaft für Nuklear-Service mbH, Germany. The prototype was tested by BAM in a 9 m horizontal drop test onto the unyielding target of the BAM drop test facility in Horstwalde, Germany.

INTRODUCTION

Feasible concepts for proof of safety, outlined in [1], include different methods, such as drop tests with prototypes or scaled models, calculation or reasoned argument, or reference to previous satisfactory demonstrations of safety. In most cases only small-scale model tests or calculations have been performed in the past for approval of large spent fuel casks. Additional classification by comparison with full-scale testing would be essential to justify acceptance of these methodologies. Full-scale testing may also improve the situation for public acceptance.

The BAM has constructed a new drop test facility [2, 3, 4] for testing spent fuel transport and storage casks of new generations with larger dimensions and higher total masses. The CONSTOR® V/TC stands for a full-scale 181 metric ton prototype with a heat capacity up to 30 kW for 69 fuel assemblies of a light-water reactor [5].

The drop test with the CONSTOR® V/TC represented the inauguration test run by BAM at the drop test facility in Horstwalde on the occasion of the first Technical Tour of PATRAM 2004. Figure 1 depicts the 9 m horizontal drop test onto the unyielding target according to IAEA regulations [1].

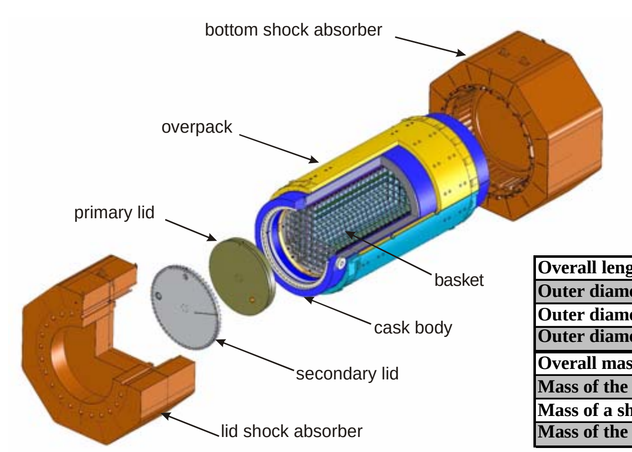
Leak-tightness according to IAEA [1] was maintained. The leakage rate at the primary lid after the test was $2.4 \cdot 10^{-10}$ $Pa \cdot m^3 \cdot s^{-1}$. A leakage rate of $8.7 \cdot 10^{-9}$ $Pa \cdot m^3 \cdot s^{-1}$ appeared at the secondary lid.

On the basis of pre-calculations performed by GNS, an instrumentation plan was proposed by GNS and evaluated by BAM. This paper focuses on crucial results of the drop test, which are presented successively. Furthermore, the measuring method, data analysis and results of the experimentally produced strain and stress are described.

Figure 1. Nine Meter Drop Test of CONSTOR® V/TC before (left) and after (right) Impact

DESCRIPTION OF THE DROP TEST SPECIMEN

The CONSTOR® V/TC consists of a cask body with primary and secondary lid, dummy basket representing the mass of fuel elements and basket, steel overpack around the cask body and two shock absorbers (Figure 2). The cask body was developed as a steel-sandwich construction. It consists of an outer and inner steel liner. The space in-between is filled with CONSTORIT® and copper heat conducting elements [5]. Liners are welded to the forged flange ring on the lid side. The two octagonal shock absorbers are composed of a large number of encapsulated spruce wood layers and an integrated steel plate. Figure 2 illustrates the geometrical dimensions and masses of the CONSTOR® V/TC package and its components.

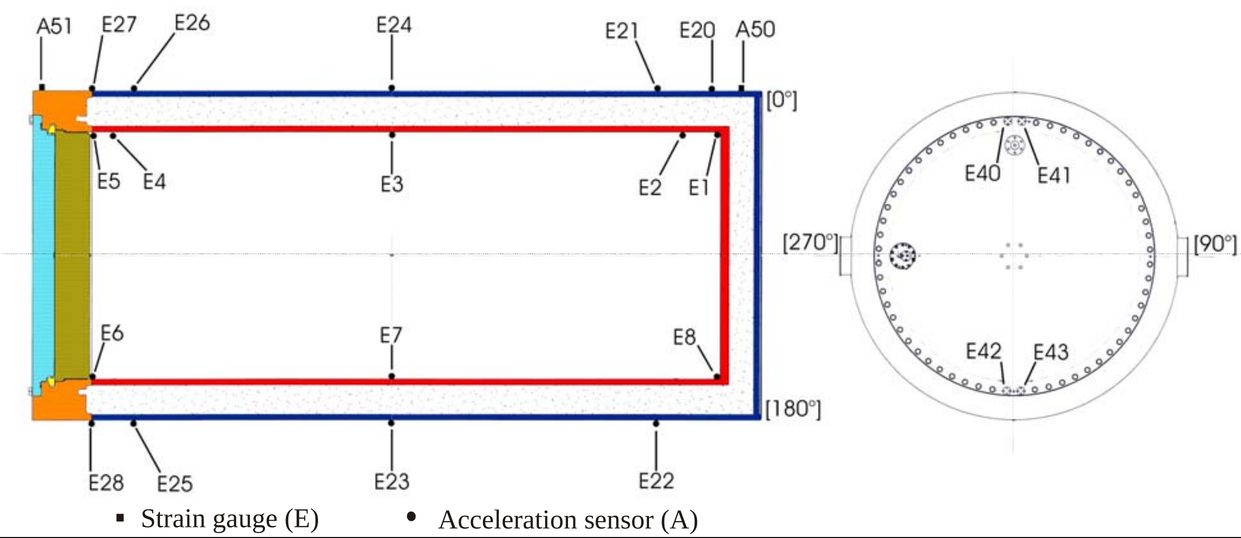


Overall length including shock absorbers	**7445 mm**
Outer diameter of the cask	**2332 mm**
Outer diameter of the shock absorbers	**3510 mm**
Outer diameter of the overpack	**2592 mm**
Overall mass of the transport package	**181 t**
Mass of the cask	**110 t**
Mass of a shock absorber	**20 t**
Mass of the overpack	**31 t**

Figure 2. Schematic View of the Package CONSTOR® V/TC

MEASUREMENT PROCEDURES

The CONSTOR® V/TC was assembled with six triaxial acceleration sensors on the cask body and basket dummy as well as 21 strain gauges on the cask body. In addition, four secondary lid bolts were equipped with four strain gauges each. Measurement positions and the axis-navigation are shown in Figure 3.



measuring point	type of accelerometer or strain gauge	position
outer surface of cask body	**EGCS-DO-5000**	**cask position**
50	50.1 - 50.2	0° bottom side
51	51.1 - 51.2	0° top side
dummy basket	**EGCS-DO-5000**	**cask position**
52	52.1	dummy top
53	53.1	dummy middle
inner surface of cask body	**RY81-6/120**	**cask position**
1 and 2	1.1 and 2.1 / 2.2	0° bottom side
3	3.1	0° middle
4 and 5	4.1 / 4.2 and 5.1	0° top side
inner surface of cask body	**XY31-6/120**	**cask position**
6	6.1 – 6.2	180° top side
7	7.1	180° middle
8	8.1 – 8.2	180° bottom side

measuring point	type of accelerometer or strain gauge	position
outer surface of cask body	**RY81-6/120**	**sensor position**
20 and 21	20.1 and 21.1	0° bottom side
22	22.1	180° bottom side
23 and 24	23.1 and 24.1	180° and 0° middle
25 and 28	25.1 and 28.1	180° top side
26 and 27	26.1 and 27.1	0° top side
lid bolts	**RY81-6/120**	**sensor position**
40	40.1-40.4	0°
41	41.1-41.4	0°
42	42.1-42.4	180°
43	43.1-43 4	180°

Figure 3. Measurement Plan of CONSTOR® V/TC

Decelerations were measured at different positions on the cask body and basket dummy by triaxial piezoresistive accelerometers A50 to A53 (type DGCS-DO-5000, ENTRAN). The cask body was equipped with 21 foil strain gauges (120 ohm nominal resistance of type RX81-6/120 and XY31-6/120) to measure strain during impact. Strains of the secondary lid bolts were measured in the positions 0° and 180° (Figure 3).Two measured bolts were equipped with four one axial strain gauges (type RY81-6/120) each on the shank in a 90° circumferential distance. In this way, the pre-strain after tightening, strain during impact and remaining strain after impact were measured.

The strain gauges were connected in a three wire Wheatstone quarter bridge circuit. A six wire Wheatstone full bridge circuit with sense wiring of the power supply was chosen to connect the accelerometers. Both methods are commonly used in experimental stress analysis.

Data acquisition was carried out using two portable measuring devices (type: SCP3200-2 by KRENZ Eckelmann Industrie Automation), each with 32 wideband (analogue bandwidth up to 100 kHz -3dB), differential bridge amplifiers for direct connection of all bridge type devices. A pre-sampling filter of 10 kHz for strain and 30 kHz for acceleration measurements with a 12-bit vertical resolution was applied to each channel.

DATA ANALYSIS AND RESULTS

Acceleration Measurements

Acceleration signals were analyzed on the cask bottom, measuring point A50, and the lid side, measuring point A51, to determinate impact kinematics of the prototype (Figure 4). Filtering was done by a Bessel-filter of second order with a 100 Hz threshold [6]. Impact duration according to both acceleration sensors (A50 and A51) was about 48 ms. The lid side impacted around 5 ms earlier than the bottom side. The time shift indicates that the cask hit the target at a calculated inclination of 0.36°. The lid side of the prototype hit the unyielding target with an impact velocity of 13.4 m/s. Due to the small rotational acceleration, the impact velocity of the bottom side was 13.8 m/s (Figure 4).

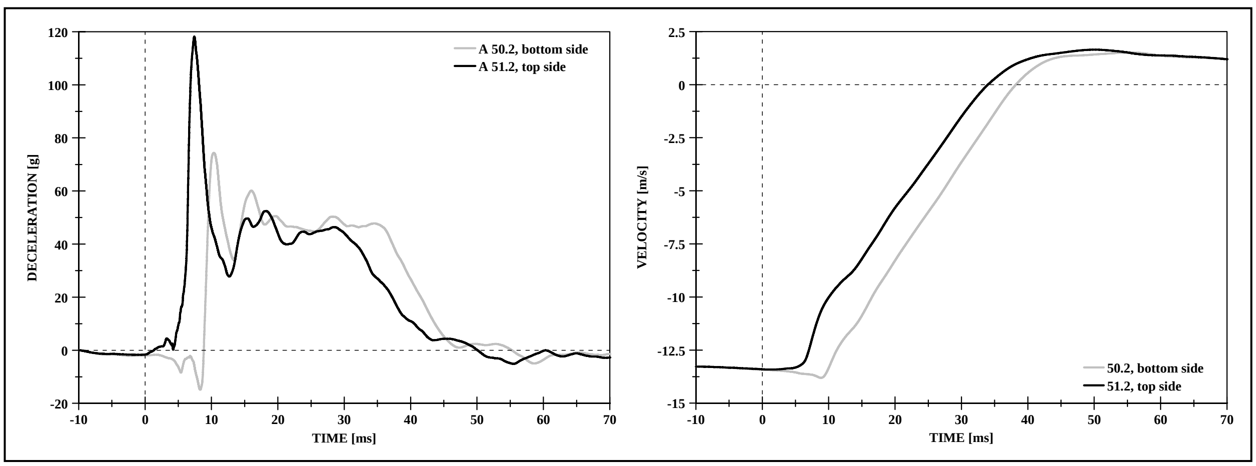


Figure 4. Deceleration and Velocity vs. Time

Maximum decelerations of the cask body were approximately 1157 m/s² (118 g) on the lid side and 726 m/s² (74 g) on the bottom side (Figure 4). Preliminary analysis indicates that mainly gap-closing-effects between the shock absorber steel structure, overpack, cask body and lids were responsible for local peaks in the acceleration-time histories.

Strain Measurements of Cask Body

Data from strain gauges on the inner liner, at 0° (E1, E3, E5) and 180° (E6, E7, E8) positions, and strain gauges on the outer surface, at 0° (E21, E24, E26) and 180° (E22, E23, E25) positions, were analyzed to assess component loading in the cask body's longitudinal direction (Figure 4). Signals were low-pass filtered by a digital Bessel-filter of the second order with a 2000 Hz threshold.

Strain data is presented in Figure 5 and Figure 6. Points of maximum strain correspond to those of maximum deceleration.

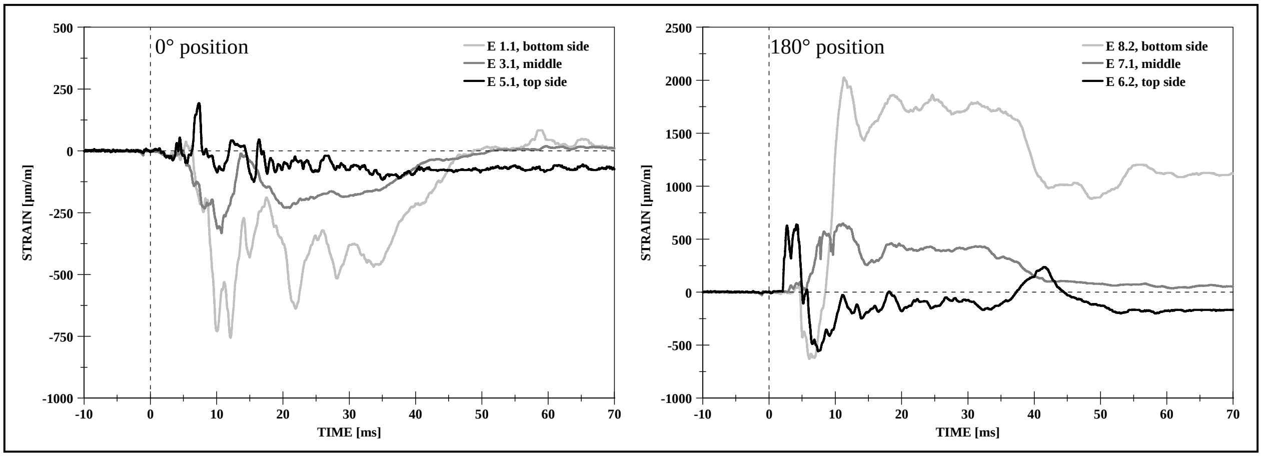


Figure 5. Strain History of the Inner Cask Body

Maximum strain values of the inner cask body occurred on the bottom side of the cask body (Figure 5). They amounted to 2026 µm/m (E8) in the 180° position. This maximum strain on the surface line corresponded to a computed stress of 426 N/mm². The resulting stresses did not exceed the yield strength of the cask body material. Further strain levels were relatively constant and corresponded with the compression phase of the wood-filled shock absorbers. Strain levels fell at the end of the compression phase, whereas residual strains remained for the measuring point E8 (residual strain: 1202 µm/m).

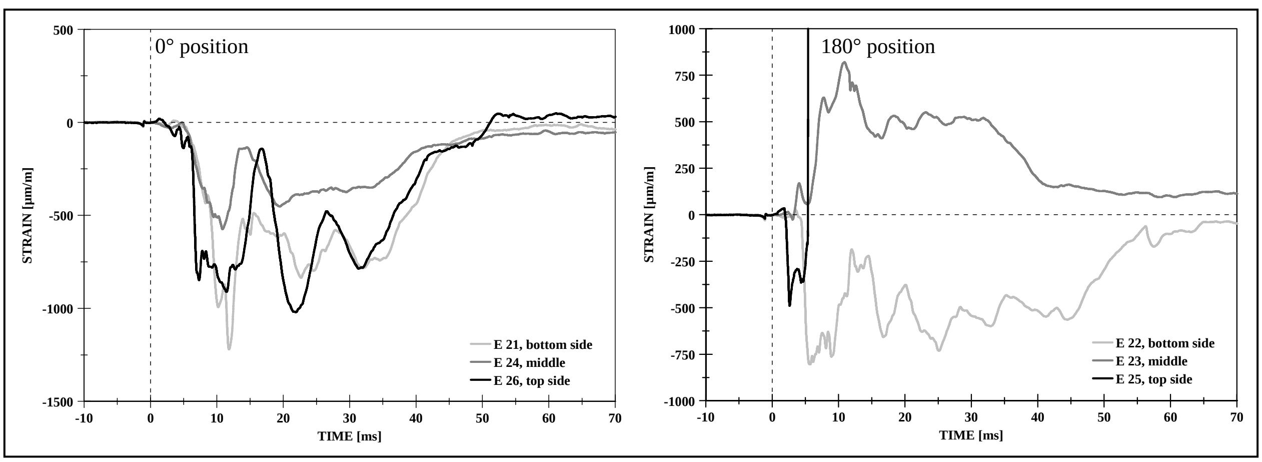


Figure 6. Strain History of the Outer Cask Body

Maximum strain values of the cask body's outer surface occurred accordingly on the bottom of the cask body, but in the 0° position at measuring point E21 (Figure 6). Maximum strain on the cask body's outer layer of 1220 µm/m resulted in a computed stress value of 256 N/mm².

Lid Bolt Strain

Loading on the lid bolts was analyzed representatively by four secondary lid bolts equipped with gauges. The bolts were tightened with 750 Nm, resulting in a pre-strain of 1000 µm/m. Loading on the bolts was caused by the relative movement of the secondary lid during impact and the weight of the lid. Axial movement of the lid caused normal strains and radial movement bending strains. Axial-, bending- and maximum bending-strains were computed from the measured bolt strains (Figure 7).

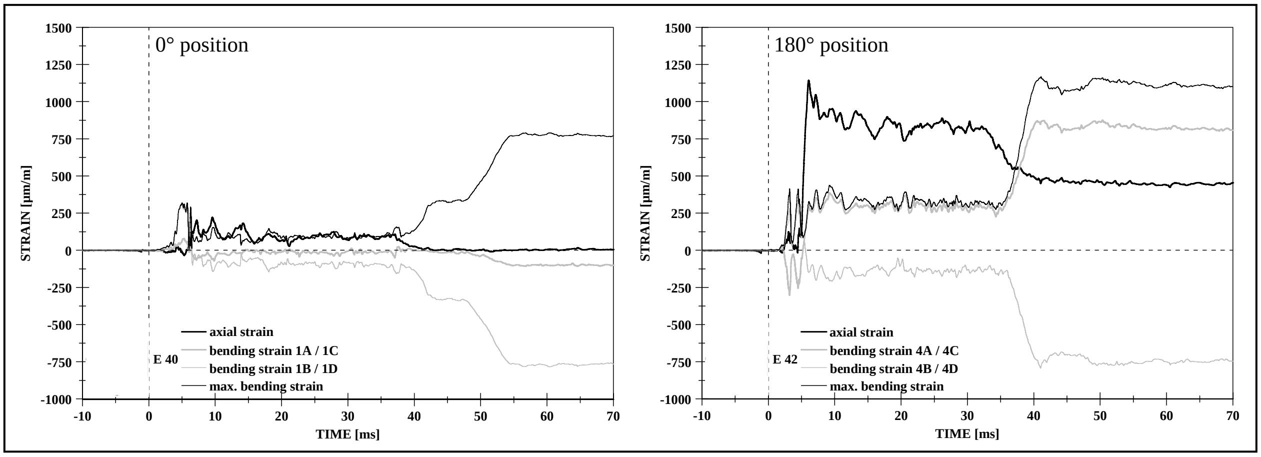


Figure 7. Strain History of the Lid Bolts

Axial and bending strains of secondary lid bolts of remained relatively constant up to the end of the impact. The maximum axial strain of the bolt (E42, 180° position) due to the impact on the lid side amounted to 1237 µm/m. Taking the pre-strain of tightening into account, the maximum axial strain of the lid bolt resulted in 2237 µm/m.

As the residual bending strain (Figure 7) after impact indicates, the lid weight generated the main load on the bolts. The remaining axial strain of bolt E42 (Figure 7, right) indicates an exceeding of the technical elastic limit of the bolt material.

FINITE ELEMENT METHOD (FEM)

Finite Element calculations with the dynamic Finite Element code LS-DYNA [7] were performed after the tests. The model had approx. 130 000 elements and 170 000 nodes. Cask body, overpack, inventory and primary and secondary lids were adequately modeled, although the impact limiter was focused. Aim of the calculations was the analysis of possible impact limiter simulation methods, including a variation of suitable material laws, contact definitions, etc. Figure 8 (left) shows the model.

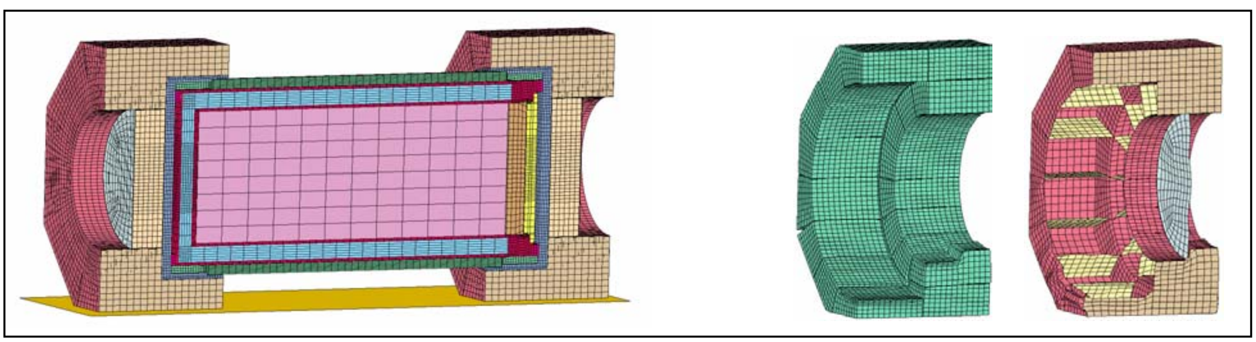


Figure 8. FEM Model of the CONSTOR® V/TC (left); FEM Model Impact Limiter Deformation (right)

Resulting impact limiter deformation of the steel casing and wooden filling is presented in Figure 8 (right).

CONCLUSIONS

In 2004 a 9 m drop test with a full-scale prototype of a transportation and storage cask for radioactive material was conducted at the BAM drop test facility in Horstwalde, Germany. The full-scale drop test with the 181 metric ton CONSTOR V/TC® was the largest drop test with a package prototype ever conducted world wide.

Visual checks after the drop test showed no apparent damage to the cask body and overpack. The mode and size of the shock absorber deformations corresponded to pre-computed data. The integrity of the primary and secondary lids was retained. Analysis of the CONSTOR V/TC® data indicated that highest strain occurred at the secondary lid bolt close to the point of impact and at the cask body inner layer (180° position).

The drop test with the full-scale CONSTOR® V/TC provided a good opportunity for analysis of cask behaviour with finite element methods. Due to the large gross weight of the tested prototype, the understanding and analysis of impact limiter behaviour could strengthen the verification basis for analysis methods that simulate impact loading.

The research confirmed, in general, possible transferability of experimental results with a full-scale prototype to finite elements calculations. The test documentation was provided to the U.S. NRC Research Department within a cooperative agreement between BAM and U.S. NRC.

ACKNOWLEDGMENTS

BAM thanks GNS for their collaboration in the research project and supply of the full-scale CONSTOR® V/TC prototype. The research was funded by the Federal Ministry of Education and Research under Contract No. 02S8274.

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