DROP TEST PROGRAM WITH THE HALF-SCALE MODEL CASTOR® HAW/TB2

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ABSTRACT

BAM (Federal Institute for Materials Research and Testing) is the competent authority for mechanical and thermal safety assessment of transport packages for spent fuel and high level waste (HLW). In context with the package design approval of the new German HLW cask CASTOR® HAW28M several drop tests were performed by BAM with a half-scale model CASTOR® HAW/TB2. The cask is manufactured by GNS (Gesellschaft für Nuklear Service mbH) and was tested under accident transport conditions on the 200 tons BAM drop test facility at BAM Test Site Technical Safety.

The sequences of the tests comprise cumulations of nine-meter free drop onto an unyielding target in various most damaging drop orientations to cause maximum package damage, and a drop from one meter onto a steel puncture bar onto the most sensitive part of the container. The subsequent release of radioactive substances must not exceed a value specified in the dangerous goods transport regulations, and radiation shielding and nuclear safety must be guaranteed [1].

For this purpose the test specimen CASTOR® HAW/TB2 was instrumented on 21 measurement planes with altogether 23 piezo-resistive accelerometers, five temperature sensors and 131 tri-axial strain gauges in the container interior and exterior, respectively. The strains of four representative lid bolts were recorded by four uniaxial strain gauges per each bolt. Helium leakage rate measurements were performed before and after each test sequence.

The paper presents experimental results of the half-scale CASTOR® HAW/TB2 prototype (14,500 kg) and provides insight into the complexity of test procedure, extensive test methods and measurement data logging.

INTRODUCTION

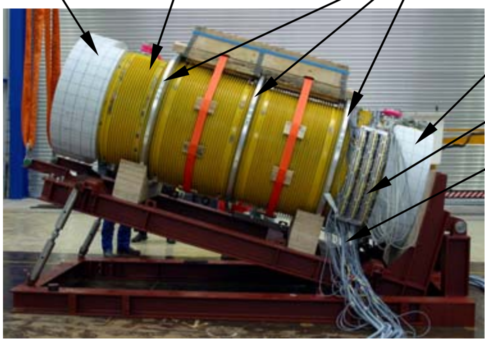
The main objective of the drop tests with the half-scale model CASTOR® HAW/TB2 was to demonstrate that the containment and radiation shielding maintains its integrity during and after the mechanical tests as per normal and accident conditions of transport. Furthermore, the testing was supposed to show that the functionality of the individual components (trunnions, fixing of shock absorber, basket for HLW containers) of the cask remains unchanged. The measured deformations and strains formed the basis for validation of Finite-Element calculation methods that had to be applied for transferring the test results to the original package design [2].

In the context with the package design approval procedure the test program comprises 17 drop tests with different drop orientations, drop heights and temperatures (ambient, -40°C, 100°C). The tests were performed by BAM at the drop test facility “BAM Test Site Technical Safety” [3]. A further drop test (0.30 m vertical drop test onto the unyielding target without shock absorber) was carried

out under the licensing procedure of the interim storage facility where the cask will be used for dry HLW storage of up to 40 years [4].
The application and the design features of the cask for the transport and interim storage of high-level radioactive waste from the reprocessing of spent fuel assemblies are described in [5].

DESCRIPTION OF TEST SPECIMEN

The CASTOR® HAW/TB2 consists of a cask body closed with a primary lid and an integrated cover plate, three circumferential aluminum ring shock absorbers, and two shock absorbers each on the bottom side and lid side (Figure 1). The cask body is made of ferritic ductile cast iron. Each pair of the two trunnions are arranged on the bottom and top side for handling of the cask.
Figure 1 illustrates the handling device with the positioned cask before the first drop test and the main geometrical dimensions and masses of the CASTOR® HAW/TB2 and its components.



overall length including shock absorbers	3383 mm
outer diameter of the radial shock absorbers	1375 mm
overall mass of the test specimen	14,5 t

Figure 1. Handling device with positioned CASTOR® HAW/TB2

MEASUREMENT PROCEDURES

The CASTOR® HAW/TB2 was assembled with altogether 23 piezoresistive accelerometers, five temperature sensors and 131 tri-axial strain gauges in the container´s interior and exterior. In addition, four secondary lid bolts were equipped with four strain gauges each. An overview of the various measurement planes are shown in Figure 2.
Decelerations were measured at different positions on the cask body and primary lid by piezoresistive accelerometers from type ENTRAN, EGCS-DO-5000. The cask body and primary lid was equipped with tri-axial foil strain gauges from type HBM 1-RY81-6/120, K-RY81-6/120 and 1-RY81-3/120 (120 ohm nominal resistance) to measure strains during impact. Strains of the primary lid bolts were measured in the positions 0°, 90°, 180° and 270° (Figure 2, level T). Four measured bolts were equipped with four one axial strain gauges (type 1-LY61-3/120) on the shank in a 90° circumferential distance. In this way, the pre-strain values after tightening, strain values during impact and remaining strain values 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 three portable measuring devices (type: DEWE5000, DEWETRON), with altogether 128 wideband (analogue bandwidth up to 200 kHz -3dB), differential bridge amplifiers for direct connection of all bridge type devices. A pre-sampling filter

of 30 kHz for strain and 10 kHz for acceleration measurements with a 12-bit and 16-bit vertical resolution was applied to each channel.

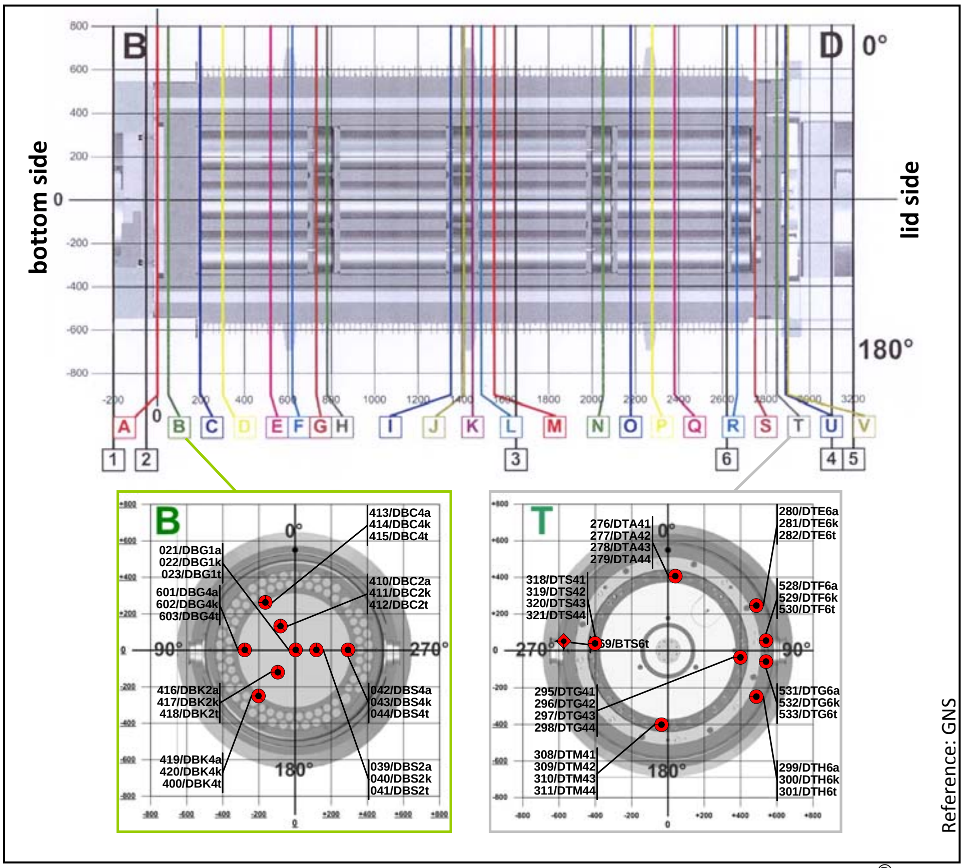


Figure 2. Instrumentation plan and measurement planes of CASTOR® HAW/TB2

Figure 3 shows instrumentation examples of the cask by accelerometers and strain gauges and in detail the central soldering terminal from which the signals are transferred by 50 m long measuring cables to the data acquisition systems.

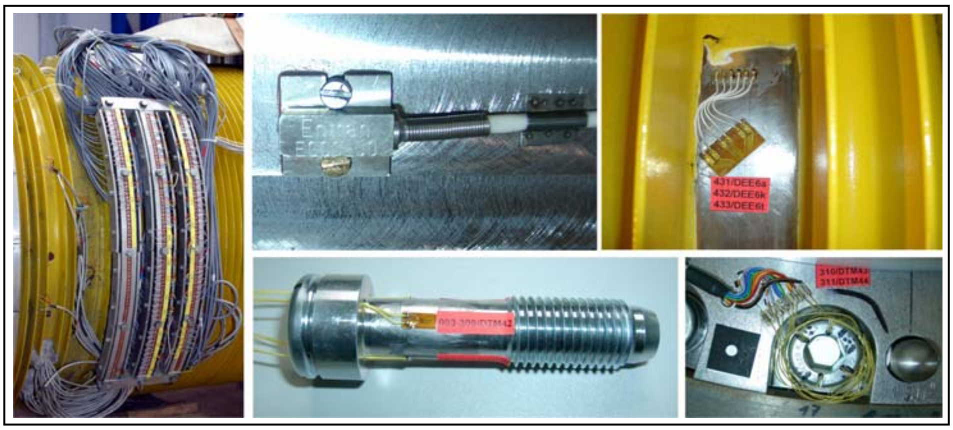


Figure 3. Central soldering terminal (left), accelerometer (top centre), strain gauge on the cask body (top right), strain gage instrumented lid bolt (bottom centre and right)

SELECTED DROP TEST RESULTS

Exemplarily, from the numerous results of acceleration and strain measurement signals obtained from 17 drop tests the results of three selected drop tests shall be presented. One measuring point per drop test is considered here.

9 m slap-down drop onto the bottom side

The cask was dropped from a height of 9 m in a 20° declined position with primary impact onto the bottom side. Figure 4 (left) schematically shows the drop test configuration of the container and the measuring direction of acceleration sensor.

The deceleration signals on the primary lid were analyzed, measuring point level S in Figure 2, to determine impact kinematics of the cask. The curve (Figure 4) shows a typical accelerometer signal of the package, as typical for most slap-down impacts [6]. Filtering was done by a Bessel-filter of second order with a 2000 Hz and 360 Hz threshold [7]. Impact duration according to both acceleration sensors (991/Bss1t) was about 12 ms. The lid side impacted around 50 ms later than the bottom side. The according velocity-time curve obtained by integration is shown in Figure 4. The bottom side of the prototype hit the unyielding target with an impact velocity of 13.3 m/s. Due to the rotational acceleration, the impact velocity of the lid side was significantly higher.

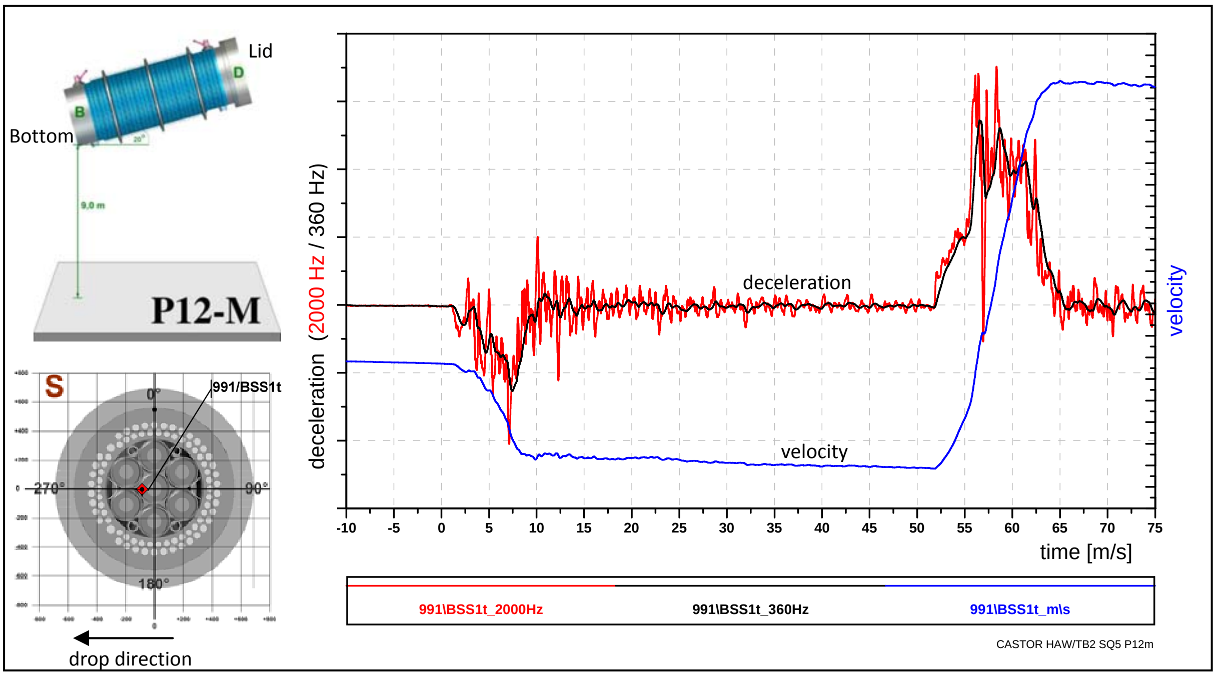


Figure 4. 9m slap-down with primary impact onto bottom side; deceleration and velocity vs. time measured at lid side

[Quantitative deceleration and velocity values are not displayed because of confidentiality.]

9 m slap-down drop onto the lid side

The cask was dropped from a height of 9 m in a 5° declined position with primary impact onto the bottom side. Figure 5 (left) schematically shows the drop test configuration of the container and the measuring direction of a tri-axial strain gauge.

Data from the tri-axial strain gauge on the inner cask body, measuring point level S (Figure 2), are analyzed in the cask body's axial (ε_a), tangential (ε_b) and complementary (ε_c) direction. (Figure 5, right). Signals were low-pass filtered by a digital Bessel-filter of the second order with a 2000 Hz threshold.

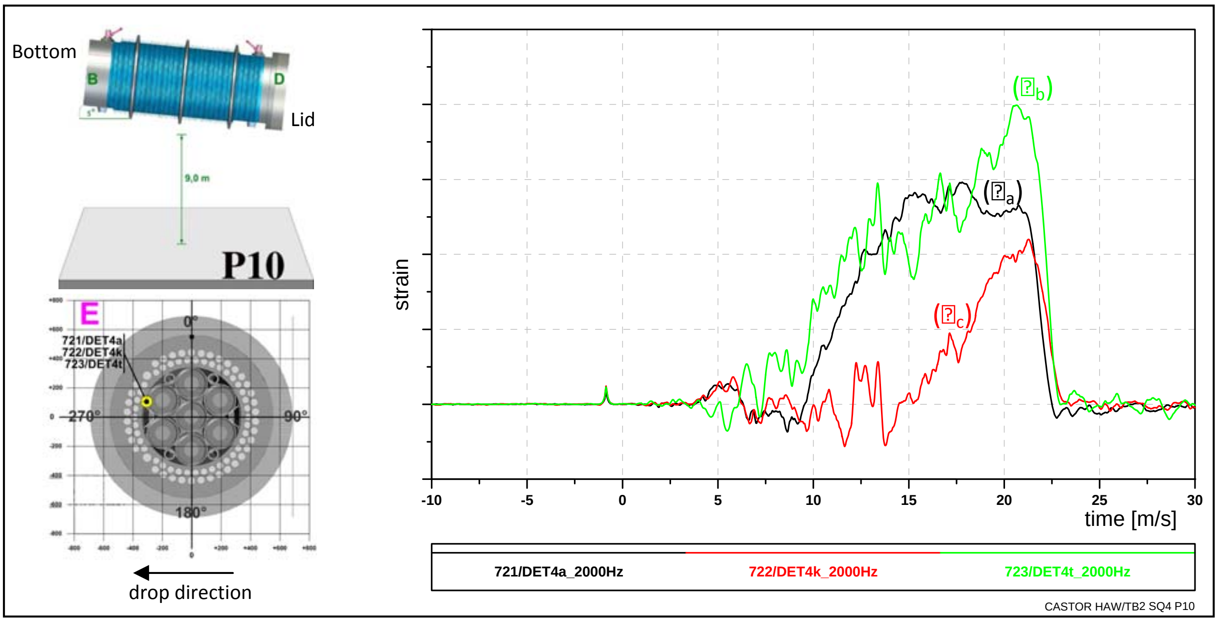


Figure 5. 9m slap-down drop with primary impact onto lid side; strain history measured at the inner cask body
[Quantitative strain values are not displayed because of confidentiality.]

From the strains, measured in three directions, the principal strain and its direction as well as the effective strain are determined. In addition the related effective stresses are deduced. The calculations are based on the equations in Figure 6.

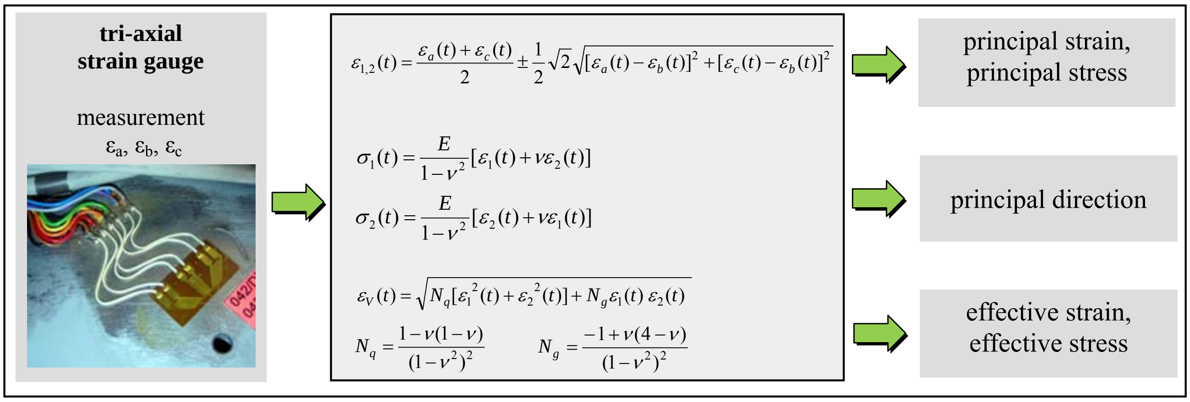


Figure 6. Overview of calculation of strain and stress

The curves in Figure 7 show the calculated first (ε_1) and second (ε_2) principal strain and effective strain (ε_V) from the measured strains at the tri-axial strain gauge in Figure 5. Maximum strain values of the inner cask body occurred between 10 ms and 20 ms. The strain signals come back to zero and there was no plastic deformation in this region.

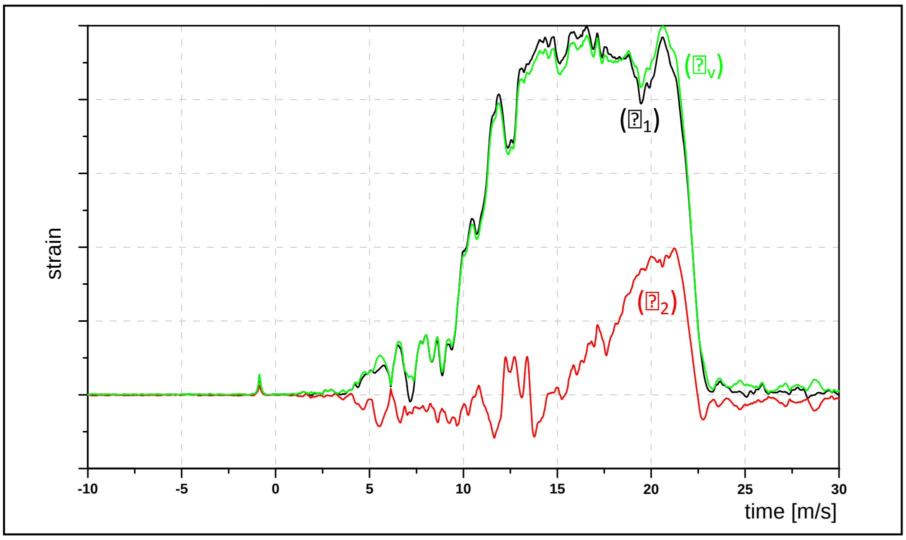


Figure 7. 9m slap-down drop with primary impact onto lid side; first and second principal strain and effective strain history of level E
[Quantitative strain values are not displayed because of confidentiality.]

<u>1 m puncture drop test</u>

The cask was dropped from a height of 1 m in a horizontal position with impact of the lid flange onto the puncture bar. Figure 8 (left) schematically shows the drop test configuration of the container and the measuring direction of four instrumented bolts.

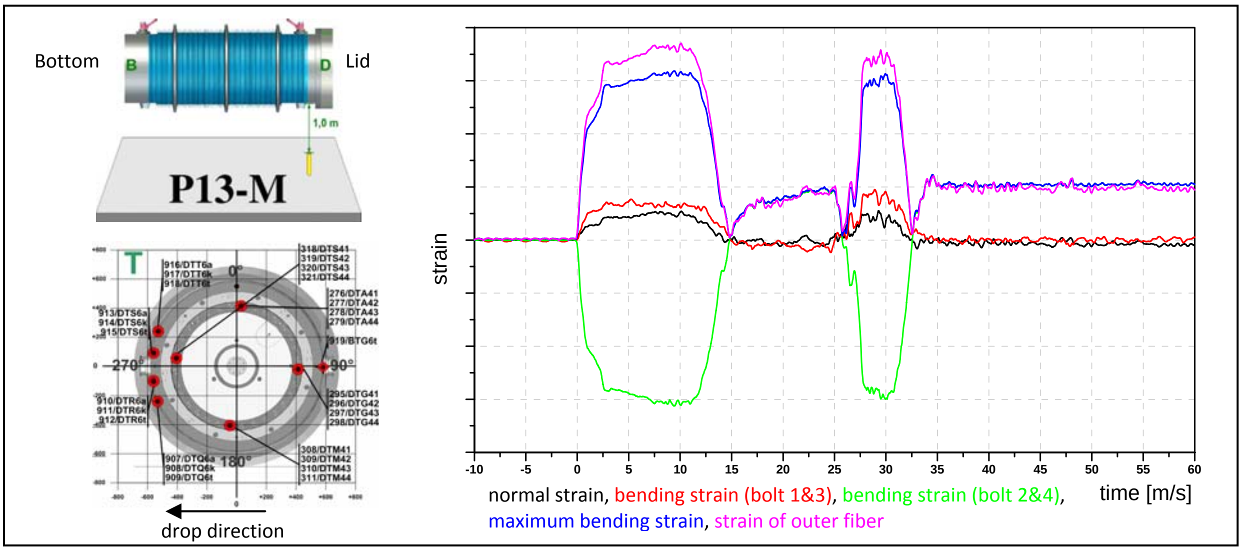


Figure 8. 1m puncture drop test; strain history of a lid bolt
[Quantitative strain values are not displayed because of confidentiality.]

The loading on the lid bolts was analyzed representatively by four primary lid bolts equipped with strain gauges. Loading on the bolts was caused by pre-strain due to bolt tightening and by the relative movement of the primary lid during impact and the weight of the lid. Axial movement of the lid caused normal strains and radial movement bending strains. Normal, bending, maximum bending and outer fiber strains were computed from the measured bolt strains (Figure 8, right).

Normal and bending strains of primary lid bolts show two areas of maximum strain. The reason for this is that there is a first and second impact of the lid side onto the puncture bar. The bolt has a slight bending strain due to a small displacement of the lid after the impact. As the residual bending strain (Figure 8) after impact indicates, the lid weight generated the main load on the bolts.

FURTHER MEASURING METHODS

For the investigations also other methods were used, for example the close range photogrammetry [8], projected fringes method [9], tightness testing, high-speed video analyzes, visual inspection, photography and video recording for detecting damage to the specimen. The Figure 9 shows some of the methods used.

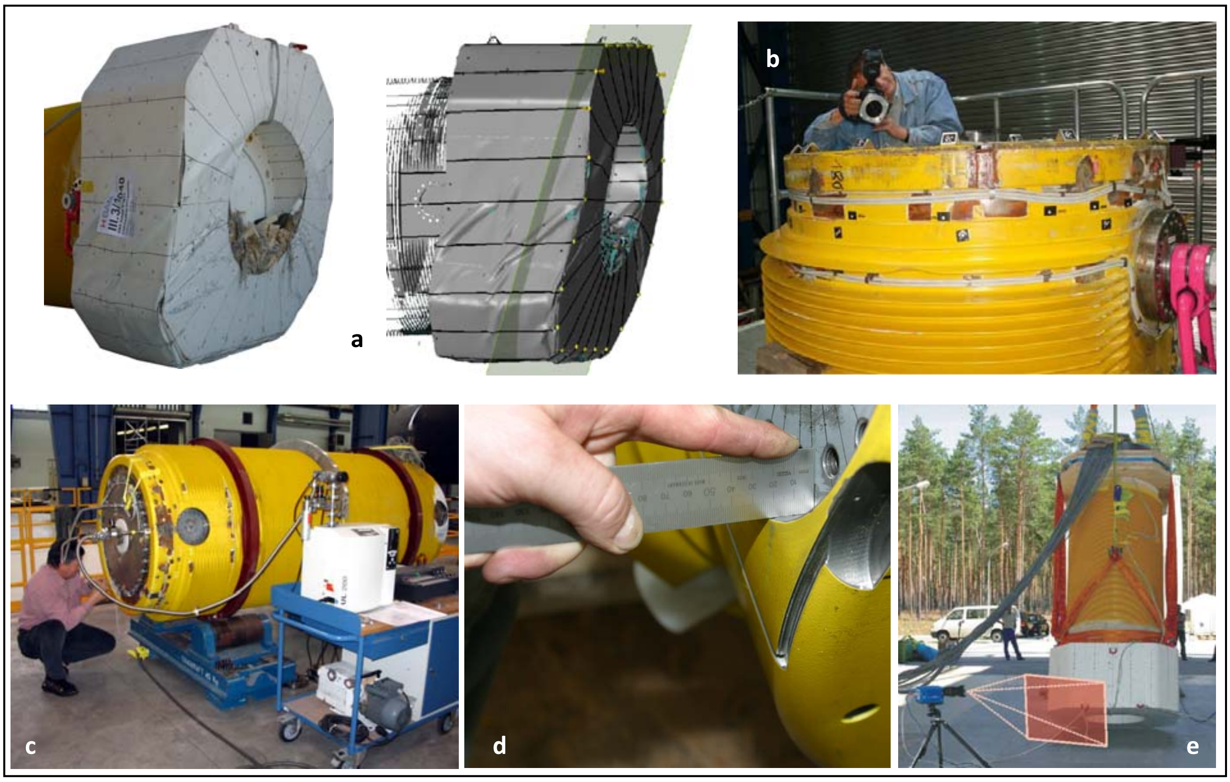


Figure 9. Projected fringes method for impact limiter deformation quantification (a), close range photogrammetry for lid displacement quantification (b), tightness testing (c), visual inspection (d), high-speed video analysis (e)

CONCLUSIONS

In the context of approval procedure of transport casks for radioactive materials there is the need to demonstrate their safety against mechanical accident conditions. The test performance of BAM is based on a comprehensively developed test program. In such tests the most modern measurement techniques methods of stress analysis, deformation analysis and integrity analysis have to be used. The documented test results are being utilized in the safety analysis reports for the transport and storage cask type to be licensed. They are also being used to prove that the safe containment boundary, radiation shielding and integrity of package components guaranteeing criticality safety are maintained. Since the experimental results form also the basis for verification of dynamic Finite-Element calculation methods an extensive coverage of measurements to quantify any deformations, stresses and leakage rates is applied.

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