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EVALUATION OF ACCIDENTAL IMPACTS ON SHIPPING AND STORAGE CASKS FOR RADIOACTIVE MATERIALS

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ABSTRACT

To demonstrate safety against mechanical impacts due to accidents different experimental investigations with casks for radioactive materials had been carried out. Test results of drop tests with a shipping cask onto an unyielding target, of drop tests with shipping and storage containers simulating handling accidents at nuclear facilities and extended drop tests demonstrating safety margins even in high velocity accidents or with test specimen containing artifical flaws will be presented.

MECHANICAL TESTS ON SHIPPING CASKS

According to the "IAEA-Regulations for the Safe Transport of Radioactive Materials" a specimen shall be subjected to the cumulative effects of 3 mechanical tests, a thermal test (30 Minutes hydrocarbon fire) and a water immersion test (1.5 bar external overpressure). These cumulative tests are for demonstrating the ability of "type B-packages" to withstand severe accident conditions in transport. The mechanical tests include 3 drop tests to cover different accident scenarios:

Drop I: Drop from 9 m onto a flat "unyielding" target ("9 m drop test")

Drop II: Drop from 1 m onto a solid mild steel bar (15 cm in diameter) mounted on the unyielding target ("punch test")

Drop III: Drop of a 500 kg mass from 9 m onto the specimen resting on the surface of the unyielding target ("crush test"to be carried out only with packages with a mass below 500 kg and a density below 1000 kg/m^3).

The specimen shall be dropped in each test as to suffer the maximum damage. Because of the fact that maximum damage of different cask components may ocur under different cask orientations, every drop case needs an equivalent number of drop tests. The evaluation of the mechanical impacts can be done by means of drop tests (using model casks of appropriate size or prototypes of original size) or by approved and bench-marked calculation methods.

In Germany the manufactoring of heavy thick-walled casks out of ductile cast iron (DCI, ferritic cast iron with nodular graphite) was developed. One example for a drop test with such a cask for transport and interim storage of 21 spent BWR fuel assemblies will be given in the following. The dimensions of the full size test object are: length 5.34 m, cavity diameter 0.91 m, wall thickness 0.365 m, mass 65 tons; to compensate the missing mass of the impact limiters and the loading (total cask weight 84 tons) the drop height was 11.8 m to cover 9 m drop test conditions. The most damaging mechanical impact of the monolithic cylindrical cask body was the flat horizontal 9 m-drop onto the trunnions so that the cask body is stressed like a bending beam with the most critical material tension stresses in axial direction at the bottom

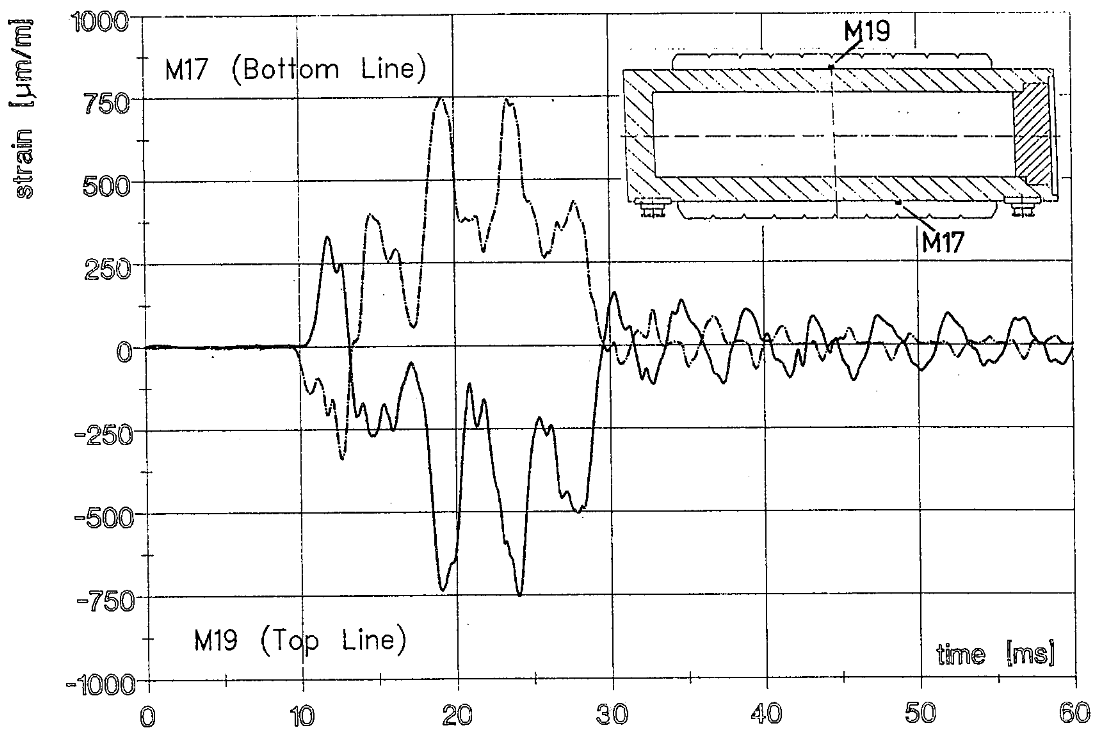

Figure 1: Axial Skin Strain of a Spent Fuel Cask in a 9 m Drop Horizontally Onto the Trunnions

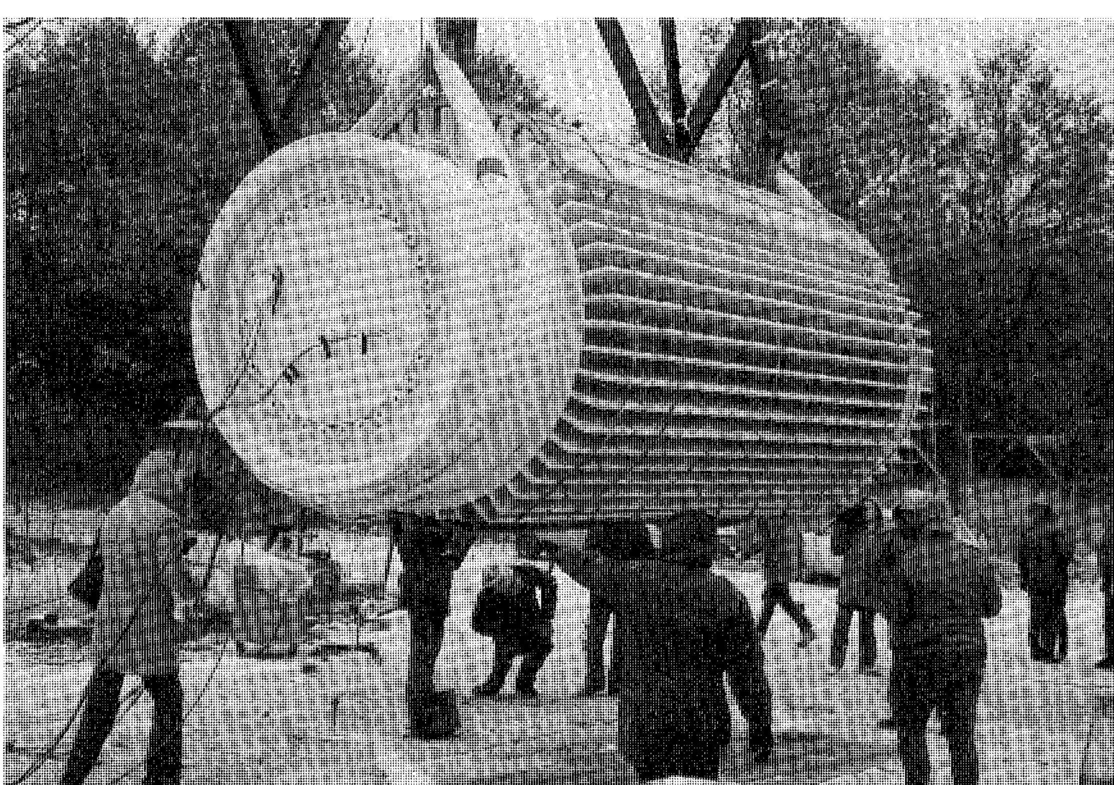

Figure 2: Full Size Spent Fuel Cask after 9 m Drop

line. Figure 1 shows the strain signals measured at the bottom and top line at the horizontal cylindrial cask of original size. To demonstrate the casks material ability to withstand the dynamic impact even under emblittlement at the lowest service temperature of - 40 °C the test specimen was cooled to that temperature. Also the impact was not decreased by impact limiters (steel sheet constructions filled with wood) usually covering head and bottom part of spent fuel shipping casks. Figure 2 shows the cask after that 9 m drop.

MECHANICAL IMPACTS FROM HYPOTHETICAL ACCIDENTS

The safety assessment of nuclear facilities sometimes requires the evaluation of special events derived from the accident analyses. To investigate the hypothetically assumed drop from greater heights, e.g. from a reactor building crane, experiments and calculations had been carried out (Ref. 1, 2). A realistic demonstration was a drop of an original size spent fuel cask (mass: 83 tons, length 5.455 m, cross section 1.73 m x 1.73 m) from a height of 20 m onto a ground simulating a road suitable for heavy loads. This real target was a 1.8 m thick compound layer (1.5 m gravely sand, 0.16 m concrete plates, 0.15 m bitumen) located above the unyielding target. After the drop the cask had penetrated nearly 60 cm into the ground (Figure 3). The measured deceleration (~ 600 m/s^2) was only half as measured in the 9 m drop test of a similar cask onto the unyielding target.

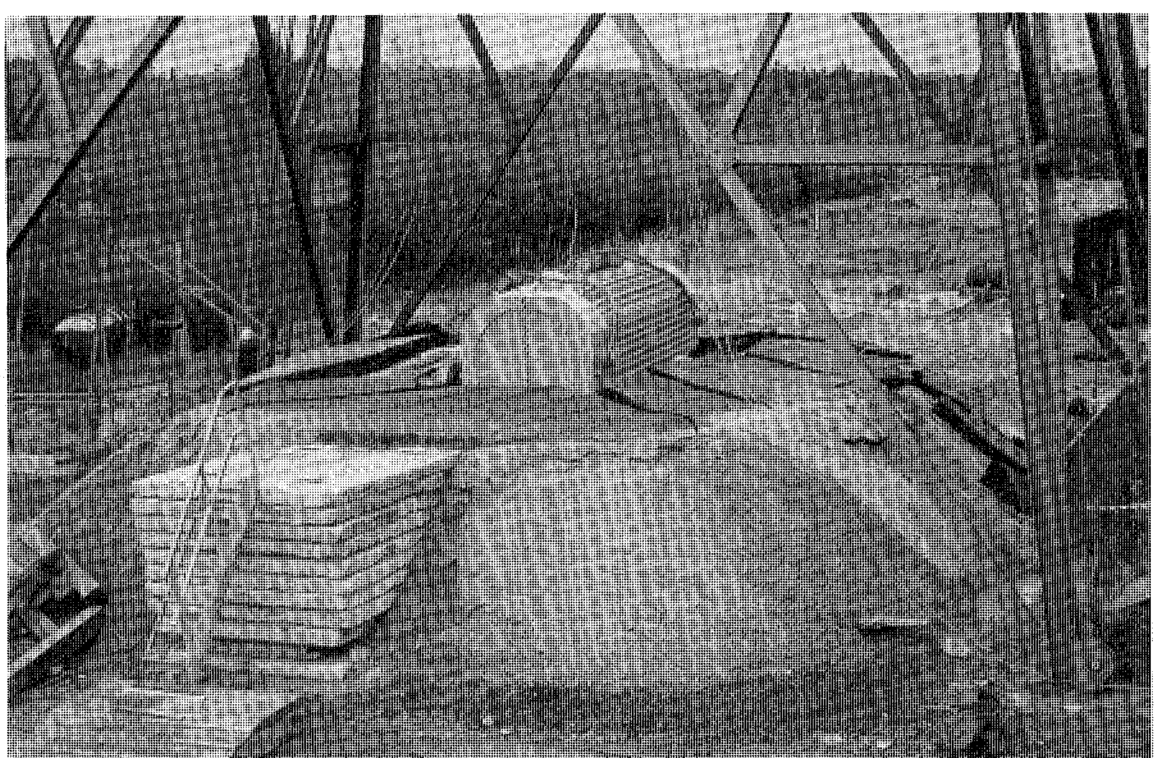

Figure 3: Original Size Spent Fuel Cask after 20 m Drop Onto a Real Target

For the disposal of radioactive waste in Germany cubically shaped containers made of DCI are intended to be used. The accident analysis of the disposal site "Konrad" requires the evaluation of a 5 m-drop onto a rock-simulating target. First drop tests /Ref. 3/ with a prototype container (mass: 20 tons, dimensions: 2 m x 1.7 m x 1.6 m, wall thickness: 150 mm) have shown a strong influence of the container orientation on the impact behaviour. The drop onto a flat container side (due to a low penetration into the target) is accompanied by deceleration values very much higher than in drops onto the edge or onto the corner. Additionally the very hard flat side drop impact has shown a buckling of the container walls in a rebound phase directly after the primary impact. This is shown by a strain signal in Figure 4 (strain gauge was located in the hollow grove between a perpendicular and the horizontal container side). The behaviour of cubic containers in those drop orientations need further investigations or the development of impact limiting components.

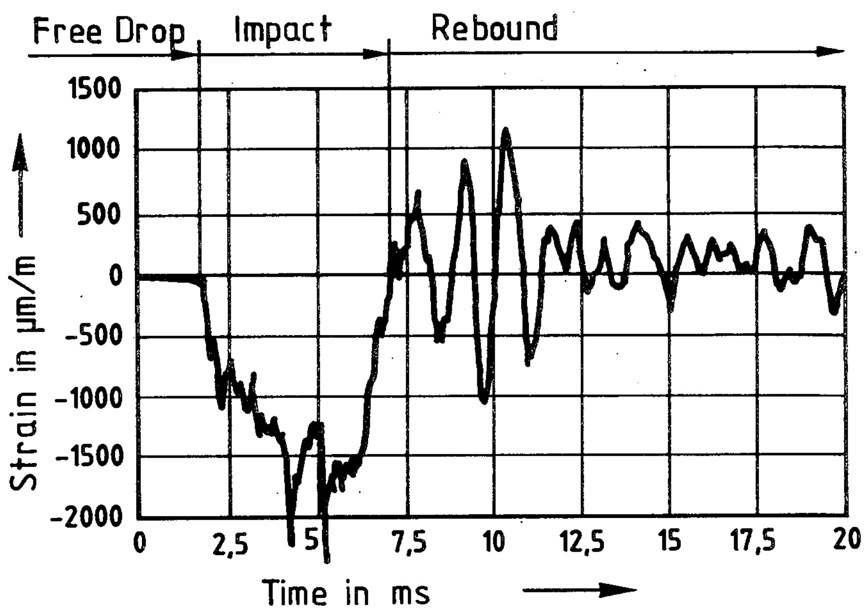

Figure 4: Flat Side Impact of a Cubic DCI Container in a 5 m Drop; Strain Signal Demonstrating Container Wall Buckling

EXTENDED MECHANICAL TESTS

Among a series of drop tests from greater heights after lifting the test objects by a helicopter /Ref. 4/ was one drop with a 1:2 scale model of a TN 8/9 spent fuel cask (7 BWR fuel assemblies) onto a concrete target (0.2 m reinforced concrete, 0.2 m concrete, 0.6 m layer of pit gravel). The drop height was 200 m, the impact velocity 225 km/h. The cask model (mass: 4.125 tons, length: 2.5 m, outer diameter: 0.85 m, cavity diameter 0.24 m, wall: 100 mm lead + 12.5 mm forged steel + copper cooling fins) was equipped with impact limiters at bottom and head of the cylinder. After that drop (Figure 5) where the cask penetrated 0.75 m into the target no loss of confinement integrity (bubble-test-leaktight) occured.
Another example for the evaluation of extended mechanical accident impacts are drop tests on casks with machined cracks inside the container wall area where the maximum tension stress occur /Ref. 5/.
Figure 6 shows a test object and flaw dimensions, the test conditions and the strain signal measured in axial direction near to the artifical flaw. Although the applied stress intensity in this 14 m drop test with a DCI cask body should have exceeded the fracture toughness no fracture and no crack initiation occured. Those tests may demonstrate that there are existing significant safety margins.

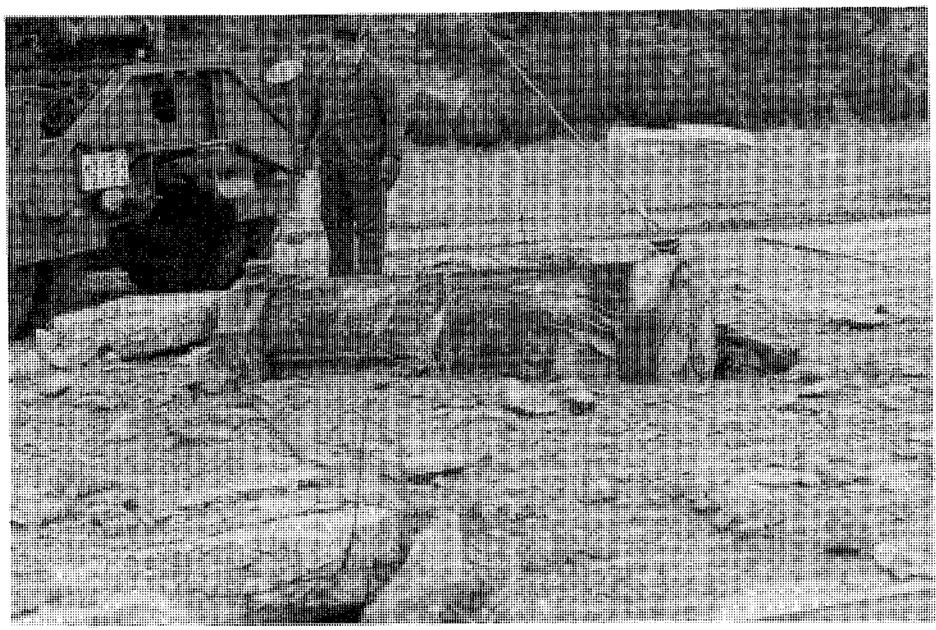

Figure 5: 1:2 Scale Model of a Spent Fuel Cask after a 200 m Drop

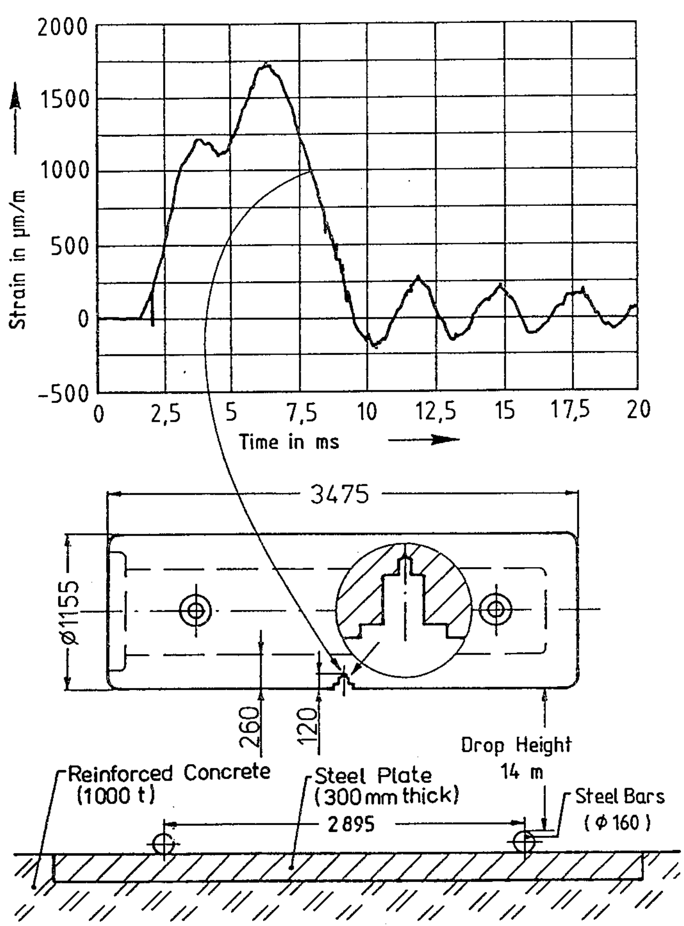

Figure 6: 14 m Drop of a Cylindrical DCI Cask with Artifical Flaw onto Steel Bars Located on an Unyielding Target. Axial Strain at the Bottom Side

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