Integrity of the POLLUX Cask for Final Disposal: Experimental Results of the Mechanical Tests

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INTRODUCTION

POLLUX is a cask designed for transportation, interim storage, and final disposal of spent-fuel elements in connection with the planned Gorleben Repository in Germany.

In context with the design safety evaluation of the POLLUX cask, BAM performed several drop tests under IAEA type B- and storage handling accident impacts with a full-scale prototype. The inner and outer cask were instrumentated with strain gauges and accelerometers of which the transient signals were basis for the stress analysis.

The drop test program, the cask instrumentation, and the measurement techniques are described by the same authors in the paper 'Drop Test Program with the German POLLUX Cask for Final Disposal of Spent Fuel'.

Three of the drop tests and their preliminary results of the stress analysis will be presented in this paper: results of the 9 m horizontal and declined drop test (cask equipped with impact limiters) onto an unyielding target and a 5 m drop test (cask without impact limiters) onto a concrete target.

THE 9 M HORIZONTAL DROP TEST ONTO AN UNYIELDING TARGET

The drop position of the cask was horizontal in this way, that the two trunnions take additionally to the impact limiters directly part of the impact. Figure 1 shows this drop position, where the POLLUX cask is shown schematically with some selected measuring points of which the strain and deceleration signals will be discussed later.

This drop position caused an impact (duration 20 ms), which was characterized by mainly two phases. During the first phase (duration nearly 6 ms) only the impact limiters were in contact with the target. After this 6 ms the deformation of the impact limiters arrived by a length of 90 mm (Figure 4), which is the geometrical distance between the width of the shock absorber and the length of the trunnion. At that time (beginning of second phase) the trunnions got additionally into contact (Figure 5) with the target. This event (duration 14 ms up to the end of impact) changed the damping and kinematic situation as well as the support conditions of the cask. This resulted in an increased deceleration (Figure 4) up to maximum values of nearly 200 g (average) along with higher bending stress of the casks. The strain curves (Figure 5) increased to higher values with a maximum material positive strain of 0.075 % on the outer cask surface. The shear failure of the trunnions collar at the time $t = 9$ ms caused a short interrupt of this situation with a time limited diminution of the corresponding strain and deceleration signals until the reaction force is fully transmitted by the trunnions again (Figure 5).

Looking at figure 5 and our other signals, the axial strain signals of outer and inner cask (measurement points located in the middle of the casks on the upper and down side) show bending as the main and typical deflection by this drop position.

The deflection of the welded lid, respectively, the welding seam, is mainly characterized by free bending vibrations initiated by the impact. Their maximum amplitudes were nearly $\pm$ 0.025 % (Figure 6).

The visual inspection of the cask after impact showed the broken trunnion collar (Gogolin, B. et al, 1995) and the deformed shock absorber with a deformation of 130 mm in good correspondence with the value taken from the corresponding two times integrated deceleration signal. The trunnions caused no damaging effects on the outer cask.

THE 9 M DECLINED DROP TEST ONTO THE UNYIELDING TARGET

The drop position of the cask (equipped with impact limiters) was with 16 degree angle of axis so that the center of mass was above the impact point and further the lid system of the casks were located in the impact zone. The two casks are coupled between shielding lid (outer cask) and welded lid (inner cask) by a damping element (Gogolin, B. et al, 1995) between the bottoms with a moderator plate. Figure 2 shows this impact situation of the cask with some selected measurement points from which the signals will be discussed later.

This drop test showed with about 58 ms the longest impact duration of our test series with the POLLUX cask. The reason lay in the declined position of the impact limiter with its out of that resulting highest possible deformation way. The displacement curve of the outer cask (two times integrated deceleration curve, a3) characterized the deformation time history of this impact limiter (Figure 8) during impact and showed a long deformation way with nearly 380 mm. This caused a relatively soft impact with small strains and decelerations of the casks.

The comparison of the deceleration signals (Figure 7) of the inner (a4) and outer cask (a3) respectively of their velocity time history curves (Figure 8) showed additional to the main motion (motion of center of gravity) a relative one between them with resulting internal collisions. The crossings between the two velocity curves as well as the opposite parts of the respective deceleration curves marked these collisions. The first collision happend at the time t = 10 ms: the internal collision causes an acceleration of the outer cask and a deceleration of the inner (Figure 7). In the following the main motion is superimposed by these effects. The way for the relative motion was given by the gap between the two casks and the damping way of the inner damping element. The measurement of the dismounted inner damping element after the test showed a plastic deformation of 2 mm. This plastic deformation does not concern the whole damping element. Only the outer ring, built by an aluminum rod showed this deformation. Going to the middle of the damper built by parallel located pieces of aluminum rods, the deformation was nearby zero (Gogolin, B. et al., 1995). This explains the positive strain signal of the welding seam (Figure 9) over the whole impact time with a maximum strain of 0,2 %. The harder damping of the middle of the inner damping element in contrast to the softer damping of the rim causes a bending of the welded lid, respectively positive strain in the support zone, the welding seam. The beginning of this loading is 8 ms time shifted to the beginning of the impact (marked by the deceleration signal of the outer cask) because of the relative motion between both casks.

THE 5 M DROP TEST ONTO THE CONCRETE TARGET

The horizontal drop position was chosen in the way that the trunnions are down side of the cask to take directly part of the impact, so that a comparison with the 9 m horizontal drop test was possible. The construction of the concrete target is described in the paper Gogolin, B. et al, 1995. The impact situation of the cask is shematically shown in Figure 3.

This impact position of the cask caused an impact (duration 40 ms) with two characteristic time periods. In the first period, the duration was 26 ms, the cask was penetrating with its trunnions the concrete layer. Looking at the deceleration time history of this period (Figure 10) this event was characterized by a constant deceleration of 16 g at the center of gravity respectively a linear velocity reduction. This deceleration was overlaid by signals of higher frequencies with high amplitudes concerning to the free vibrations of the cask. This relative low constant deceleration over a time of 65 % of the whole impact duration caused by the cask no deformation: the strain signals (Figure 11) show only free bending and/or free ovalization vibrations with relative low amplitudes during this period. A very high percentage of the kinetic energy was consumed by this local destruction of the concrete target, so that during the second period (duration 14 ms) where the cask body was in direct contact with the target only low strain values appeared. The deceleration rises to a maximum value of

90 g at the time t = 32 ms, the middle of the second period. Along to this deceleration time history respectively the corresponding acting mass force the elastic deformation of the cask was mainly characterized by ovalization/bending. This causes for example in the middle of the outer cask a negative strain curve with very little values.

The loading of the welded lid (inner cask) was characterized only by free bending vibrations similar to the 9 m horizontal drop test with impact limiters. The free bending vibrations caused bending-change stress in the welding seam but with lower amplitudes.

The visual inspection of the cask after impact showed undamaged trunnions.
The concrete target showed at the impact points of the trunnions conical perforations with a depth of the trunnion lengths (Gogolin, B. et al, 1995). No other destructions like severe cracks etc. were found on the concrete target.

CONCLUSION

We assume that in the 9 m drop test onto the unyielding target the horizontal drop position with trunnions down side so that they took directly part of the impact caused higher bending stresses (main deflection) than without.

This was not the case in the 5 m drop onto the concrete target. The local destruction of the concrete layer consumed a relative high percentage of the initial kinetic energy, so that the following deflection of the cask (cask and concrete layer in contact) was low. An impact situation without participation of the trunnions would probably have caused higher stresses on the cask.

The expected damaging effects of the trunnions to the shielding cask did not appear; no cracks or plastic deformation were detected.

The welded lid respectively the welding seam got the highest stress in the declined impact position. The main reason for the relative high bending of the lid was the construction of the inner damping element that can be easily improved. The horizontal impacts initiated only free bending vibrations in the welding lid with resulting bending - change stress in the welding seam. The amplitudes were relatively low and took maximum values (average) of ± 0.025 %.

The experimental stress analysis shows that POLLUX is safe under mechanical impact conditions. With final ultrasonic, helium leaktightness, and surface crack tests, no leakage or crack was detected.

REFERENCES

Gogolin, B., Droste, B., Quercetti, Th. *Drop Test Program With the German 'POLLUX' Cask for Final Disposal of Spent Fuel,* 1995

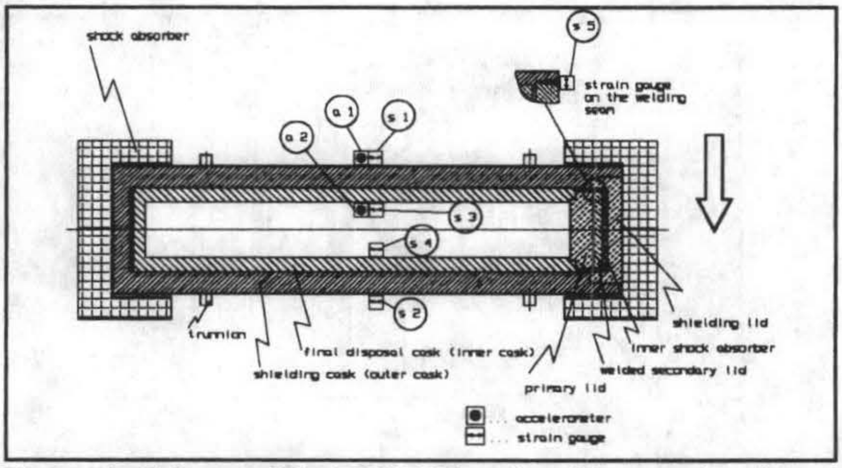

Figure 1: Scheme of the POLLUX cask and impact situation of the 9 m horizontal drop test onto the unyielding target. Some selected measurement points.

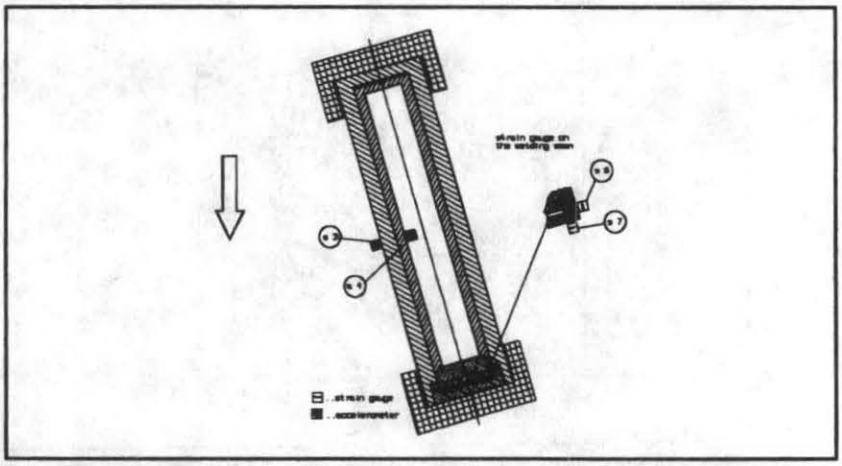

Figure 2: Impact situation of the 9 m declined drop test onto the unyielding target. Some selected mesurement points.

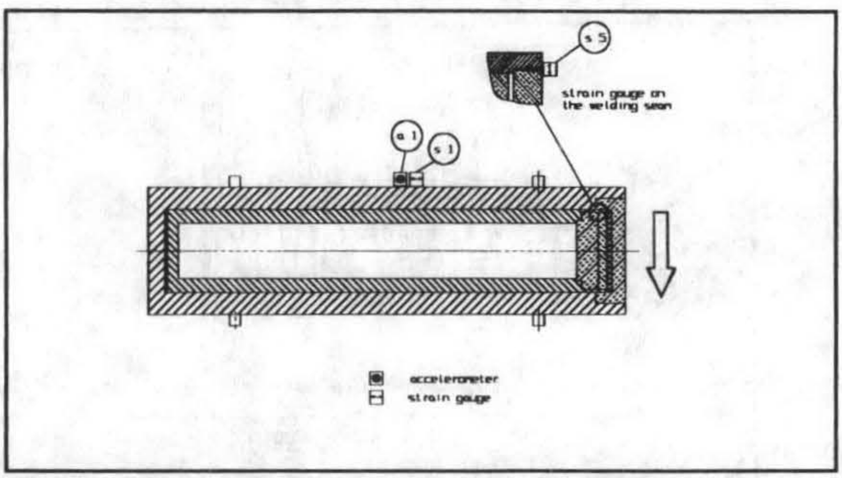

Figure 3: Impact situation of the 5 m horizontal drop test onto the concrete target. Some selected measurement points.

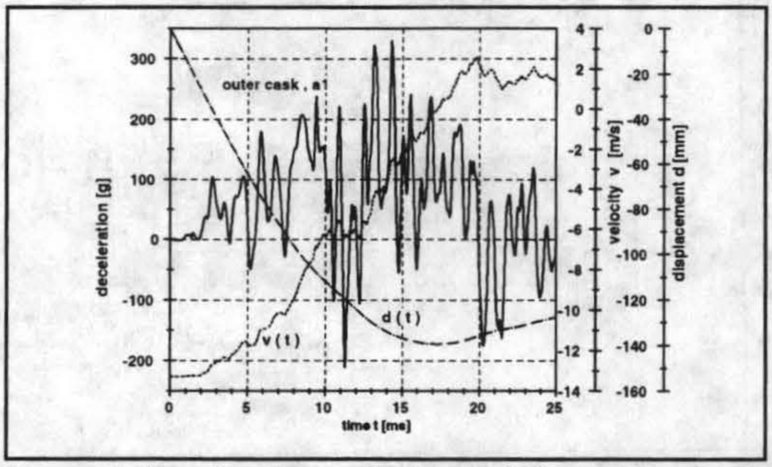

Figure 4: Deceleration, velocity and displacement time history of the outer cask. Impact duration, 20 ms.

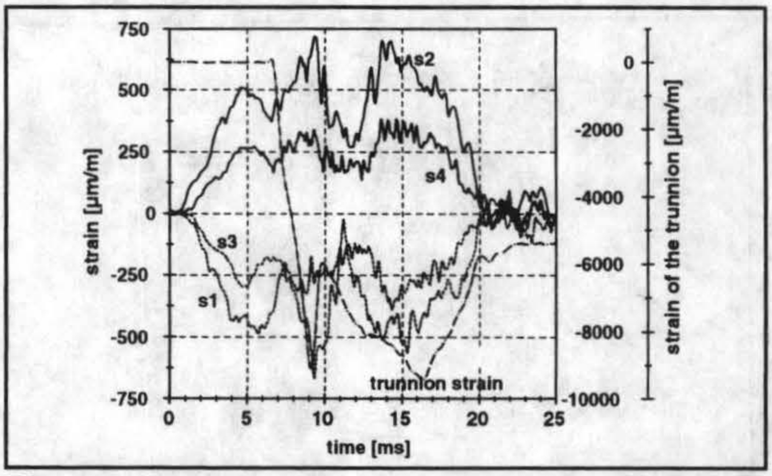

Figure 5: Strain signals (low pass 1 kHz) of the outer (s1, s2) and inner (s3, s4) cask on the upper and down side. Strain signal of a trunnion.

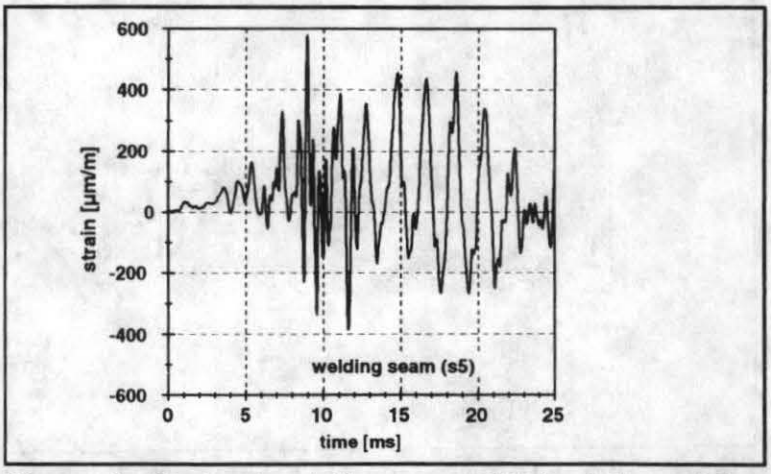

Figure 6: Strain signal (low pass 1kHz) of the welding seam. Free vibrations.

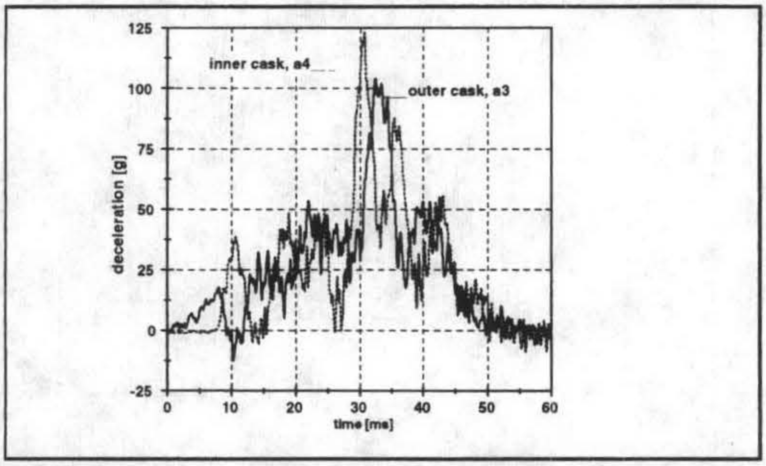

Figure 7: Deceleration curve (low pass 1 kHz) of outer (a3) and inner (a4) cask. Impact duration, 58 ms.

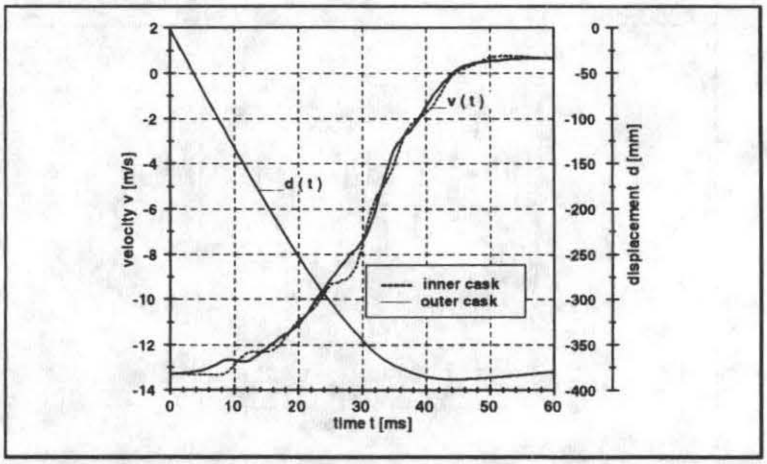

Figure 8: Velocity curve of inner and outer cask. Displacement time history of outer cask respektively deformation curve of impact limiter.

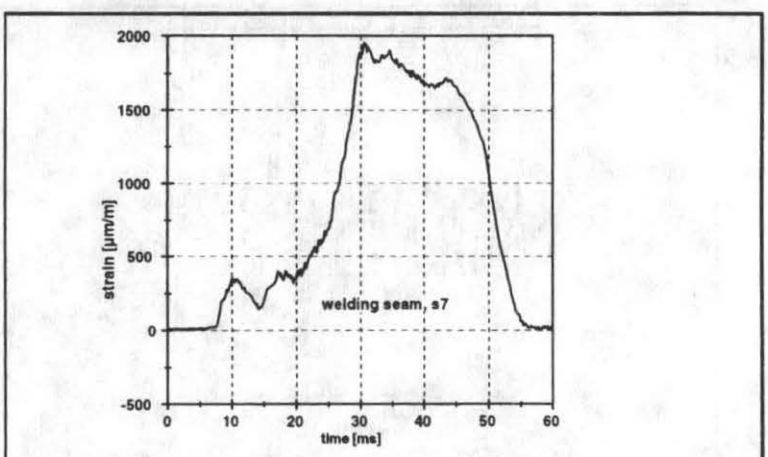

Figure 9: Strain signal of the welding seam caused by bending of the welded lid.

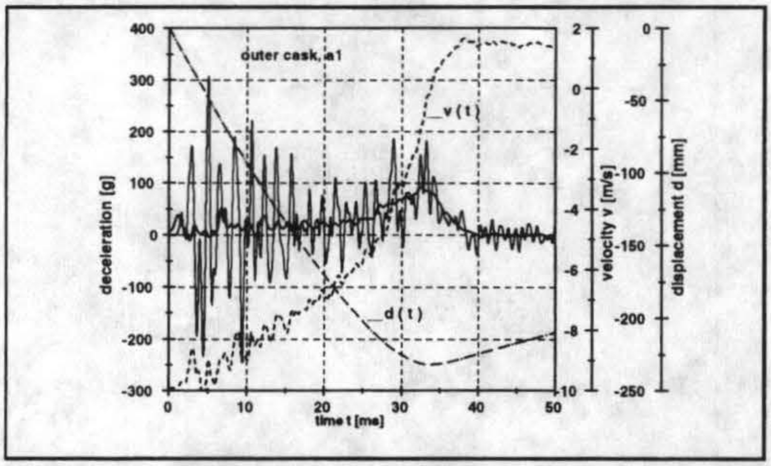

Figure 10: Deceleration, velocity and displacement time history of the outer cask. Impact duration, 40 ms.

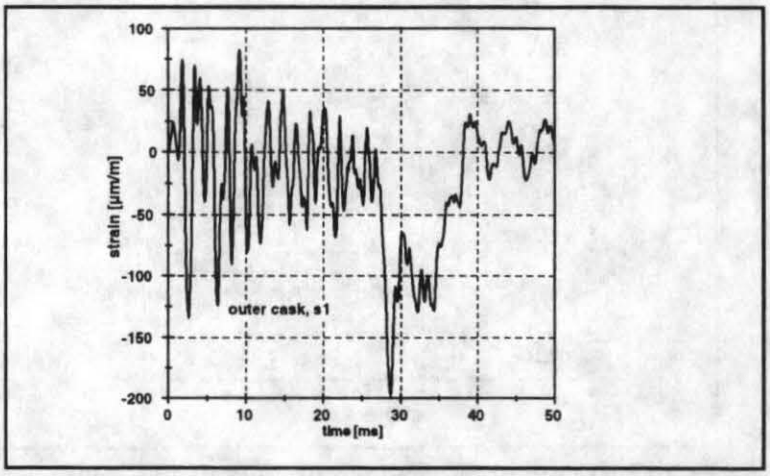

Figure 11: Axial strain in the middle of the outer cask surface.

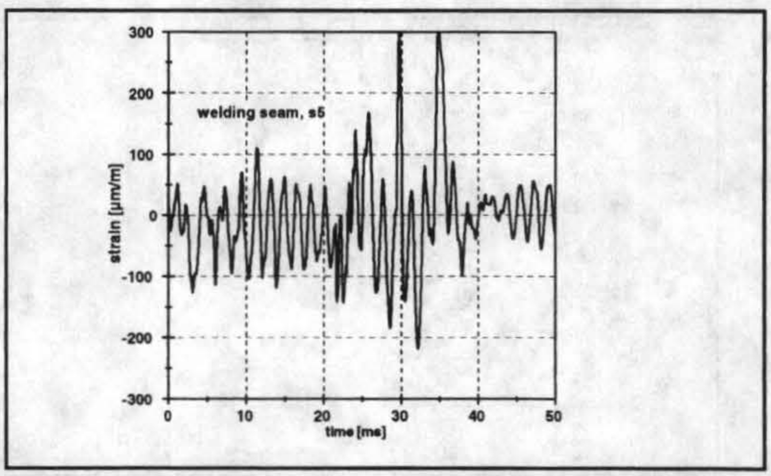

Figure 12: Strain signal of the welding seam caused by free bending vibrations of the welded lid.