Drop-Test Program With the German "POLLUX" Cask for Final Disposal of Spent Fuel

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Abstract

A fullscale prototype cask for shipping, interim storage and final disposal of spent fuel in a German repository, named POLLUX, designed and manufactured by GNS/GNB, was tested by BAM according to the transport regulations and under impacts resulting from handling accidents in a storage site. The tests, test conditions, and instrumentation of the cask are described.

Survey of the Design

POLLUX a schematic view is given in Fig. 1 consists of an inner cask made of fine grained steel (15 MnNi 6.3) with a body pressed out from one piece. The wall thickness of this inner cask is 160 mm, its mass is 21 tons. This inner cask is closed by a bolted primary lid and a secondary welded lid. It is inserted in a loose manner in an outer cask (material DCI, GGG 40) for additional shielding. In the space between both casks there is mounted an additional impact limiter at the lid side and at the bottom side, a special plate with additional moderator elements. The outer cask has to withstand the isostatic mountain pressure in the salt formation. The outer shielding cask with a wall thickness of 265 mm is closed by a heavy lid with acme thread. The total mass of the loaded cask system equipped with impact limiters is about 70 tons. Detailed information you can find in *Spilker et al (1992)*. For the simulation of the load we used a solid steel cylinder instead of the normal basket loaded with spent fuel canisters.

Planning the Tests

BAM decided that for the safety assessment of such a novel cask system it would be necessary to make performance tests with a full-scale prototype. Because the tests give a good chance to verify FEM calculations by measurements, such calculations were done, and the results were presented before the tests.

It took us nearly 2 years of planning and realizing the test program. We projected three

9 m drop tests with the cask equipped with impact limiters in accordance with the IAEA regulations for type B packages, and two subsequent tests to meet the

German licensing procedure for intermediate storage and final disposal (Fig. 2). The most severe accident in handling the cask by crane had to be taken into account by these tests. Therefore, POLLUX was to drop from a height of 5 m without impact limiters onto concrete layers, manufactured in accordance with the actual base of the spent fuel intermediate storage building in Gorleben. We simulated the situation at the storage building as can be seen in Fig. 2 by using relatively small reinforced concrete slabs, the armoring of which was fixed by welding to a solid steel frame. So we could be sure that the reaction of this target would not be too soft due to the tearing out the armoring. These slabs (thickness 400 mm, quality B 400 with a compression strength of 40 kN/cm^2) were placed on the 1000 t IAEA-target with a layer of compressed wet grawel enclosed in a steel frame.

For handling the POLLUX in an easy manner there was a special hanger designed with a pivotal point near the center of gravity. With this hanger it was possible to turn the cask in any necessary position.

Instrumentation and Measurement Equipment

The choice of the cask instrumentation and the points of measurement was made with respect to the different stress conditions resulting from the respective drop positions. More than 80 strain gauges or accelerometers were applied. Of these 68 were activated for each test. In two 32 channel measuring systems (data acquisition units with integrated dc-po-wer supply for direct strain gauge measurements, sampling rate 100 kHz per channel, resolution 12 bit) 64 measurements were taken, while the remaining four were taken as redundant measurements from seperate gauges with cables separated from the normal cable tree, leading to another measuring system.

For the strain measurements we used gauges with 350 ohms and a gauge length of 6 mm, except for the gauges on the welding beam of the inner cask secondary lid (700 ohms, 60 mm). All gauges were connected in three wire half bridge technics with a compensation resistor placed in the connectors.

For decelleration we used different accelerometers of piezo resistive types. At the first test there were applicated accelerometers with a measuring range of 500 g, damped types wherever there was enough space, and undamped miniature accelerometers at all points where we had to mount them in a groove. The damped accelerometers worked well, while all the undamped ones failed. So for the later tests we installed where it was possible - other types with measuring ranges of 2000 g and 6000 g, but some of these failed too. The explanation for this is that impact causes vibrations with high magnitudes at high frequencies which often destroy accelerometers. This effect is described in the literature as the metal to metal effect.

Preparation of the POLLUX

The preparation of the measurements was very complicated, because both casks had to be instrumented on each inner and outer side. The manner of instrumentation would have to minimize the disturbance of the stress field. Therefore, the recesses we needed for appli-cation of the strain gauges and the accelerometers (in the gap between the two casks, as between the outer cask and the impact limiters and as between the different lids) had to be very small and flat. Most of the hollows, the notches and the holes for the cables were made by hand for they could not be machined.

As one can see at the instrumentation plan of the inner cask (Fig. 3), all cables from measuring points from the outer side of the inner cask were led through holes directly to the inner side of the wall. From there they were led in a bundle of 120 wires through a thick walled pipe fixed in a central hole of both bottoms to the outside of the outer cask, then through a covered groove to a moderator hole, and then to the soldering points at the outside of the outer cask. All cables were protected in such a way we thought, that neither relative movement of the two casks nor of the solid steel bar inside the inner cask could destroy them. But nevertheless it happened, and in the time between the tests much repair work was requested. The instrumentation plan for the outer cask is given in Fig. 4. At the outer cask we led all cables directly to the outer surface and then in grooves out of the area of the impact limiters to the middle of the cask.

The Tests

The test series was carried out in summer 1994 and started with a drop test in a horizontal position from a height of 9 m (Fig. 5) onto the trunnions. This test showed that the trunnions were severely affected. They sheared in the classic manner for compressive stress with a shear angle of 45 degrees (Fig. 6). But the fastening region at the outer shelf showed no cracks or deformations, which we had feared before the test would result from the disturbance of the shell at these points. More information about some selected measurements is given in *Quercetti et al* (1995). A misfortune of this test was that the moderator plate placed between the bottoms of the two casks cut the cable protection pipe and all cables from the inner cask. As a result of this, our signals broke off after two-thirds of the impact duration time, and we decided to repeat this test with repaired cables at the end of the series.

The second test, top down, with impact limiters showed relatively small compressive strain on the bodies of the two casks because the long deformation time of the impact limiters but unexpected high bending strain at the welded lids so that we had an overflow of the measuring range for the gauges on the welding zone, but no crack or deformation was visible. This bending strain in the welded lid was caused by the special design of the inner impact limiter (soft at the rim, hard in the center) and can be minimized easily by modifing the design. Fig. 7 shows the plate with the deformed aluminium rods. More information to this effect and to the difference between measurement and FEM calculation can be found in *Zeisler et al(1995).*

The third drop was top down in an inclined position (16 degrees), center of gravity above edge of the lid side. For this test a new inner impact limiter was used. It was a very soft drop with an impact duration of 58 ms. No damage was found on the drop corner, on the lids, or on the casks bodies. Even the thread of the shielding lid of the outer cask was not deformed, and there was no problem in opening the cask for the inspection. The bending strain of the welding zone of the seconary lid of the inner cask was nearly as high as in the test before. More information of some measured results and some ideas of the kinematics during the impact are given by *Quercetti et al (1995)*.

The fourth drop was made to meet the requirements for the intermediate storage. This drop without impact limiters on the concrete slab was the hardest one of the series because the expected breaking of the target did not happen and the impact duration was very short with a duration of about 10 ms. The deceleration near the bottom was measured with a peak near 1000 g (filtered with 1 kHz). As Fig. 9 shows, there was a penetration into the surface of the slab with a depth of about 2 mm, and some small pieces of concrete broke from the surface of the slab in the region of the contact diameter. Very interesting are the measured strain curves of the welding zone of the lid of the inner cask (for example, see Fig. 9). It shows moderate amplitudes during the real impact time (0 - 10 ms). But when the cask is thrown back (10 to 18 ms) there is a free bending vibration with amplitudes up to twice the peaks during the impact. In the following 5 ms there is a single peak of an amplitude greater than the measuring range, caused by an inner collision of the two casks. At 80 ms after this peak (not shown in the picture) at a time when the signal shows a very low level, there is another single peak of the same shape and amplitude. A definite explanation for this effect is not yet known, but there is a good correspondence with other strain signals, so we are sure about the correctness of our measurement. Effects of relative movement between the outer and inner cask was observed also at the second and third test and they are discribed by *Quercetti et al (1995)*. Similar behavior was found in tests with other casks with liners inserted in a loose manner.

As a consequence of the fifth drop, trunnions down on concrete slab, we expected the cracking of the slab in its longitudinal direction. But only the trunnions penetrated the concrete and caused two craters as can be seen in Fig. 10. The trunnions themselves were absolutely uneffected so that they could be used for the following repetition of the first drop. The effect of the penetrating trunnions was a two phase drop, with a long period of moderate deceleration and a short period of high deceleration when the generatrix contacted the slab. More details about this effect to the measurements can be found in *Quercetti et al (1995)*.

The repetition of the first drop gives a good correlation of both measurings and showed the same effect to impact limiters and trunnions.

Final Remarks

After the six tests were finished there were about 400 single measurements waiting for interpretation. This work of interpretation and analyzing is still continuing; and therefore, the first results you find by *Quercetti et al (1995)* are preliminary. It would be necessary to understand the difficult kinematics and interaction of the three masses during and after the impact duration to give a satisfactory interpretation of all measured results.

Nevertheless, six hard drop tests showed no outer damage of the POLLUX cask and investigations performed of the dismantled container showed that there also was no inner damage. Evidence of this was provided by a helium leakage test and a surface crack test performed at the critical points of the weld seam of the lid of the inner container.

With these tests, the BAM has contributed to providing a clear evaluation of the safety of this special type of a multipurpose cask.

References

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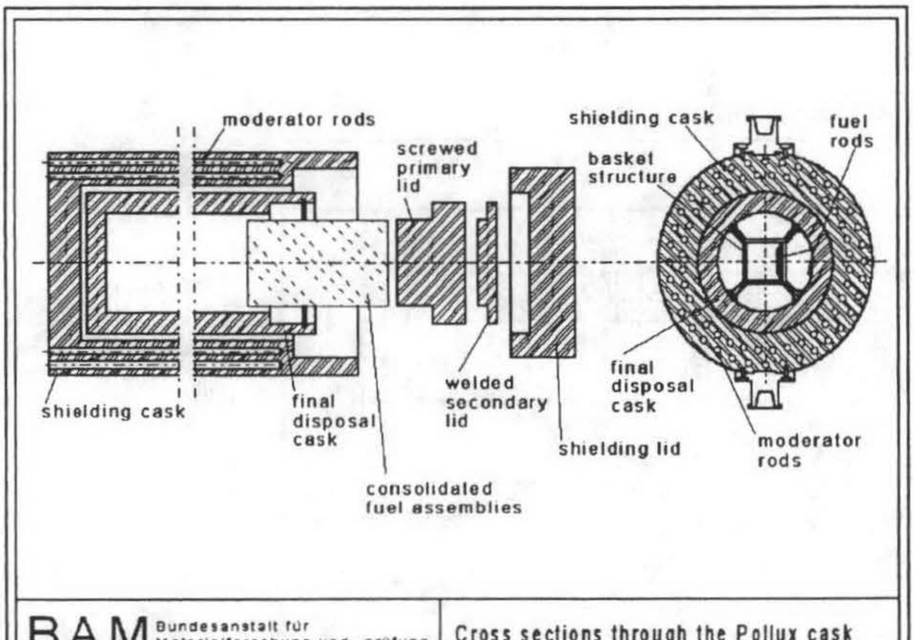

Fig. 1

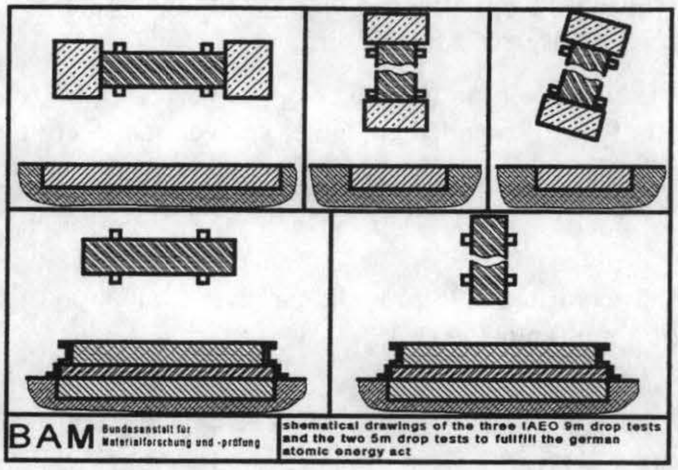

Fig. 2

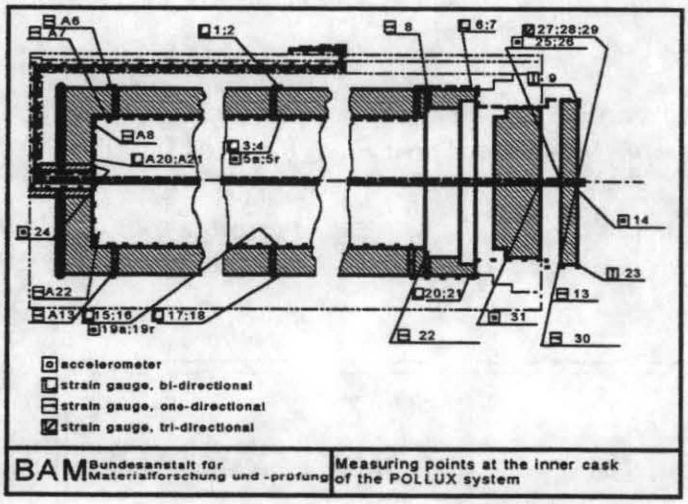

Fig. 3

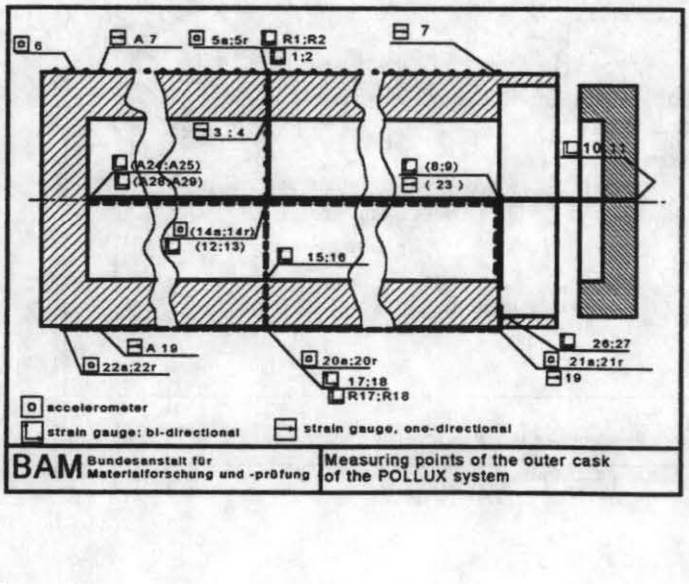

Fig. 4

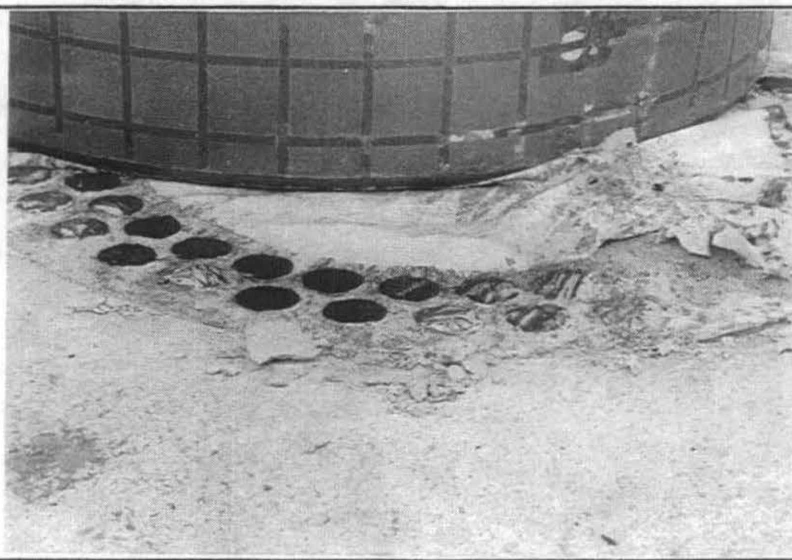

Fig. 5

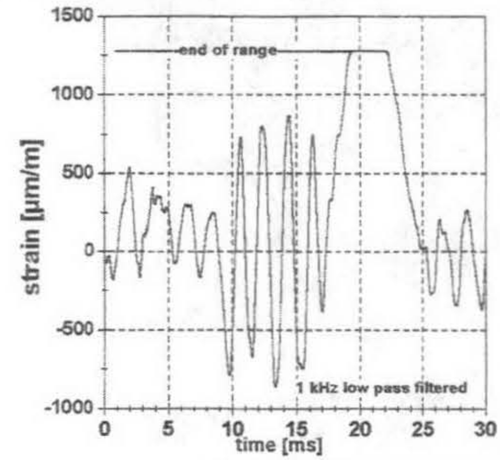

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Fig. 6

Fig. 7

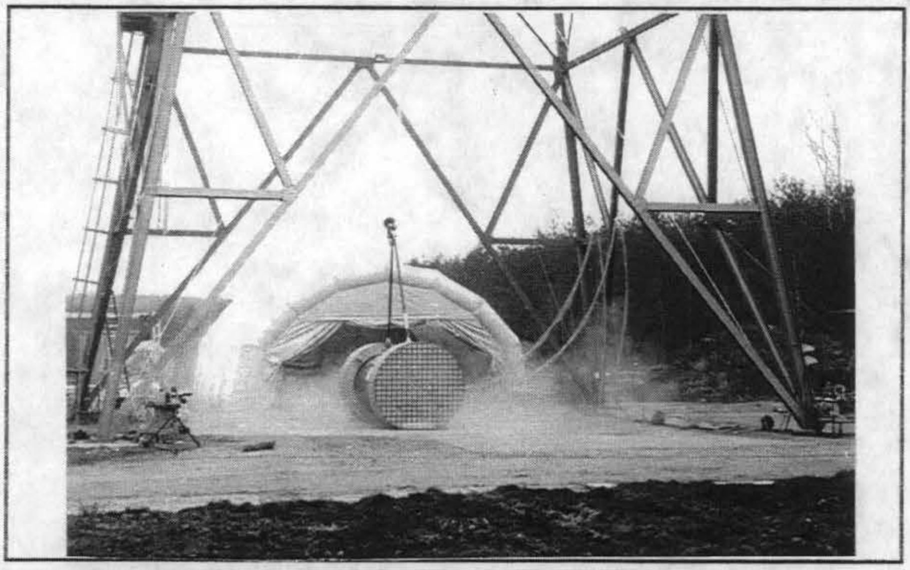

Fig. 8

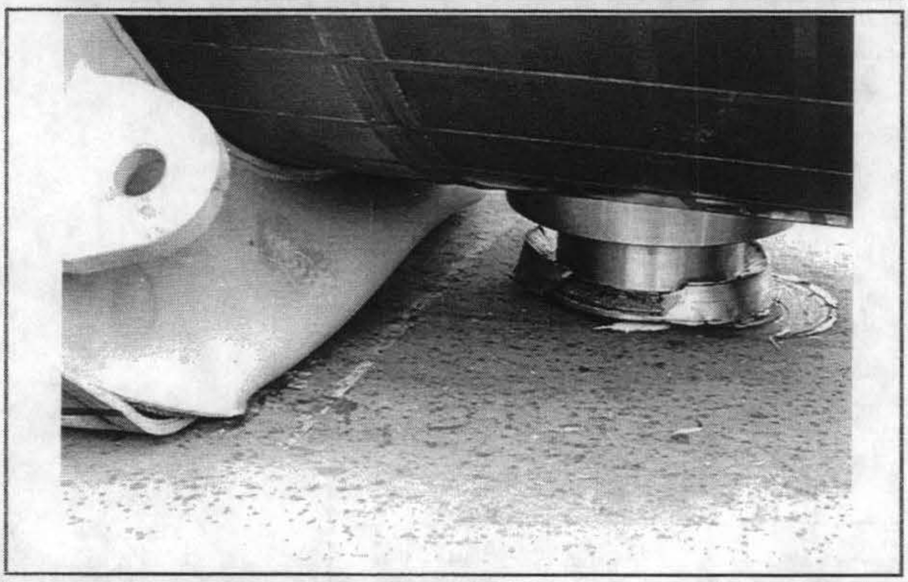

Fig. 9

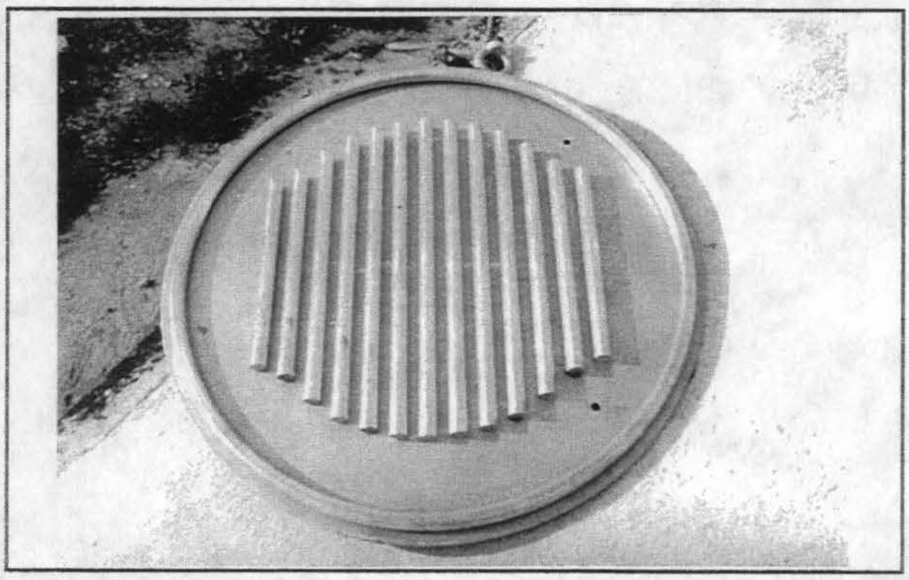

Fig. 10