DROP TESTS WITH THE „RA-3D“ SHIPPING CONTAINER FOR THE TRANSPORT OF FRESH BWR-FUEL ASSEMBLIES

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ABSTRACT

With two original packages taken from the stock of used transport containers, seven drop tests were performed. The test objects was applied with accelerometers and strain gauges outside and inside. From the measured values diagrams for deceleration, velocity, and displacement, as well as for strain were generated. From the results information of the different behavior of the single components of the package during the period of the impact were taken. This paper describes the tests and the results in detail.

INTRODUCTION

In order to gain an extension of the approval of the already existing shipping container „RA-3D“, BAM, as the competent authority for safety assessment and quality assurance in Germany, requested new drop tests. The aim was to show that under accident conditions no deformation could take place that would lead to an unacceptable rise of criticality.

At the first discussion with the applicant in April 1998, it was decided that lead pellets should be used for the fabrication of the dummy elements in the drop tests. Finally the applicant decided to perform the drop testing with fuel assemblies loaded with natural uranium pellets so that there was no question that the test results were representative. This caused a problem for BAM because of the German state authority has not given approval for the handling of uranium at the drop test facility in Lehre. In summer 1998, it was decided to construct a special IAEA target at the fabrication plant of “ENUSA” near Salamanca in Spain in order to allow getting an approval within such short time.

A test facility was built at the ENUSA Factory at Juzbado, under the supervision and acceptance of BAM, with a solid mass of about 32 tons upon the factory gr ound. A special authorization from the Spanish Competent Authorities was also obtained to perform this activity in Juzbado. The preparation required more time than expected, but in December 1998 the tests were carried out in the presence of members of the Spanish and French authorities.

More details concerning the test, the preparation, the package etc. are given in Perez Millan, P. [1]

A BRIEF DESCRIPTION OF THE PACKAGE

The tested packaging for the transportation of two fresh BWR fuel assemblies consisted of an outer wooden box and an inner double walled container made of stainless steel. The outer wooden box as well as the inner container were lined with shock absorbing material: honeycomb material made of hard paper and foam material respectively. A schematic view is given in Figure 1. A pre-test had shown that the existing design of the wooden box would not withstand a vertical corner drop. Therefore, the front plates were strengthened with a steel frame. Each of the two test packages was loaded with two fuel assemblies, one with a 9 x 9 lattice and one with a 10 x 10 lattice. The fuel assemblies were exactly like the standard BWR fuel assemblies designs.

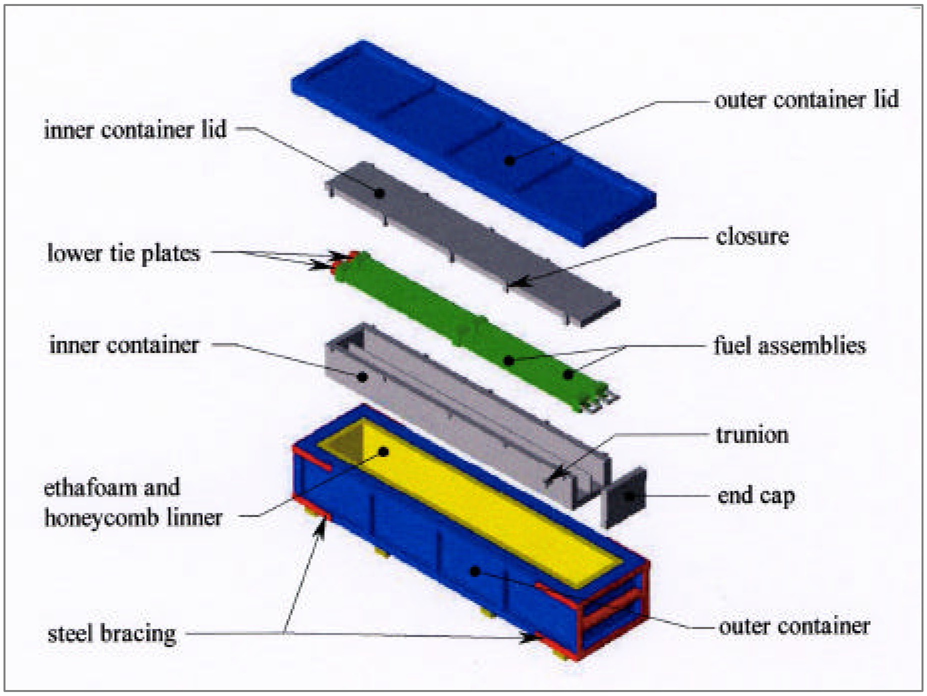


Fig. 1: *parts of RA-3D package*

INSTRUMENTATION

In order to gain some understanding of the packages' behavior during the impact, each test object was applied with accelerometers on the inside and outside. A piezoresistant type with ranges of 500 g and 5000 g respectively were chosen as accelerometers. In order to obtain information about the stress in the fuel rods, some strain gauges were attached to some of the rods at special positions. The cables from the instrumentation inside the inner container were led to the outside through a gap in the gasket and through a hole in the wall. Thus, the strength of the package was not effected by the instrumentation. In addition to the instrumentation of the packages, each of the bars for the bar drops (puncture test) was applied with four strain gauges. For acquisition of the measurements, a 32 channel data acquisition unit was used. With a sampling rate of 10 µs, 512000 samples were taken for each channel.

TEST SEQUENCE NO. 1

For this drop position, a maximum effect on the endplate, and on the end cap of the inner container respectively, was anticipated. The fuel rods were expected to suffer the risk of buckling.

The sequence no. 1 consists of a

(a) 1.2 m vertical corner drop, head down, c. g. above impact corner onto the flat target
(b) 9 m drop, in the same position, onto the flat target
(c) 1.0 m drop, in the same position, onto a bar
and additionally a
(d) 1.0 m drop with the lid side onto a bar. Drop position: length axis horizontal, cross axis 25° inclined, c. g. above impact point.

The package was applied with four accelerometers in top position: one on each fuel assembly, one on the head closure of the inner container, and one at the plate of the outer container. For the horizontal drop (d) two accelerometers were installed: one on the center of the bottom plate of the inner container, and one on the bottom plate of the outer container.

Figure 2 shows the test object in drop position for the vertical bar drop (c). Figure 3 shows the object during the horizontal drop (d) just before hitting the bar.

Fig. 2: *vertical bar drop (c)*

Fig. 3: *horizontal bar drop (d)*

For the 9 m vertical drop (b), an example of the results of the measurements is given in Figure 4, which shows deceleration, velocity, and displacement vs. time. On the diagram for velocity in particular, you can see that the reactions of the inner components of the package were delayed in relation to those of the outer container. This is an effect of the shock absorbing material inside each container.

The *curves for the velocity* of the inner components show two phases, a first one with a soft rise of the curves, and a second one with a strong rise. In the first phase, the rise of the curves was nearly identical to the one that occurred in the 1.2 m drop (a). Here the shock absorbing material was still working. In the second phase, the compressible materials were fully compressed. Therefore, the deceleration of the inner container and the fuel assemblies rose to values nearly ten times higher than in the first phase. In the curves for the fuel assemblies, the shifts to negative velocity result from the buckling of the handles.

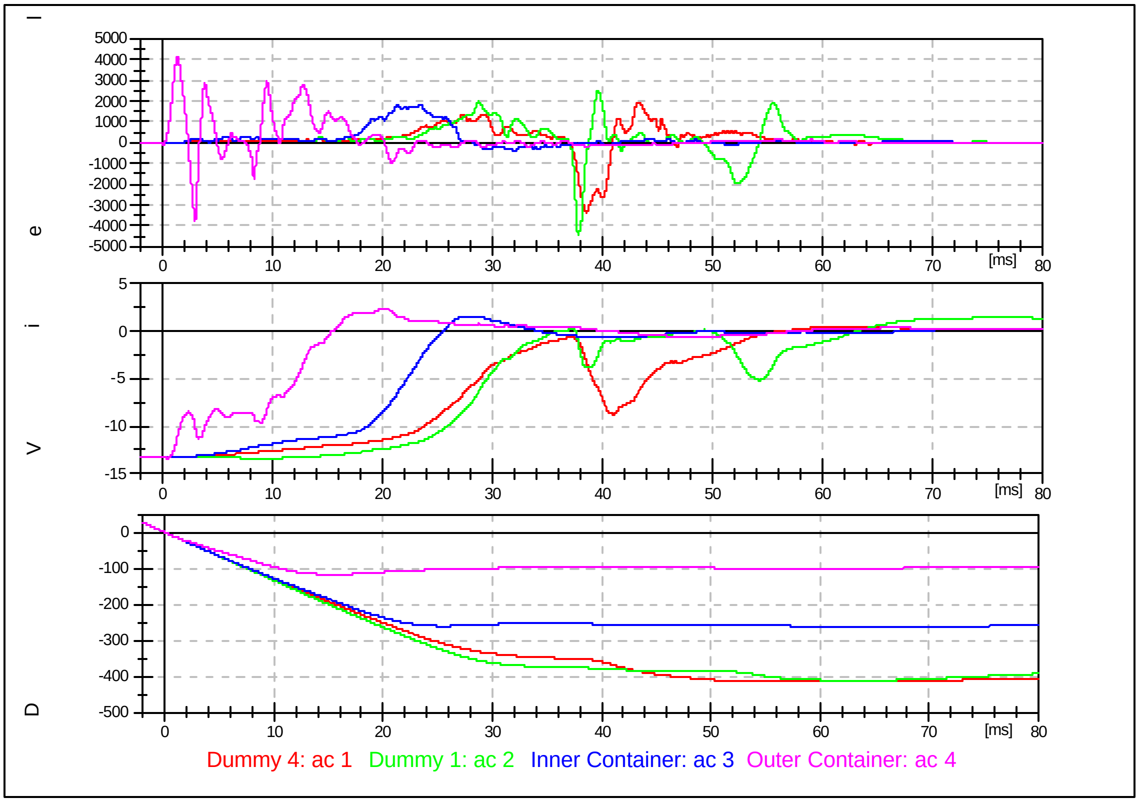


Fig. 4: *deceleration, velocity and displacements from the vertical 9 m drop (b)*

The *curves for the displacement* show that the inner container had moved ~ 160 mm, and the fuel assemblies had moved ~ 150 mm relative to the outer container. When the container was opened after the test sequence, these values were confirmed by static control.

The corner drop onto the bar (c) was not more severe than the 1.2 m drop, although the shock absorbing material was already fully compressed in the 9 m drop before. This is due to the fact that at the end of the impact, the container had slipped a little bit to the side, and thus the bar destroyed the edge of the wooden box along a stretch of about 300 mm.

As to the bar drop on the lid side (d), Figure 5 compares the measured strain in the middle of three rods with the velocity curve that was taken from an accelerometer placed in the middle of the bottom side of the container. It shows that when the bar penetrates the wooden container (during the first 40 ms) there is nearly no effect on the velocity or the bending of the rods.

When the bar hits the inner container and buckles its lid (depth ~ 76 mm), we observed peaks of high (bending) strain.

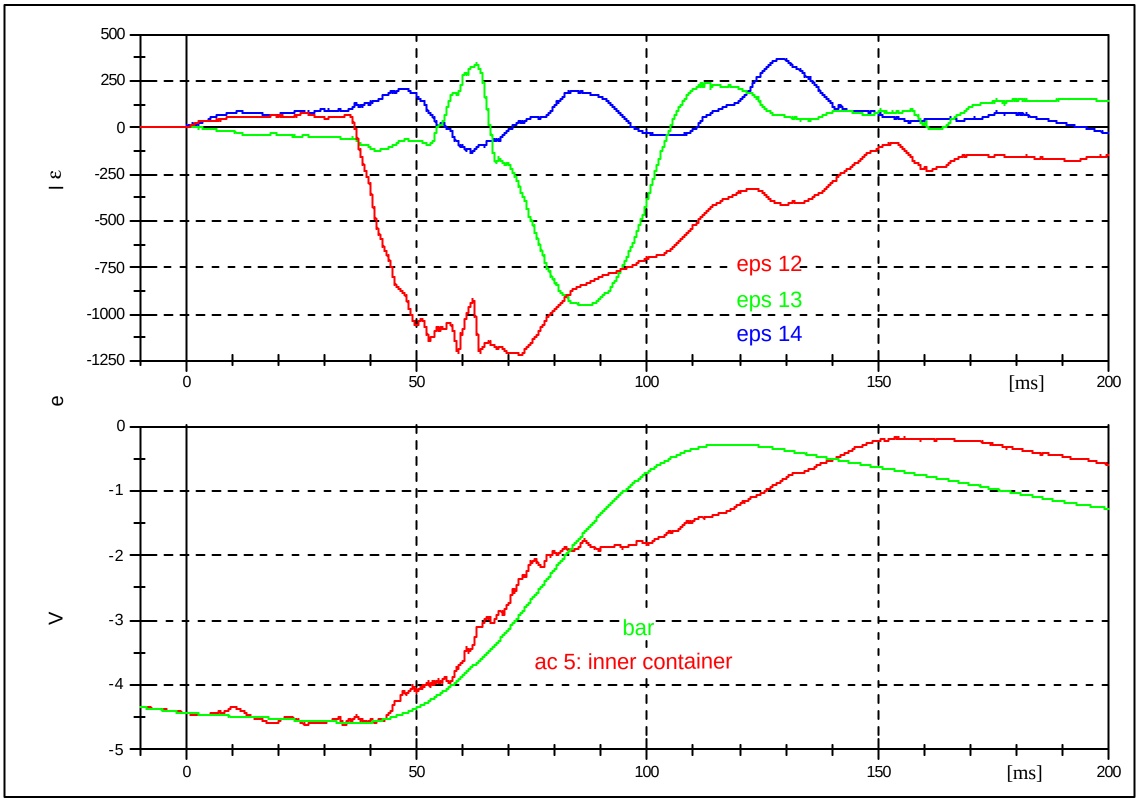


Fig. 5: *rod strain and velocity from the horizontal bar drop (c)*

Figures 6 and 7 show the situation of the foot and the head side after opening the inner container test sequence no. 1.

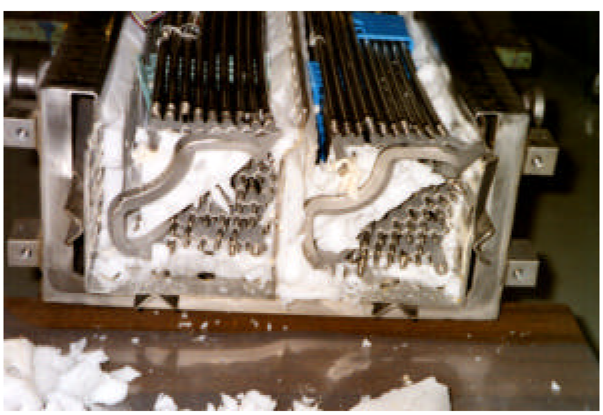


Fig. 6: *deformation of the handles after test sequence no. 1*

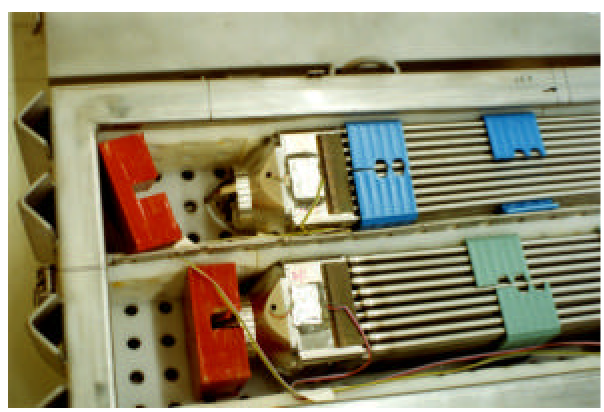


Fig. 7: *displacement of the fuel assemblies after test sequence no. 2*

TEST SEQUENCE NO. 2

The reason for carrying out this sequence was to assess the damage that would happen to the compartments of the inner container and the fuel assemblies by a slap down impact, and to demonstrate that the bar could not penetrate the inner container.

The sequence no. 2 consists of a

(e) 1.2 m drop, 10° inclined slap down on the flat target, side wall down, head region upward
(f) 9 m drop, 10° in the same position onto the flat target
(g) 25° inclined drop on a bar, same side wall down

Fig. 8: *RA-3D in position for 9 m slap down drop (f)*

The package was applied with seven accelerometers: one at each end of the outer container, one at each end and one in the middle of the inner container, and one at each end of one fuel assembly. Eight strain gauges were fixed in the middle section of the fuel assemblies, each one to a corner rod.

An example of the results of the measurements taken in sequence no. 2 is given in Figure 9. It shows the velocity curves – that is the integrated deceleration curves – for the outer container, the inner container, and one fuel assembly. One can see the typical effect of a slap down drop with additional acceleration of the secondary impacting end. A slap down impact can be divided into four phases:

Phase 1 (rectilinear and rotational movement): The object hits the target with the primary impact edge (A). The lateral drop velocity changes to rotational velocity, with the impact point A as center of rotation. The impact edge suffers elastic-plastic deformation. This phase ends when the velocity of the impact point is zero.

Phase 2 (rotational movement): In the beginning of phase two, the object has only rotational speed with the center of rotation in point A. Now the elastic deformation of the impact edge springs back, so that this edge is accelerated. This acceleration produces a small rectilinear component and adds rotational velocity around the center of gravity. Therefore, for the sum of both rotational velocities the center of rotation moves a little bit from the impact point A towards the center of gravity. The force of gravity acts around the impact point and adds another small component to the rotational velocity. This phase is completed when the contact of point A with the target ends.

Phase 3 (rotational and rectilinear movement): While the object has no more contact with the target, gravity adds lateral acceleration to it. The result is a negligible component of translational velocity in downward direction, additional to the rotational velocity resulting from the sum of phase one and two. In certain cases this phase does not occur, e.g. in the case of the 9 m drop with the RA-3D (f), but could clearly be seen in the results of the 1.2 m drop (e), not given in this paper.

Phase 4: (secondary impact of edge B): This phase is similar to phase 1, with the difference that the initial velocity is (almost) only rotational speed. The final velocity is rotational velocity in the inverse direction, with edge B as center of rotation.

This is a rough description of the mechanics of a slap down impact. In the case of an object with loose components, all phases can be effected by the forces interacting between these components. This happened to the RA-3D package.

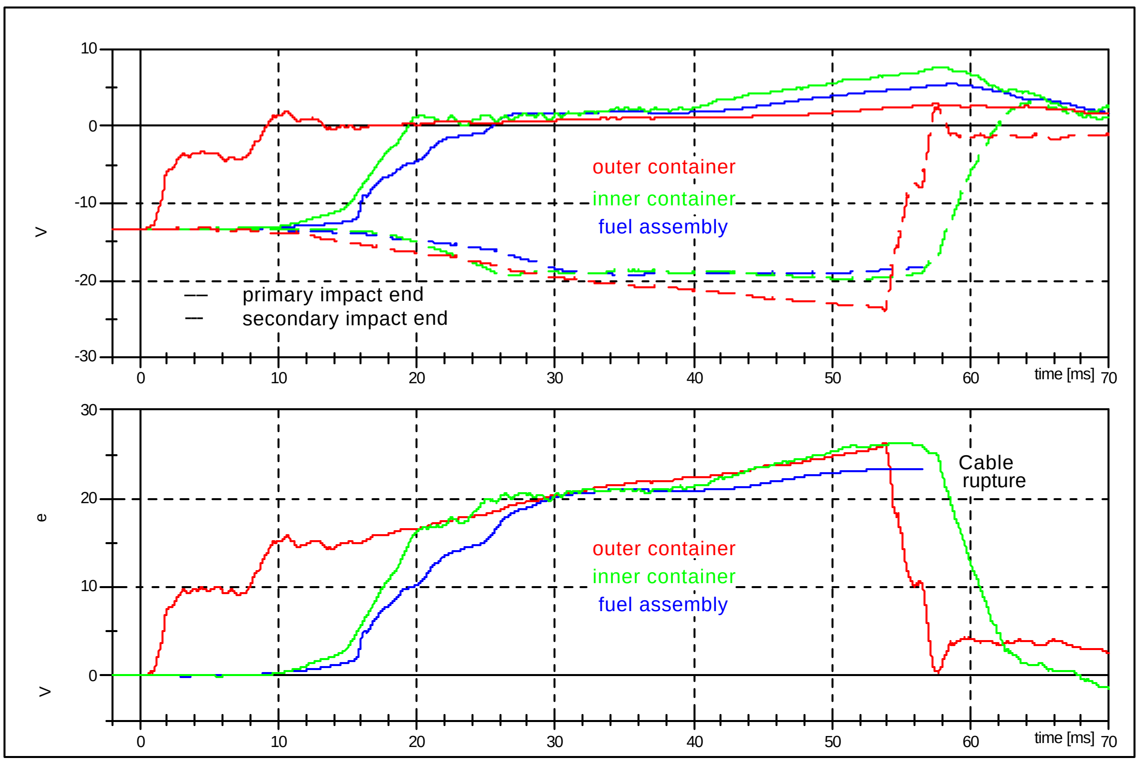
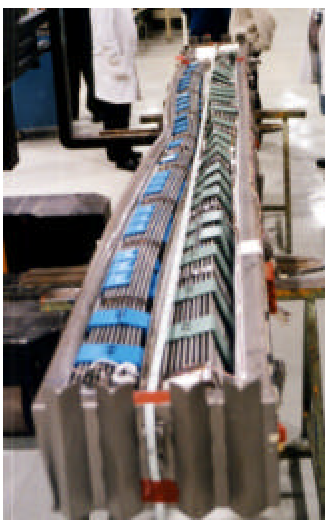


Fig. 9: *velocities from the 9 m slap down drop (f)*

When the difference $v_{rot}=v_B-v_A$ is calculated, the translation component is eliminated and the result is the rotational velocity relating to point A. A diagram of these differences is given in the lower part of Figure 9.

In both parts of Figure 9, there is a delay between the reactions of the different components. The explanation for this is the fact that in the previous 1.2 m drop the honeycomb material inside the outer container was partly compressed, and thus the inner container had some clearance inside the outer container. This makes it possible for the inner container to move relative to the outer container. More information on the moving of loose masses during the drop is given in [2] and [3]. When the outer container hits the target, the inner container and the fuel assembly continue their free drop inside the outer container, and therefore the beginning of the deceleration of these components is time delayed. From the displacement curves – not given in this paper – we deduced that there had been clearance of about 60 mm inside the outer container. In the lower part of Figure 9 it can be seen quite clearly that there is a vibration of the rotational speed of the inner container relative to the speed of the outer container. So it seems that at the moment when the secondary end of the outer container hits the target, the inner container is in an upward position, which would explain its time delay for the secondary impact.

Some other effects can be seen in the Figure9. For the outer container, the curves for the deceleration show very steep gradients, that is high values of deceleration (maximal 650 g and 1150 g). The gradients of the curves for the inner container and the fuel assembly are very different. At the beginning of the primary impact, they are very soft and correspond to those of the previous 1.2 m drop. Then there is a sudden increase of the gradients to values up to ~250 g for the inner container and 450 g for the fuel assembly (secondary impact: ~450 g for inner container, fuel assembly value lost). The significant difference between the values of the outer container and the values of the inner container shows that the inner shock absorbing materials did a good job. The bends in the curves for the inner components show that the shock absorbing material was compressed too early.



The deformations resulting from all three drop tests of this sequence are shown in Figure 10. One can see clearly the dent in the side wall of the inner container, caused by the drop onto the bar. This dent is the center point of the bending of the lower (in drop direction) fuel assembly. The global compression of this fuel assembly is predominantly an effect of the 9 m drop. The upper positioned fuel assembly is twisted in its longitudinal direction, but its cross section is (nearly) not effected. This unexpected twisting is a result of the 9 m drop and indicates that the impact forces caused a torque moment.

The final inspection showed that no rod of the fuel assemblies had been broken. The criticality analysis led to the conclusion that the deformation did not result in an unacceptable increase of criticality.

Fig. 10: *opened inner container after test sequence no. 2*

REFERENCES

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