# DROP TEST FOR THE LICENSING OF THE RA-3D PACKAGE IN THE TRANSPORT OF BWR FRESH FUEL ASSEMBLIES

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## ABSTRACT

The RA-3D package for the transport of BWR fresh fuel assemblies was first licensed by BfS in 1992. The design was based on the RA-3 package and the safety basis was demonstrated by correlation to the tests performed on the RA-3 in the late 1960s and early 1970s including some engineering evaluations necessary for design differences between the packages.

In 1998 it was determined that testing of the package to 1985 IAEA standards would be required in Germany and in other European countries. GE, ENUSA, BAM and BfS embarked on a drop test program for the package and included participation by the Spanish and French regulatory agencies. This paper outlines the testing performed and the results obtained in support of the subcriticality evaluation to demonstrate safety to the 1996 IAEA standards. Based on the Safety Analysis Report, BfS will issue a new license for this package under 1996 IAEA Transport Regulation.

## *Introduction for the drop testing for packages to transport fissile material*

The Transport Regulations for the Safe Transport of Nuclear material (TS-R-1, 1996 as amended) establish a testing sequence to verify the ability of packages to withstand accident conditions of transport. In the case of the transport of nuclear material it is important to determine the most reactive configuration of the fissile material under accident conditions in order to analyse and demonstrate the subcriticality of the single package and an array of packages, all of which suffer accident condition damage.

In 1998 the Federal Office for Radiation Protection (BfS) requested as a condition of renewing the license for the D/4306/AF-85 package, testing directly applicable to the RA-3D design package that demonstrated subcriticality under the accident test conditions specified in TS-R-1.

## *Preparation of the drop testing*

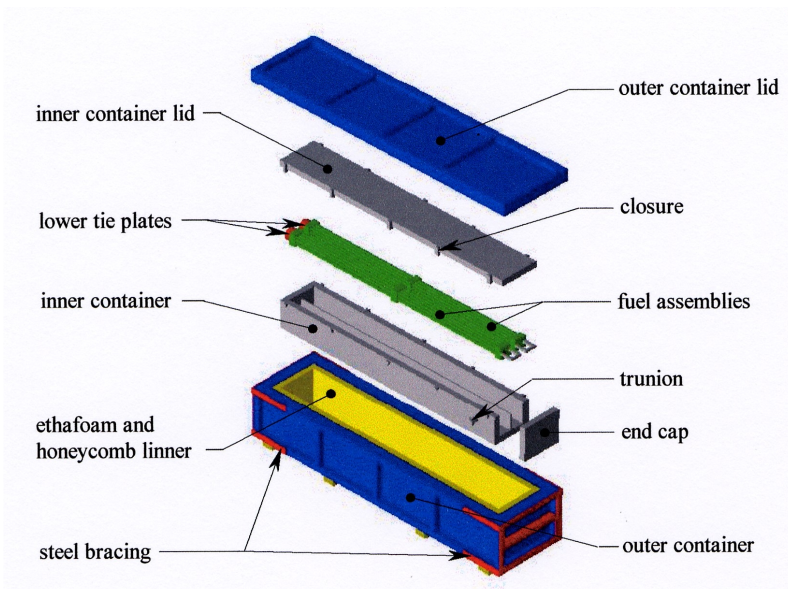
In March 1998, GE and ENUSA began to work with the Federal Institute for Materials Research and Testing (BAM) planning to perform the drop testing required by BfS at the Testing facilities of BAM in Germany.

As a result of these considerations it was decided to perform the drop testing with fuel assemblies loaded with natural uranium pellets so that there was no question with regard to the representativeness of the test results.

To conduct tests of this nature, a facility with regulatory authorisation and a radiological protection program was needed. A testing facility was built at the ENUSA Factory at Juzbado, under the supervision and certification of BAM. A special authorisation from the Spanish Competent Authorities was also obtained to perform this activity in Juzbado.

The project was conducted using parallel tasks to minimise the overall time to complete the tests as follows:

- Design and construction of the drop testing facility according to IAEA Regulation in Juzbado facilities.
- Fabrication of 4 fuel assemblies with natural uranium pellets of different BWR fuel designs.
- Study and evaluation of drop orientations most likely to result in maximum damage effecting the subcriticality of the package
- Development of the testing program by BAM.
- Involvement of Spanish and French authorities in the testing program




***The RA-3D package model***

The RA-3D package consists of two main parts

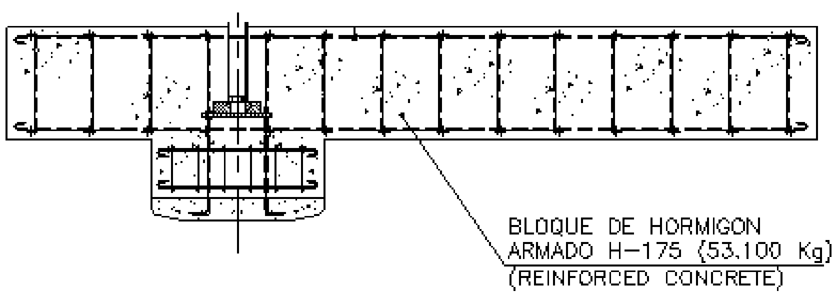
- a wooden overpack constructed of plywood and thick pine planks. This overpack is internally coated with honeycomb impact limiters and ethafoam pads, to fill the space between the wooden overpack and the inner container. This impact limiting material absorbs vibration during normal shipment and handling, and under accident conditions absorbs some of the impact energy. The ends of the wooden box are reinforced by steel bracing.
- The stainless steal inner container is of welded construction. It consists of a body, cover and end cap, made of welded 2-mm sheets. It contains two U-shape chambers cushioned by perforated ethafoam covered metal plates to separate the two fuel assemblies. This inner container protects and maintains the geometry of the fuel assemblies during normal handling.  Under accident conditions the inner container protects and strongly influences the geometry of the region of the package containing the fissile material.

*Testing facility*

The main component of the test equipment was the impact foundation fabricated for this test series. The impact area was 7 m x 3 m with a thickness of 0.5 m and was covered with a steel plate firmly connected to the concrete block by tie rods. The concrete foundation was additionally deepened in the area of the bar attachment. The total mass of the impact foundation was approximately 32 metric tons. The impact foundation was located centrally in a concrete test area of 12 m x 16 m having a decontaminatable coating.

For the bar tests, bars were inserted into a special holder in the drop-test foundation. The bracing was in the interior of the impact foundation. The bars were made of structural steel corresponding to grade St 50 according to IAEA requirements. It was used two bars with different free length (1800 mm and 600 mm) from the top edge of the impact foundation was.

The test objects were released from a truck-mounted crane. A torqueless electromagnetic release device was used for the release. All the sequence were recorded in photographic and video documentation




*Drop testing*

Before packing the assemblies for testing, they were fitted with strain gauges and acceleration transducers as directed by BAM. These devices were added to obtain scientific and engineering knowledge related to package testing. They did not play a role in determining if the package performance met the requirements of IAEA TS-R-1.

The drop testing was performed in December 1998 with representatives from BAM, GNF, Enusa, and the Spanish and French Competent Authorities. BAM functioned as the "test lead" with significant technical support from GNF and Enusa. Workers from the Enusa factory were instrumental in supporting the work associated with the testing. The spirit of cooperation and contribution by the international team was a very important element in the quality and success of the testing effort.

Two packages with assemblies were subjected to the specified drop testing sequence in order to assure the most damaging configuration was studied.

## *1st sequence*

The test sequence began with a drop test from the simulation of the normal conditions of transport, the 1.2m drop test on a flat surface, because it was considered the only one with a potential of affecting the total damage accumulation. In previous testing it was shown that the low velocity impacts to the end of the package tended to leave the inner container vulnerable to falling out of the outer container. Based on the tests of the inner RA-3 container in 1980, this did not appear to create a safety problem for use of the package. However, with this potential for an unplanned accident, it was determined that it would not be safe to conduct the test in this configuration due to the value of the package and the time constraints. Additionally it was felt that testing without the wooden overpack was not desirable at this time. To avoid this situation, a metal reinforcement piece was added to the ends of each RA-3D outer container. This provided ample strength in the ends to keep the inner and outer components together.

The final first drop testing sequence was the following:

- ❖ Drop onto flat surface from 1.2m high in vertical position onto corner at the lid
- ❖ Drop onto flat surface from 9m high in vertical position onto corner at the lid
- ❖ Drop onto to a bar from 1m high in vertical position onto corner at the lid
- ❖ Drop onto to a bar from 1m high in horizontal turner position onto the lid

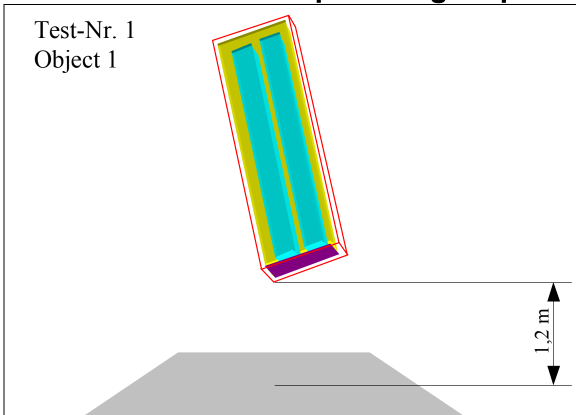
The drop corner suffered very noticeable damage but the reinforcements maintained the outer structure of the package satisfactorily for the duration of the testing. The outer container absorbed some of the energy associated with the impacts.

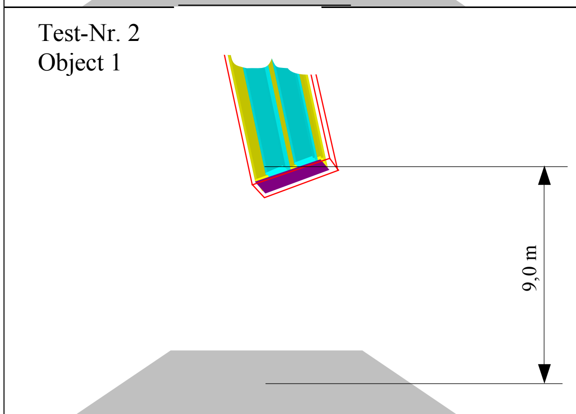
The inner container clearly protected against the puncture bar impact and the deformation of the packaging did not significantly affect the fuel assemblies. The closure system worked satisfactorily.

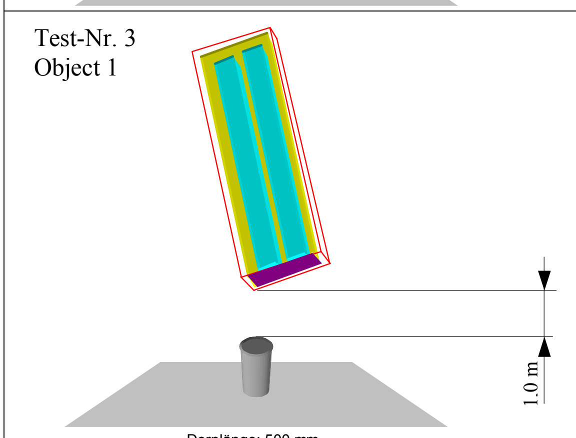
The deformations of the outer and inner containers are such that the positions of the two bundles in the container relative to each other and relative to bundles in adjacent containers in a container stack were not appreciably changed.

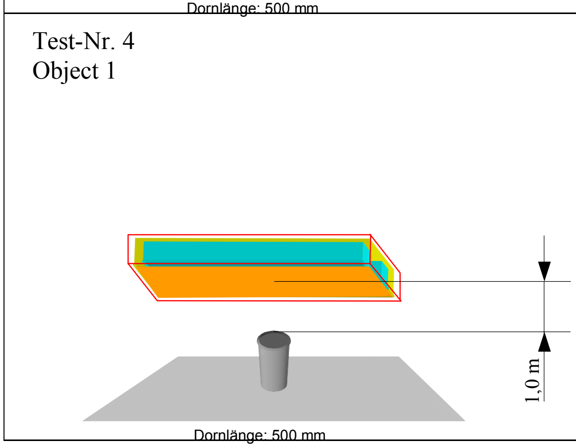
The fuel assembly lattice geometry changed, however, these changed did not contribute to a condition which significantly increased the reactivity of the fuel and subcriticality was assured. No breaks occurred in the fuel rods, so there was not release of nuclear material.

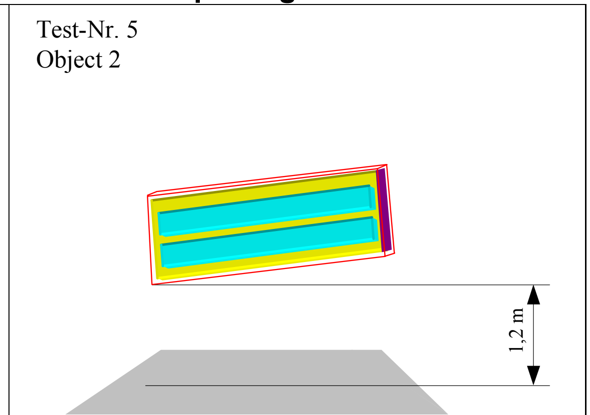
# Drop Testing sequences for RA-3D package

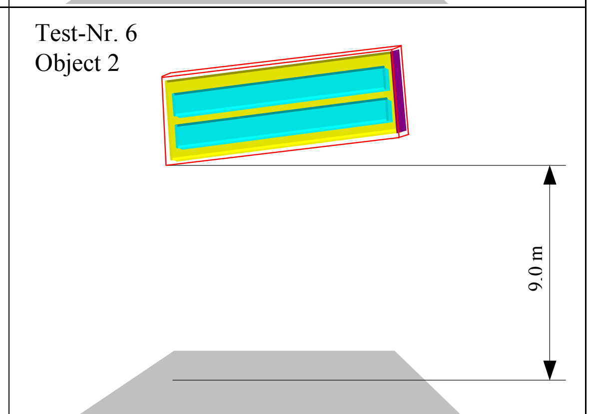


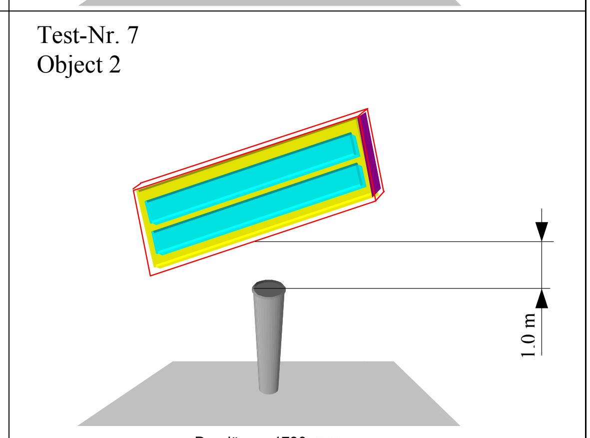




- Outer container
- Inner container
- End cap
- Lid
- Fuel bundles

1. inclined 11° to vertical, above corner
2. inclined 11° to vertical, above corner
3. inclined 11° to vertical, above corner
4. longitudinal axis horizontal, transverse axis inclined 25°
5. inclined 10° to horizontal
6. inclined 10° to horizontal
7. inclined 25° to horizontal

***2nd sequence***

A second package was subjected to slap-down drops to observe possible local effects due to large decelerations and a oblique drop to observe the maximum puncture damage.

The final second drop testing sequence was the following:

- Drop onto flat surface from 1.2m high in quasi-horizontal position onto a side
- Drop onto flat surface from 9m high in quasi-horizontal position onto a side
- Drop onto to a bar from 1m high in inclined horizontal position onto a side

The testing bar used on this drop was 1800mm long in order to assure the possibility of total penetration of the package before the sides could touch the floor. This drop was performed with a penetration angle adjusted to produce the maximum cutting effect on the inner container.

The outer package suffered significant damage along the impact surface, but the handling could be performed without danger or any problem throughout the test sequence. The inner container was deformed by the puncture bar but was not penetrated by it. There was compressing of the assembly structure but the fuel rods were not damaged. The package remained sufficiently closed.

The fuel assemblies were somewhat deformed after this test sequence. The assembly placed on the upper part suffered a twisting deformation of approximately 45ºover part of it's length. The one placed at the bottom part showed a compression of the lattice to a rectangular shape, in particular the region of the impact point of the puncture bar. The outer band of the spacers did not break or fracture. Notwithstanding the visual changes, the reactivity of the fuel did not change significantly and subcriticality was demonstrated. No breaks occurred in the fuel rods, so there was not release of nuclear material.

The results of this testing sequence were considered the most unfavourable for the criticality evaluation due to the change on the relative position of the bundles and changes into the lattice geometry.

***Results on drop testing important for the criticality evaluation***

These test sequences produced significant visual damage to most components of the package and to the fuel assemblies. In particular, these tests indicate that the inner container can be distorted by the combined 1 meter penetration and 9 meter drop tests in such a manner that the fuel assemblies may be twisted or bent. In the case of bending, the cross section of the fuel assemblies could be changed from a square to a taller thinner rectangle, a geometry change which would be of concern in the criticality analysis of interacting arrays of damaged containers. The same is the case for fuel assemblies subject to twisting, since rotated lattices would increase the projected surface area of interaction between horizontal or vertical neighbors in adjacent shipping containers without significantly increasing the separation distance. The crushing and bulging of the inner container resulting from the drop tests offset each other and do not result in reduced overall dimensions for the accident arrays

The results and the possible effects as described, were evaluated in the criticality analysis.

- Rotation: $45^o$ rotation results in the maximum interaction surface area for adjacent fuel elements
- Deformation and separation: Due to the bending and distortion of the spacers, the drop tests can result in rectangular bundle configurations in which bundle segment heights are greater than the height of an undamaged bundle. Since the adjoining faces between fuel assemblies in the same inner container were potentially increased in size, it was necessary to see if this resulted in a greater interaction between the assemblies with a resulting increase in the neutron multiplication factor.
- Deformation and rotation: A combination of deformation and rotation has also been considered. This situation was for one assembly deformed into a rectangle and one assembly rotated for both 9X9 and 10X10 assemblies
- Localised damage: evaluation of localised change in the fuel rod pitch rather than a general deformation of the entire system; the assembly average rod-to-rod spaces at the same lattice points will be no greater than the equivalent average spaces for undamaged bundles.
- Effect of preferential flooding: reconfirm that preferential flooding of the $H_2O$ moderator for the RA-3D shipping container is no more reactive than the standard assumed case of equal density water in all internal void regions

***Conclusions***

The criticality evaluation of arrays of RA-3D containers has been reevaluated as a result of the new drop test data. Neutron multiplication factors were calculated for the new damage situations as a function of moderation, assembly spacing, and assembly orientation. The results show that the effective neutron multiplication values obtained for all situations are within 1 to 2% of the base case and all are acceptable when including the applicable bias under the established criticality safety limits.

It would be concluded the success on the behaviour of the RA-3D package to withstand accidental conditions and it was demonstrated that neither the package nor the fuel assemblies suffered damage or deformations that would impair their criticality safety.

The results of those evaluations ratified the availability of RA-3D package design for the transport of fissile material as the original design; only some minor modifications has been improved to the outer container.

After this development a new compiled Safety Analysis Report has been submitted to the Federal Office for Radiation Protection (BfS) to get a new license for this package according to edition 1996 of IAEA Transport Regulation for the Safe Transport of Nuclear Material. The new licence will be applied for validation in USA and Europe (Spain, France, Switzerland, Sweden, Finland).