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HISTORICAL VIEW AND EXPERIENCES WITH THE CRUSH TEST FOR LIGHT WEIGHT PACKAGES

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ABSTRACT

The crush test for light weight and low density Type B packages was introduced for the first time into the 1985 edition of the International Atomic Energy Agency (IAEA) transport safety regulations.

In the early 1970s the need for an additional mechanical test besides or instead of the well known 9 m drop test was deliberated. Various authors and test facilities, including BAM and Sandia National Laboratories (SNL), were able to prove that the level of safety provided by IAEA drop and puncture tests in the regulations did not protect against dynamic crush forces to smaller packages. As early as the 3rd PATRAM symposium held in 1971 (Richland/USA), Robert F. Barker asked for "…a more strenuous crushing test for protecting small, light weight packages…". BAM developed from research activities a proposal as to which types of packages should be subject to crush tests and how the crush tests should be performed, which was presented on the 5th PATRAM symposium held in 1978 (Las Vegas/USA).

At the IAEA, the possible need for a crush test was first mentioned in 1977. The subject for a discussion, besides the principal need for this test, was also the development of suitable set of crush test boundary conditions. It took more than four years of discussion until a dynamic crush test similar to today's test was recommended by experts to the IAEA regulatory revision panel. Finally, after a rigorous evaluation process in which also the boundary conditions were determined, the crush test was proposed to be incorporated into the IAEA regulations.

BAM and SNL participated in the crush test development and implementation process right from the beginning in the early 1970s until its implementation in the IAEA regulations in 1985.

Today, BAM performs crush test procedures according to para. 727 (c) of TS-R-1 [5], which have not been changed since their first implementation. Crush tests performed in 2002 at BAM will be discussed. These approval design tests were performed on birdcage pellet transport containers under normal and accident conditions according to the IAEA- Regulations.

INTRODUCTION

In the early 1970s the regulations for Type B packages only required two mechanical tests: the 9 m drop test and the 1 m puncture test. The effects of mechanical impacts were judged to be covered by the 9 m drop test on to an unyielding target considering crash forces, while crush forces had not been taken fully into account.

In 1970, Kelly and Stoddart [1], based on tests and calculations, indicated that the joint transport of light weight and heavier packages could lead to serious crush forces to these packages in the event of accidents. Four vehicle (truck/semitrailer) impact tests at various velocities were conducted to acquire quantitative data on nuclear material transport systems and to investigate the behaviour of the transport system during the impact. The cargo consisted of drums and birdcage packages with different loading weights. Various packages were crushed due to cargo induced crush forces during the impacts.

As early as the 3rd PATRAM 1971 (Richland/USA) Robert F. Barker [2] asked for a more strenuous "crushing" test to be incorporated into the regulations for protecting small, light weight packages because of the likelihood of such packages being mechanically loaded with heavier packages or other heavy cargo. Referencing to Kelly and Stoddart [1], Barker wrote: “We agree a ‘crushing’ test, more strenuous than the compression test may be needed”.

In 1976 R. K. Clarke et al. [3] published a study performed at SNL on the "Severities of Transportation Accidents". The major purpose of the report was to describe the severities of air, highway, and rail transportation accidents from the point of view of relatively small Type B packages -especially light weight ones- such as those which might be carried in an enclosed van. The truck crush environment was differentiated by two types of crush: (1) essentially static forces acting on a container because of the latter's position underneath the truck or other containers, and (2) dynamic loads resulting from the transfer of momentum from other cargo in the accident situation. The probabilistic analysis showed that, at a probability of $2{,}5 \times 10^{-6}$ accidents/mile, every non-trivial accident could cause crush forces to packages (see Fig. 1). This study was one of the early fundamental efforts both on accident environments and risk probability studies.

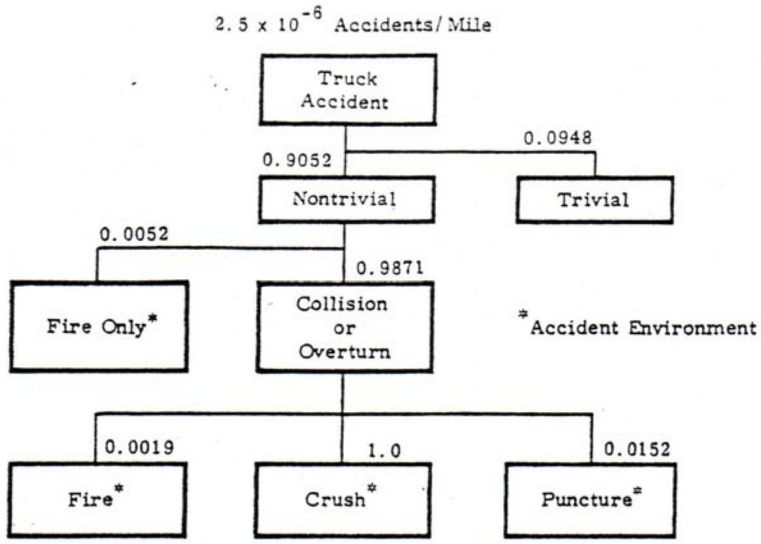

Figure 1. Probabilities of forces due to truck accidents [3]

At the 5th PATRAM symposium convened in 1978, McClure [4] from SNL presented his "Analysis of the qualification Test Standards for Small Radioactive Material Shipping Packages". He stated

that various risk assessment studies had shown that the risk to the public due to severe transport accidents was very low. For the surface transport mode a range of 99% to 100% of all accidents had an impact equal or less severe than an impact onto an unyielding target at a velocity of 13.3 m/s. The level of severity in the existing qualification test standards appeared to be essentially fully reflective of the damage that small packages were likely to incur except for the crush environment. McClure concluded his observations by stating: “The existing standards do not specify crush tests and, since the crush environment is of primary influence in the surface transport mode, the addition of a crush test will make the qualification test standards more relevant to the actual accident stresses which where determined in the base study” [3].
Summarising the above, studies it could be said that in the surface transport mode damaging crush forces to light weight packages are likely to occur.
In accident conditions light weight packages could receive more severe damage compared to heavier packages even if all types of packages where able to meet the demands of the regulatory test standards. This is because the released energy at a 9 m drop test (and at the 1 m puncture test) is proportional to the package mass. Thus the level of safety depends on the package mass.
Even in the early 1980s it was assumed that the regulations were insufficient to cover crush forces, especially those to light weight packages since these crush forces were still not considered in the regulations for Type B packages.

BAM STUDIES ON CRUSH FORCES TO LIGHT WEIGHT PACKAGES

BAM conducted a large number of different tests on light weight Type B packages, evaluating the effects of crush forces. The lessons learned from these tests were summarized in a BAM proposal which was submitted in 1978 to IAEA to be taken into account for the next revision of the regulations.

BAM Tests on Light Weight Packages

The goal of the investigations by BAM was to design a package for the transport of radioactive material, which would meet all requirements according to the IAEA transport regulations, but fail under certain accident or even incident conditions which had not been considered up to that time. The following tests, which were then required by the IAEA for all Type B packages, were performed as follows:

- 9 m guided drop in different drop positions
- Thermal test
- Penetration test
- Water immersion test

During each test, the content was simulated by a filled juice can. After having proven that the design of the BAM Demonstration Package had met the IAEA transport requirements, it was then demonstrated that this design was quite sensitive to crush loads. Crush testing of BAM Demonstration Packages was carried out at the former BAM test facility, Berlin-Grunewald. Test parameters were: crush mass of 1000 kg plate with a base area of 1 m² from 4.5 m onto the test specimen lying on an unyielding target.
After every crush test, the relevant package including the inner container was found to have been totally damaged, see Fig. 2.

Figure 2. Crushed BAM Demonstration Package which met the IAEA requirements

All crush tests which were carried out by BAM with the BAM Demonstration Package led to total rupture of the package.
On the other hand, since it had already been shown that crush forces are possible in transport and handling, BAM simulated the following incidents:

- Crush by a fork lift in operation
- Crush by the running over with a truck and
- Crush by the lowering of a truck load ramp.

Nearly every package was deformed such that the total failure of the inner container could be detected, liquid content poured out, e.g. see Fig. 3. The tests showed that for light weight packages the test impacts required by the transport regulations at that time did not create the highest possible damage.

Figure 3. BAM Demonstration Package crushed by a truck run over

<u>BAM Proposal for a Crush Test</u>

The BAM research indicated that even Type B packages compliant to the former IAEA test requirements could fail under crush force caused e.g. by handling mishaps. It could be easily seen that this failure was caused by the small amount of energy which light weight packages have to withstand during the known 9 m drop test. To find a set of adequate crush test parameters BAM assessed all Type B packages in use at that time concerning the relationship between the package mass and the package volume which could then be related to the package effective density, see Fig. 4.

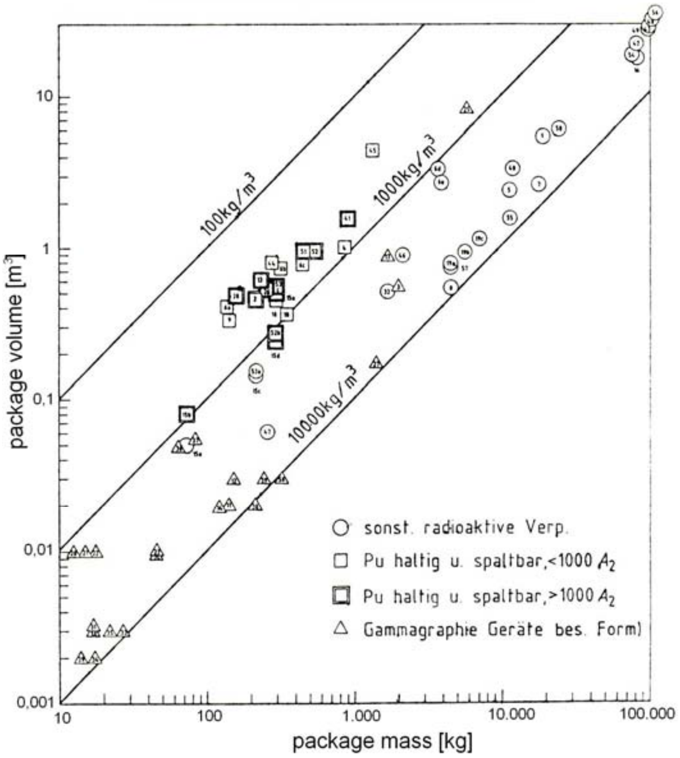

Figure 4. Diagram of Type B packages in use according to weight and volume

Covering nearly all crucial packages, boundary conditions of an effective density of 1500 kg/m^3 and a mass of 500 kg were chosen to define when a crush test should be required. A mass of a drop weight of 2000 kg, provided of a 1 m by 1 m mild steel plate, was chosen as a result of the consideration of the energy released during the test. Additionally a crush with a 15 cm spike weighing 2000 kg as a 1 m free drop was planned. This configuration was submitted to the IAEA as the BAM proposal for the crush test and to complete regulatory test requirements for light weight packages.

FROM PROPOSAL TO IMPLEMENTATION OF CRUSH TEST INTO THE REGULATORY REQUIREMENTS

Even though in the early 1970s it became apparent that a crush test would be a useful instrument in a testing procedure, the IAEA transport regulatory revision process in 1973 did not consider a crush test.

For the first time the crush test was considered within the beginning of the next IAEA regulatory revision process at the Advisory Group AG-126 in 1977. In December 1977 the Advisory Group AG-144 stated: "It was concluded that it is necessary to study carefully the possibility of adding a crush test for light weight packages." At the first meeting of *Standing Advisory Group on the Save Transport of Radioactive Materials* (SAGSTRAM) in 1978 the Working Group 2 agreed with AG-144.

In 1979 the Technical Committee TC-272 could not come to an agreement about the crush environment but the members concluded that the implementation of a crush test would be justified for packages weighing less than 500 kg. Participants at TC-272 could not agree whether the test should be a static or a dynamic one, so they could not agree upon test boundary conditions. It was agreed that details should be evaluated by the next Technical Committee.

The Advisory Group AG-266 in 1980 did not consider itself to have enough information to determine whether the addition of a crush test could be justified.
A joint study from the French CEA and BAM prepared 1981 for the European Commission [6] supported the technical background. The former work and technical views of BAM are summarized in [7].
In 1981 the Technical Committee TC-406 recommended the addition of a requirement for a crush test in the regulations. The test should be required of packages that:

- contained normal form material,
- had contents greater than 1000 A_2,
- had a mass less than 500 kg, and
- had a gross or effective density less than 1500 kg/m^3.

In 1981 IAEA invited Mr. S. Williamson as a consultant on this topic. He reviewed 21 available sources of information about a crush test and he concluded: “There is no case made that crush is a significant problem. A crush test should not be introduced.” The package density of “…1500 kg/m^3 needs further consideration. A figure of 1000 kg/m^3 is more realistic."
And finally, the 1982 Advisory Group AG-365, the working group WG-2 proposed the solution that the 1983 revision to the regulations incorporates a crush environment. The test should be required of packages that:

- contain normal form material,
- have contents greater than 1000 A_2,
- have a mass less than 500 kg, and
- have a density less than 1000 kg/m^3 (revision of TC-406 recommendation).

TODAYS BAM CRUSH TEST PERFORMANCE

The dynamic crush testing according to para. 727 (c) of the IAEA-Regulations [5] is illustrated here for a pellet transport cask. The crush testing of the cask was part of the test procedures for demonstration of its compliance with the standards fulfilling the requirements for Industrial Packages Type 2 (Type IP-2) for fissile material (IF). In this context the main safety criteria was criticality safety under normal and accident transport conditions. The tests were performed by the working group ‘Experimental Testing of Containers’ of the BAM division III.3 ‘Safety of Transport Containers’ by order of Frameatome ANP GmbH in the year 2002.
This pellet transport cask is named ANF-50, a product of Frameatome ANP GmbH and designed for the shipping of non-irradiated uranium-dioxide pellets (see Fig. 5). The ANF-50 consists of a pellet-container, surrounded by an outer-container which is again connected to a cubical-shaped space truss by welding. The pellet-container is made of austenitic steel plate and closed by a bolted lid. The pellets are positioned on special pellet-layers which are arranged one upon the other in a basket. A single pellet-layer has 22 parallel lines for the inventory of pellets. Maximum content are 11 to 14 pellet-layers depending from the diameter of the pellets. The outer-container is built in sandwich construction with an inner and outer austenitic steel plate and in-between a stiffening frame construction in combination with inorganic isolation material. It is closed by a lid. The space truss is a welded construction built of austenitic tubes and flat sections and closed by a protection lid. The mass of the empty ANF-50 container is 172 kg. During the mechanical tests the original content and therewith its mass effect was simulated by rods made of lead alloy material with nearly

the same density as uranium-oxide. The content mass was 57 kg, so that the total mass of the package was 229 kg.

Figure 5. Dynamic crush test configurations for the ANF-50 (first line) with results after crush testing (second line).

The drop test program comprised in total four test sequences. In each test sequence a new specimen of the ANF-50 was subjected to the following mechanical tests: penetration test ([5], para. 724), 1.2 m free drop test (drop I, para. 722 (a)), 1 m pin drop (drop II, para. 727 (b)) and dynamic crush test (para. 727 (c)), in that order.

In order to fulfill the requirement of choosing the most damaging position, and because no single most damaging position could be determined before testing it was decided to investigate the crush behavior of the cask concerning four positions. The positions were (a) the transport position of the cask standing on its bottom feet, (b) the lateral position, (c) the horizontal corner edge position, and (d) the corner edge position. Fig. 5 shows the several test configurations and the specimen after crush testing.

The tests were performed at BAM’s indoor drop test facility at Berlin, Germany. The drop test facility has an unyielding target according to the IAEA Regulations and allows a maximum drop height of 12.5 m. The target, a reinforced concrete block has got a mass of 280,000 kg (dimensions 6 m x 6 m x 3 m). The impact pad is a steel plate of 18,700 kg (4 m x 2 m x 0.3 m) embedded and fixed with anchor bolts to the concrete block.

In preparation of a crush test the specimen was positioned and fixed – in the cases of horizontal corner edge and corner edge position by welding – onto a separate steel plate placed on the impact pad (see Fig. 5). The crush mass consists of a solid mild steel plate 1 m by 1 m with a mass of 500 kg and drop in horizontal attitude onto the specimen. The height of the drop (9 meters) was measured from the underside of the plate to the highest point of the specimen. Fig. 5 shows the four crush tests.

The test results showed that, for all crush tests, partly high deformations of the space truss resulted; although the outer container showed very small or no deformation, and the pellet-container itself was fully undamaged.

CONCLUSIONS

Currently the crush test according IAEA regulations for light weight packages is a mandatory part of the regulatory test requirements, implemented in the 1985 edition of the IAEA regulations.
In the beginning of the 1970s it could be shown, there are light weight packages compliant to the former regulations, but they can fail during real incidents or accidents under crush loads.
A number of studies and investigations, including significant efforts at BAM and SNL, showed that there was a “lack of safety” for the group of light weight packages. During several IAEA meetings the arguments were collected, and the experts discussed the different positions intensively.
In the former days BAM started an extensive research project in order to bring the evidence there was a need for an additional (crush) test for light weight packages. Data of packages in use were collected and analyzed. The result of all this work was summarized in a BAM proposal for implementation of a crush test in IAEA regulations.
Since the 1985 Edition of the IAEA Regulations [5] the crush test belongs to the mechanical drop test requirements for light weight Type B packages.

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