THE 9 m DROP TEST ONTO AN UNYIELDING TARGET VERSUS DROPS FROM GREATER HEIGHTS ONTO REAL TARGETS

B. GÜNTHER
Federal Institute for Materials Testing,
Berlin (West)

Abstract

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In order to calculate the mechanical cask stresses which occur in a real impact, a method of calculation was used based on the model of an inelastic impact. It was found that the stresses resulting from the hypothetical drops of two different cask types from a height of 27.2 m were greater than those resulting from a typical Type B test. It is worth noting that the 27.2 m drop was onto a 2 m thick reinforced concrete platform. The greater stress which was discerned demanded additional verification. Thus, drop tests were conducted using an existing model of one of the actual casks, corresponding to the calculated results. For the second cask, previously ascertained findings of instrumented high-impact drop tests, showing the degree of tolerable stresses, were used. These figures could be accepted for the cask to be evaluated because of the geometrical similarity, as well as the similar material properties and comparable sealing system. It was shown that both casks were able to withstand the more rigorous requirements.

1. INTRODUCTION

In the transport and handling of Type B shipping containers for radioactive materials (RAM), it must always be taken into account that mechanical stresses greater than those approved for Type B tests might be encountered. With ever-growing public concern about the actual safety of transporting RAM, the question arises as to whether test conditions are comparable with the conditions likely to be encountered in a genuine accident. This concern affects not only the public, but also the responsible authorities whose job it is to license nuclear facilities. These authorities have to ascertain whether Type B test conditions still hold under more stringent conditions, i.e. in the cases of drops from heights greater than 9 m.

Generally accepted methods which allow a direct comparison of any real problem with the well-known requirements contained in the IAEA Regulations do not exist. Such investigations in any case require a step-by-step solution as follows:

(1) Selection of a worst-case drop position that would cause the maximum possible impact load either for the cask or for the building structure.

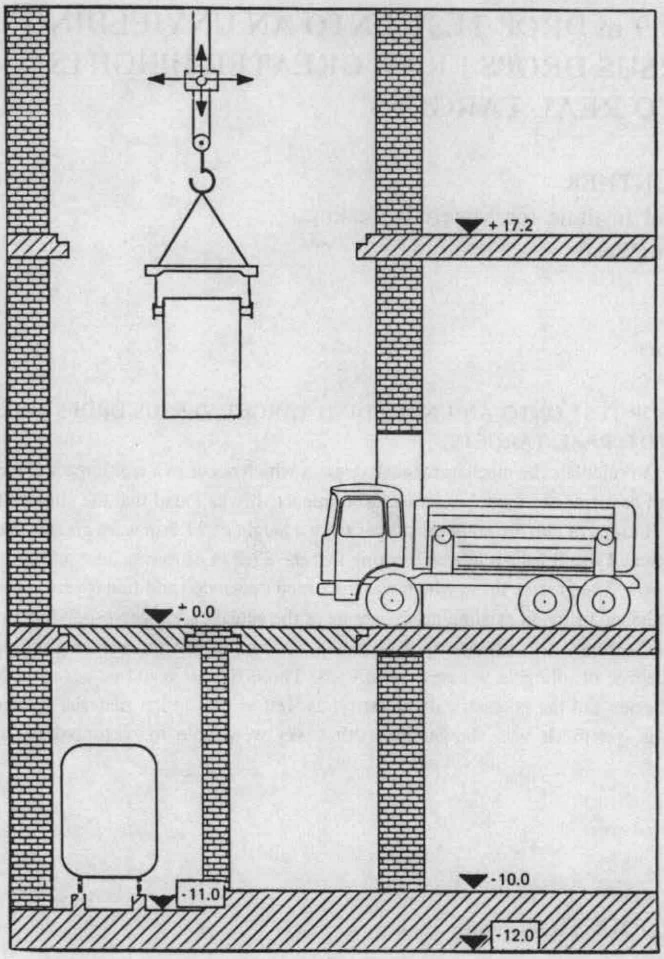

FIG. 1. Handling area for transport casks at a nuclear power plant.

(2) Determination of energy dissipation, based on a suitable calculation model, in order to compare the stresses that occur with those of Type B requirements.
(3) Additional verification tests to demonstrate compliance with the evaluated requirements, provided that the Type B requirements are exceeded.

2. DESCRIPTION OF THE PROBLEM

In this work, the hypothetical drops of two different fuel element transport casks are examined. The drops are assumed to take place in the lifting area in front of the

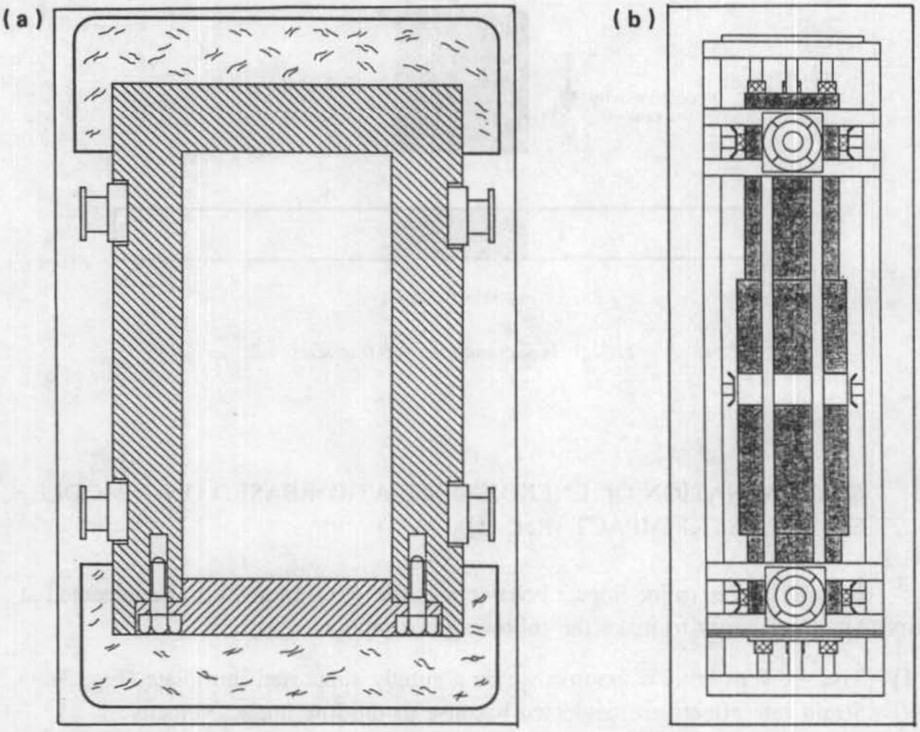

FIG. 2. *(a) 80 t cask for transporting spent fuel elements. (b) 6.6 t cask for fresh fuel elements.*

containment building of a nuclear power plant. The maximum lifting height is at the +17.2 m level (Fig. 1). The first part of the building structure to be impacted is a concrete floor at a level of ±0.0 m, on which the cask is picked up from the transport vehicle. The vehicle is removed before the cask reaches the maximum lifting height, as a result of which the additional energy absorption by the vehicle cannot be taken into account. Below the ±0.0 m level, there is another concrete floor at a level of −10.0 m, with a thickness of 2 m (right-hand side) and 1 m (left-hand side).

The two casks to be examined have quite different designs with respect to their geometry, material properties and purpose. The cask shown in Fig. 2(b) (in the following Type 1 cask) is used for the transportation of unirradiated fuel elements. The second one (Fig. 2(a)) (in the following Type 2) is used for the transport of spent fuel elements. The different shielding requirements, in particular, cause significant differences in weight between the two. The Type 1 cask (made of stainless steel) has a mass of 6.6 t. It is protected against mechanical impacts by a steel cage. The second one (made of nodular cast iron, GG40) has a mass of 80 t. It is equipped with shock absorbers (welded steel plate construction filled with wood) at the top and the bottom.

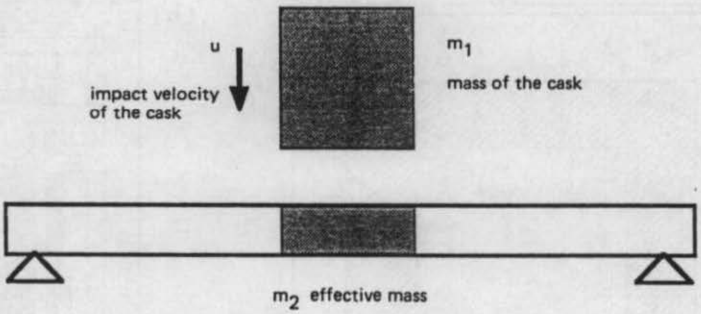

FIG. 3. Impact onto the ±0.0 m level.

3. DETERMINATION OF ENERGY DISSIPATION BASED ON A MODEL OF INELASTIC IMPACT (Ref. [1])

In order to determine impact behaviour at the ±0.0 m level (to be impacted at first), it is necessary to make the following assumptions:

(1) The ±0.0 m level is assumed to be a simply supported thin plate (Fig. 3).
(2) Strain rate effects are neglected because of the low impact velocity.
(3) The effect of inertia will be taken into account by using an effective mass m_2 of the plate concentrated at the area of impact (Fig. 3).
(4) For the first range the impact can be assumed to have the characteristics of a plastic impact of short duration. Conservation of energy and momentum requires an energy loss of $E_V = E_1/(1+M)$, where E_1 is the kinetic energy $E_1 = m_1 v^2/2$ and M is the mass ratio $M = m_1/m_2$. The energy loss E_v is associated mainly with plastic deformation of the shock absorbers.
(5) The structure has to absorb the remaining kinetic energy E_R during the second impact range, assumed to be of long duration. Here $E_R = E_1 M/(M+1)$. If the energy E_R is such that the local failure energy E_F is not exceeded, the cask remains on the plate without penetration occurring. However, if penetration does occur ($E_R > E_F$), it is found for the remaining energy after penetration that $E_P = (E_R - E_F)M/(1+M)$, assuming the same velocity for the masses m_1 and m_2 at the end of the second impact range.

With the actual dimensions of both casks, and using experimental data from Ref. [2] for the failure energy E_F, it is calculated that for a Type 1 cask

$$E_R \approx 0.8 \text{ MNm} > E_F = 0.2 \text{ MNm}$$

while for a Type 2 cask, $E_R \approx 13.3$ MNm $\gg E_F = 0.2$ MNm.

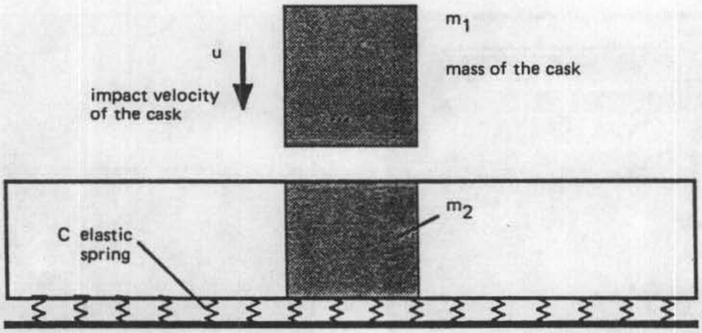

FIG. 4. Impact onto the −10.0 m level.

That means that the ±0.0 m level is penetrated by both casks. The calculation of the energy loss E_v to be absorbed by plastic deformation of the shock absorbers results in $E_v = 0.3$ MNm for Type 1 and $E_v = 0.5$ MNm for Type 2 casks, corresponding to a drop of 4.5 m onto an unyielding target (Type 1) and 0.6 m for a Type 2 cask. As expected, for a Type 2 cask, the penetration at the ±0.0 m level is accomplished without the loss of a significant amount of kinetic energy.

The energy remaining after penetration, E_p, has to be taken into account to determine the impact onto the −10.0 m level. It can be assumed that the 2 m thick concrete floor is almost 'unyielding' with respect to the Type 1 cask. The sum of the kinetic energy corresponding to a drop height of 10.0 m and of the remainder of the energy E_p after penetration causes stresses on the cask equivalent to a 16 m drop onto an unyielding target.

For the Type 2 cask, a 27.2 m free-fall drop onto the −10.0 m level is considered. Using the same model as described above for the determination of E_v (to be absorbed by the cask) and E_R (the remainder of the energy after the first range of the short inelastic impact), it is found that $E_v = 0.6 \cdot E_I$ and $E_R = 0.4 \cdot E_I$. If penetration occurs, only the cask mass m_1 and the effective mass m_2 have to be considered in order to determine the acceleration $a_p = c \cdot x/(m_1 + m_2)$, where c is the 'stiffness' of the ground, which is assumed to have elastic characteristics (Fig. 4).

The value x is the deformation of the masses m_1 and m_2 according to $x = \sqrt{2E_R/c}$. The actual c value was available from the data on the buildings.
With regard to the actual data, $a_p = 92g$. Whether or not penetration occurs depends on the punch–shear resistance F_p of the actual foundation. In particular, the F_p value takes into consideration the geometrical dimensions and the material properties. In the present series of tests, it was found that $F_p = 134$ MN [3]. With knowledge of F_p, it is possible to estimate that the acceleration $a_B = 170g$, acting on the cask prior to penetration. Because $a_B > a_p$, the acceleration a_B has to be taken into account for further investigations.

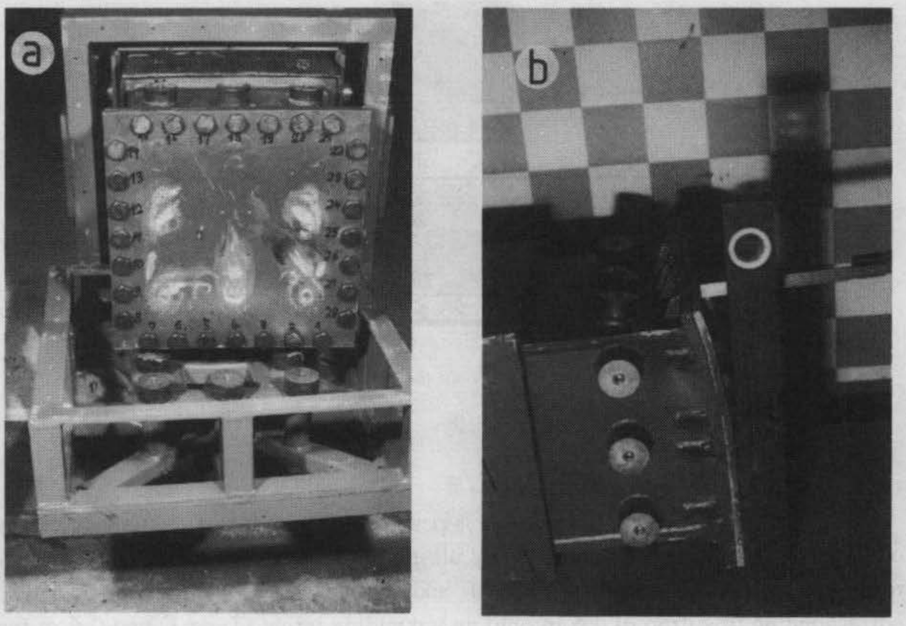

FIG. 5. (a) Condition of steel cage after a 4.5 m drop onto an unyielding target. (b) Unprotected cask body after a 16 m drop onto an unyielding target.

4. VERIFICATIONS TO FULFIL THE REQUIREMENTS

The requirements for the Type 1 cask were easily verified because a 1:2 model of the cask was available. Based on the specified conditions, two drop tests were performed. First, a drop test onto an unyielding target was carried out from a height of 4.5 m, simulating the impact of the Type 1 cask on the ±0.0 m level. From Fig. 5(a) it can be seen that one part of the protection cage is broken as a result of the impact. Consequently, the required subsequent drop test — simulating impact on the −10.0 m level — was performed without the protection cage. Figure 5(b) shows the unprotected cask body after a 16 m impact on an unyielding target. Additional drop tests were carried out with single fuel elements to verify their impact behaviour, as a result of which a comprehensive survey of the behaviour of the whole packaging system was obtained [3].

A different procedure had to be chosen to verify the behaviour of the Type 2 cask because no packaging system was available for test purposes. In this case, already existing test results from instrumented high-impact drop tests of casks having comparable geometrical dimensions, as well as the same material properties, were used.

The procedure is depicted in Fig. 6. A maximum acceleration $\hat{a} \approx 1000g$ was measured on a cask assumed to be a model of the actual cask to be evaluated. The

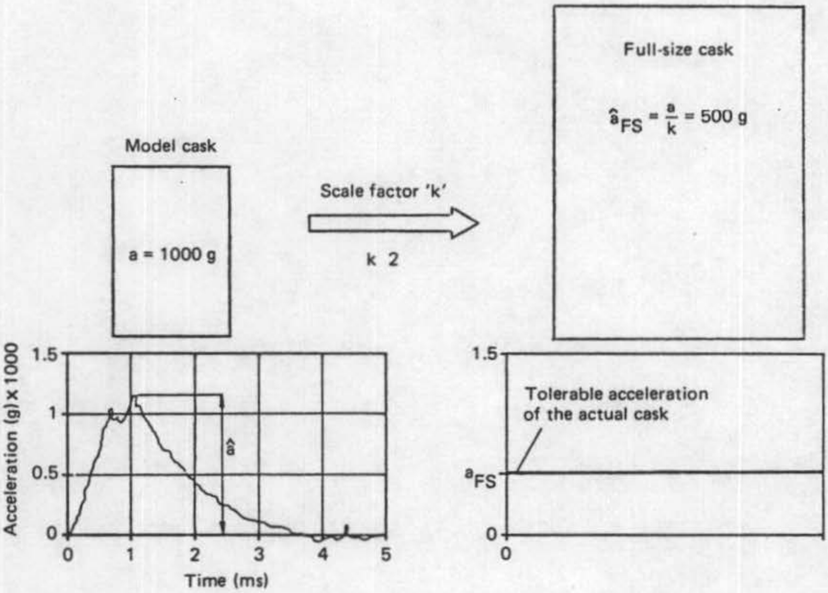

FIG. 6. Use of experimental data to evaluate the impact behaviour of an actual cask.

model was dropped vertically from a height of 9 m onto an unyielding target without shock absorbers or other impact limiters. Suitable investigations (leaktightness measurements, etc.) showed that the cask withstood the stresses. This test provided a correlation of mechanical loading, stress situation and material behaviour. In order to adapt these results to the full-size cask model, laws based on pure elastic deformation have been applied. This means that (1) the stresses occurring on the model and on the full-size cask are equivalent. (2) The acceleration, i.e. the forces acting on the cask, are reciprocal to the scale factor. The behaviour of the actual cask could thus be evaluated by using the available test results.

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