The TK-C30 Compound Unit for the Transport of Spent Fuel Assemblies From WWER-440 Type Nuclear Reactors

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1. THE TK-C30 SHIPPING UNIT

Brennstoffinstitut Freiberg (Freiberg Fuel Research Institute) has developed a shipping cask with a capacity of 54 spent fuel assemblies from WWER-440 type pressurized water reactors. This cask, known as C30 (see Fig. 1), consists of a 320 mm thick solid cylindrical shell made of a higher-strength weldable structural steel (H52-3N). It is closed with a lid of the same thickness by means of bolts. The cask has a diameter of approx. 2 m and a height of approx. 4 m. Its total weight is 85,000 kg, contents included. The cask is fabricated out of three forgings, which are welded together over the entire wall length, and provided with fins all around in order to dissipate heat and diminish impact forces. A special rail car is used for transporting the cask (see Fig. 2). For this shipping cask, compliance with the Type B package requirements laid down in the IAEA recommendations /1/ had to be proved.

2. STRENGTH CHARACTERISTICS UNDER DROP TEST CONDITIONS

The strength characteristics of the cask were both calculated by means of simple methods of plasticity mechanics and determined experimentally using reduced-scale models (1 : 20; 1 : 10; 1 : 6; 1 : 3.4).
The final demonstration of sufficient radiation shielding and leak-tightness was carried out on a 1:3.4-scale model. The drop tests took place at the test facility of Brennstoffinstitut Freiberg, which is described in IAEA-TECDOC-295 /2/. The model was subjected to 9-m drop tests in several different impact attitudes:

square on the bottom, on the bottom edge, on the side (fins, supporting plate, pivot), on the lid edge, square on the lid.

These tests were carried out at room temperature.

The measuring programme included the determination of impact decelerations, impact forces and strains at impact, the measurement of the cask geometry as well as the leak rate determination before and after each test. In addition, each impact process was filmed with a high-speed camera.

Because of the shock-absorbing fins, the deformations caused on the model during the tests were only slight and did not impair its structural integrity (see Figs. 3 and 4). The impact decelerations found at the individual impact attitudes were converted into values for the full-scale cask using the well-known model laws. These values are shown in Tab. 1.

Impact attitude	Impact deceleration in g's
Bottom (fins)	250
Bottom edge	230
Side	
- Supporting plate	140
- Pivot	160
- Fins	345
Lid edge	191
Lid (fins)	125

Table 1. Impact decelerations on the C30 shipping cask following the 9-m drop

With regard to the loads effective in the 1-m drop test, the central plug in the lid was the only endangered part of the C30 cask. The test with the 1:3.4-scale model resulted in only slight deformation, and the tightening torques of the plug and lid bolts were still unchanged after the test.

During all drop tests the model remained leak-tight. The maximum leak rate encountered, which was found after impact on the lid edge, amounted to 6×10^{-4} $Torr \cdot l \cdot s^{-1}$ after conversion into the full-size cask, whereas the permissible value is 2×10^{-3} $Torr \cdot l \cdot s^{-1}$.

Fig. 5 shows the concept for the demonstration of safety against brittle fracture for the thick-walled steel cask in the 9-m drop test.

The calculational evidence of safety against brittle fracture was produced according to the principles of lefm (linear-elastic fracture mechanics) by means of probabilistic methods. The stress analy-

sis required for providing this evidence was carried out on the basis of both FEM calculations and strain measurements during drop tests on the 1:3.4-scale model.
The crucial material parameter for evaluating the fracture safety in this case is the dynamic fracture toughness, K_{Id}. The K_{Id} values were determined using a test facility based on the principle of the Hopkinson bar. For the following values of fracture toughness and defect size the safety of the cask against fracture can be guaranteed:

(1) $K_{Id} \geq 22.7$ MPa $m^{1/2}$

(2) semi-elliptical surface crack with a length of $l \leq 4$ mm and a depth of $d \leq 1$ mm.

The experimental investigation of the fracture behaviour of the cask was carried out on the 1:3.4-scale model. For this purpose the model was cooled down to -40°C and subjected to three successive 9-m drop tests in three different impact attitudes. Ultrasonic testing and the examination for surface cracks indicated that no structural and surface changes of any kind had been caused by the tests.

Simultaneously, a drop-weight tear test was conducted on a full-scale specimen. This specimen (see Fig. 6), which had been cut out from a forged part of the cask, had a height h equal to the wall thickness, s, of the cask (h = s = 320 mm). By means of this test the effect of the wall thickness in the transition from the model to the full-scale cask was studied. On the bottom side of the specimen a notch having a length of l = 8 mm, a depth of d = 1.35 mm and a notch base radius of 0.05 mm had been produced, and the specimen was impacted with a drop weight at a temperature of -40°C (see Fig. 7). The tensile stress generated on the bottom side was $\sigma = 765$ N/mm^2, this is twice the value of the maximum nominal stress occurring in the cask under 9-m drop test conditions. The specimen was left undamaged and showed no changes whatsoever at the notch base.

In addition to the Type-B test programme, the strength characteristics of the cask were to be assessed under the conditions of an accident within the nuclear power plant, assuming the fall of the cask from a height of 25 m and its crash onto the concrete foundation of the railway corridor, which has a basement under it. The foundation was also modelled to reduced scale for the experiment, and a drop test from a height of 25 m was carried out with the 1:3.4-scale cask model. The model foundation was partly destroyed in the test (see Fig. 8). The model cask remained intact. The impact deceleration was 60 % lower than in the 9-m drop test.

3. THERMAL BEHAVIOUR DURING THE 800°C THERMAL TEST

The temperature behaviour of the cask under the conditions of the thermal test and the subsequent cooling period was investigated using the TEMPN 2 computer code. This code can calculate nonsteady multidimensional temperature distributions even for bodies with considerably temperature-dependent material parameters.

Starting from the steady-state temperature distribution determined for normal thermal conditions (residual heat output: 15 kW, ambient temperature: 38°C, insolation), the temperature distributions were calculated for the end of the thirty-minute thermal test as well as for the time during the cooling period when the temperature at every point of the cask wall begins to fall.

The results of these calculations showed that the coolant temperature, which is crucial for the cask safety, reaches its maximum value of 143°C approximately 60 minutes after the end of the thermal test.

This temperature increase causes an internal pressure of 1.1 MPa in the cask, which value is below the test pressure.
Sufficient strength and leak-tightness of the cask under thermal test conditions are ensured.

4. SUMMARY

In the course of an experimental programme it was demonstrated that the C30 shipping cask for spent fuel assemblies from WWER-440 type nuclear reactors maintains its structural integrity in the Type-B packaging drop tests. The cask fulfils the requirements of radiation protection and for leak-tightness. The calculation and evaluation of the temperature distribution in the cask under normal transport as well as thermal test conditions indicated that with a cask loaded to capacity the permissible values are not exceeded and leak-tightness is guaranteed.

So far four TK-C30 shipping units have been built. They are in use in the GDR, in Hungary, and in Czechoslovakia.

REFERENCES

/1/ Regulations for the Safe Transport of Radioactive Material; IAEA Safety Standards, Safety Series No. 6; 1985 Edition; IAEA, Vienna (1985).

/2/ Directory of Transport Packaging Test Facilities, IAEA-TECDOC-295, IAEA, Vienna (1983).

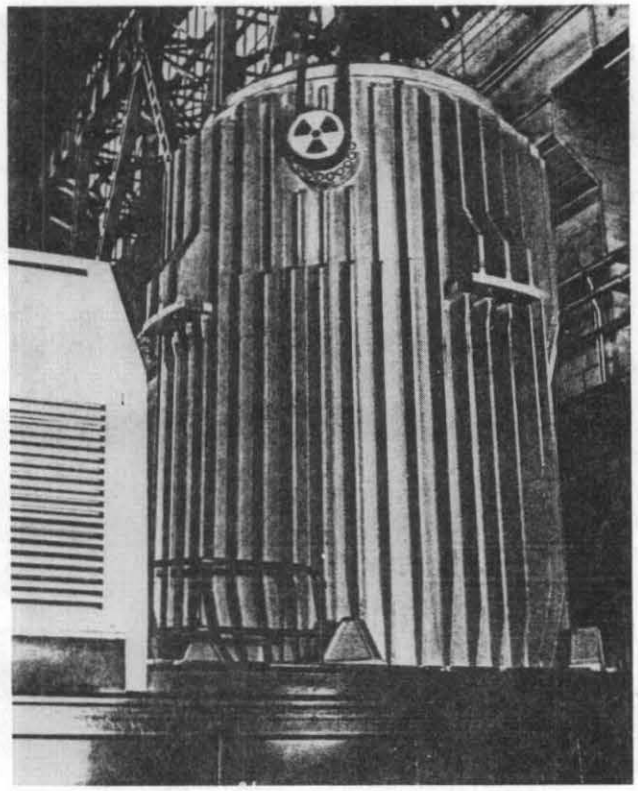

FIG. 1. C30 shipping cask

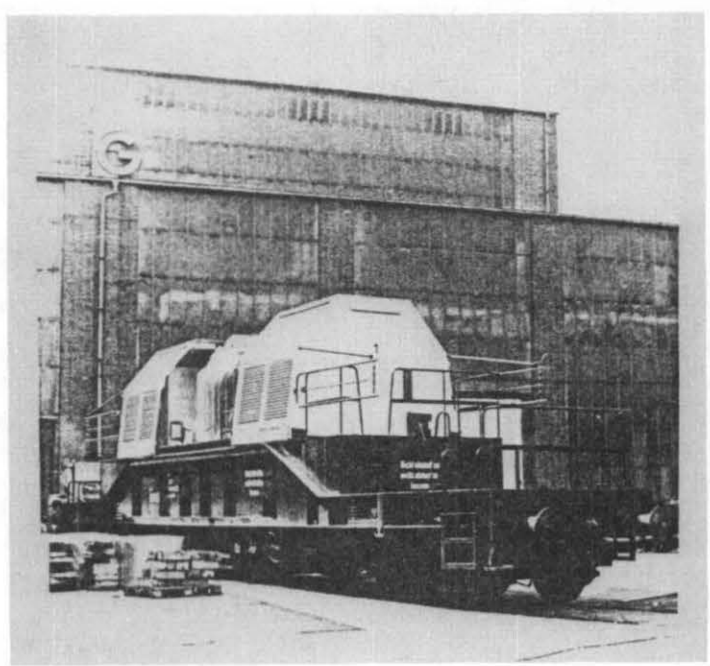

FIG. 2. Rail car for the C30 cask

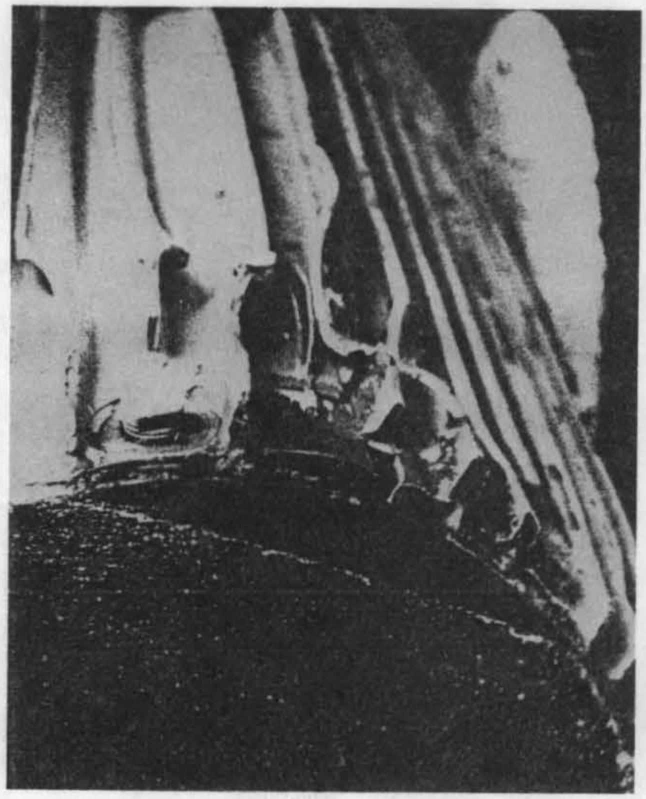

FIG. 3. Bottom edge deformation on the 1:3.4-scale model after the 9-m drop

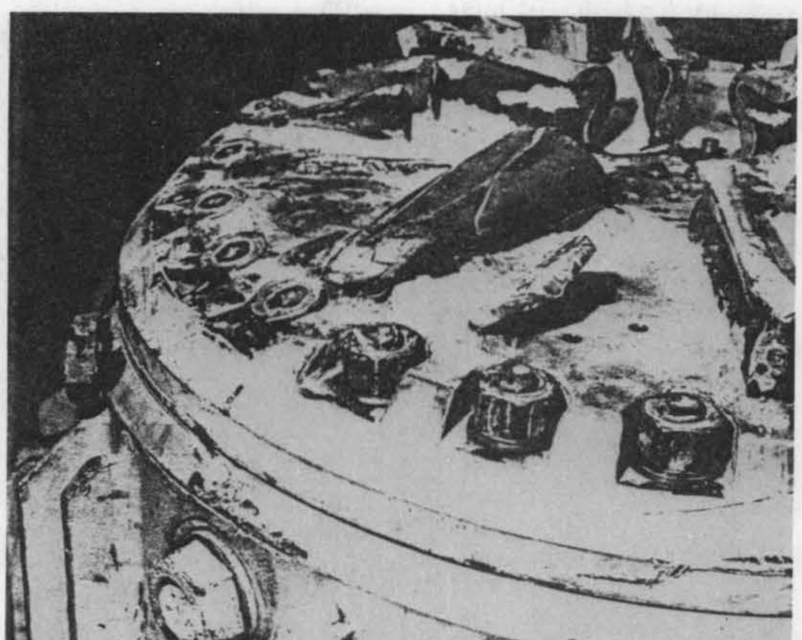

FIG. 4. Lid edge deformation on the 1:3.4-scale model after the 9-m drop

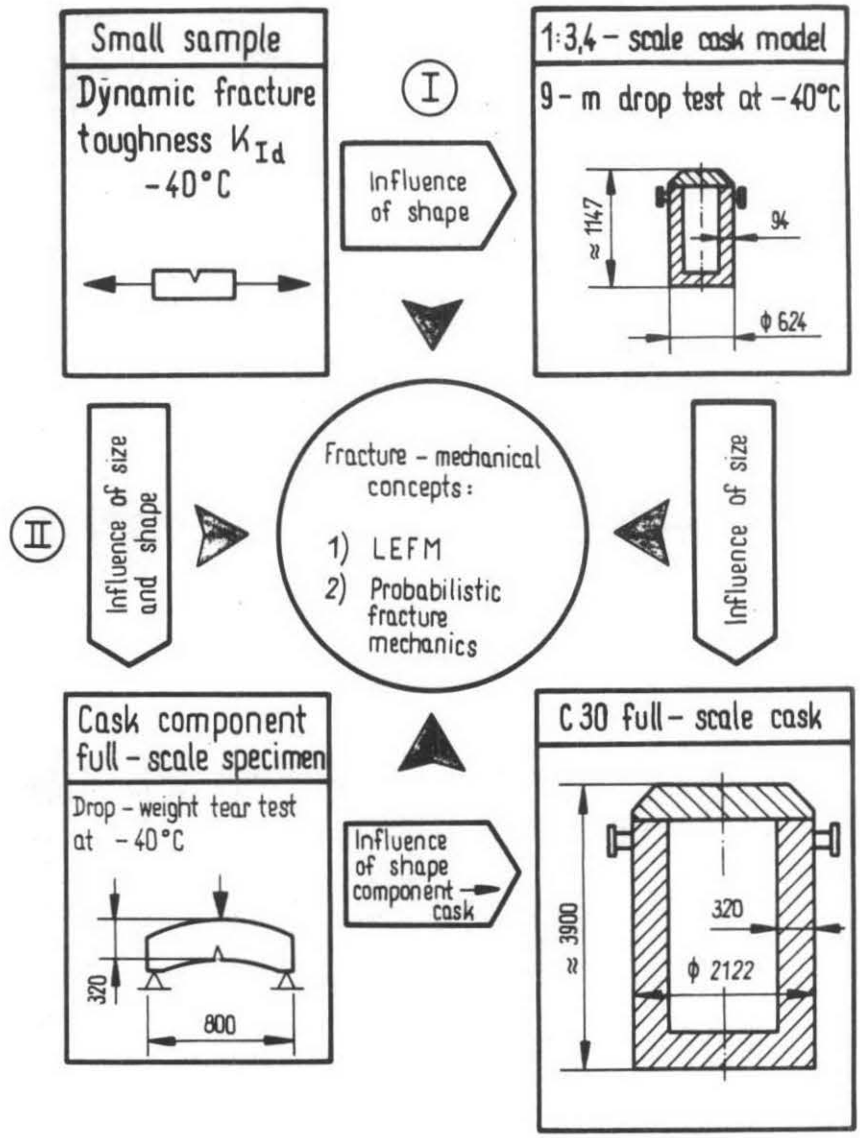

FIG. 5 : Concept for the demonstration of safety against brittle fracture for the C 30 shipping cask

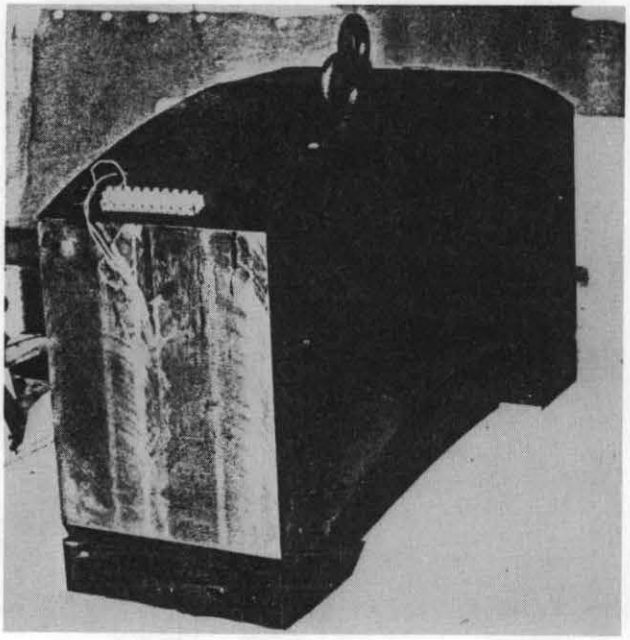

FIG. 6. Full-scale specimen for the drop-weight tear test

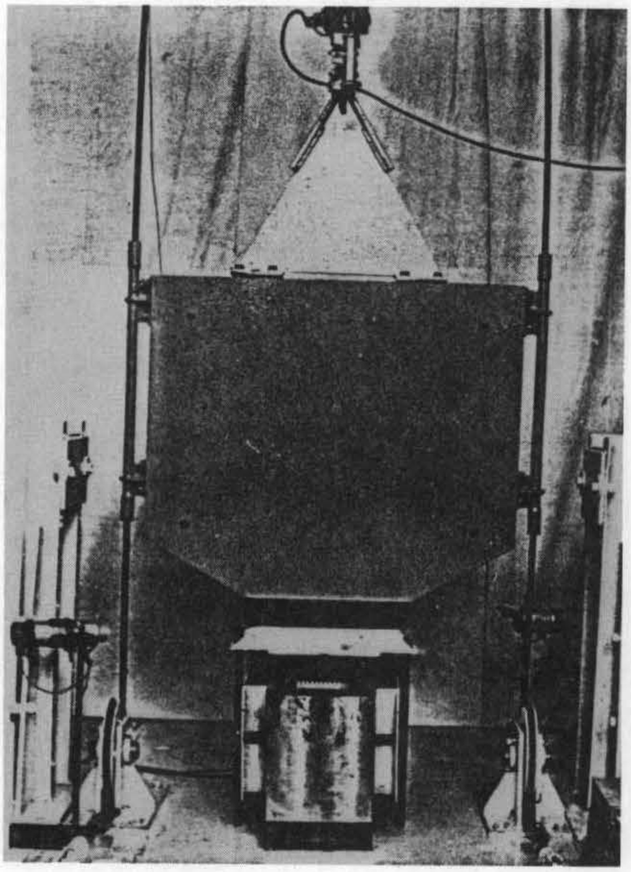

FIG. 7. Drop-weight tear test facility

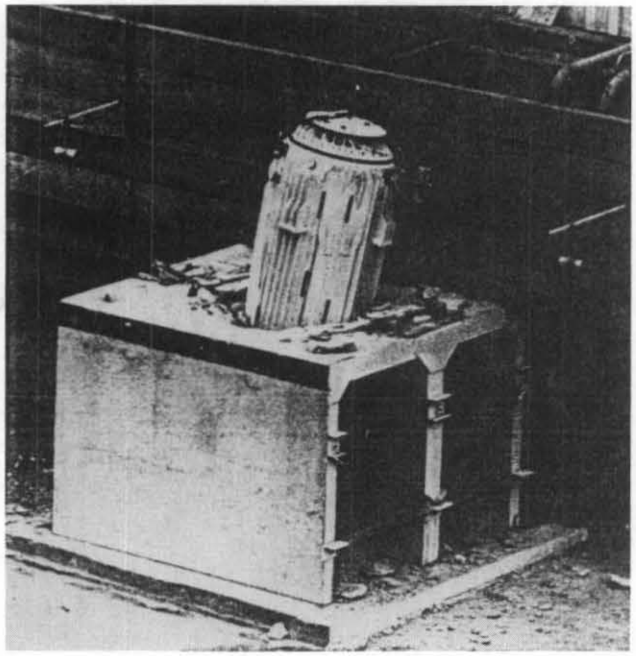

FIG. 8. 1:3.4-scale model after the 25-m drop onto a concrete foundation