Behavior of a Spent-Fuel Transport/Storage Cask When Impacted by an Airplane

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INTRODUCTION

In June 1992 TRANSNUCLEAIRE has been awarded a contract by SYNATOM, the Belgian nuclear fuel management company, and its engineering company, BELGATOM, to provide transport and storage casks for the interim storage of the Doel spent fuel. The model supplied is the TN 24 D, which has capacity of 28 PWR fuel assemblies. It has to comply with international regulations for transport and with specific Belgian requirements for storage.

One original aspect to be studied was the ability of the cask to withstand the crash of a military airplane fighter (F16) with a speed of 150 m s^{-1}. The purpose of this paper is to describe the approach followed by Transnucléaire and the results obtained.

DESCRIPTION OF THE TN 24 D CASK

The main component of the TN 24 D packaging is a body constituted by a forged steel shell, with a thickness of about 200 mm (ranging according to angular orientation), welded to a forged steel bottom. The shell is surrounded by neutron shielding, protected by an external steel envelope, and crossed by copper heat conductors to allow thermal dissipation. The body is closed by a lid, whose leaktightness is provided by a double metallic O-ring.

Inside the cavity, a basket allows the positioning of the fuel, while keeping subcriticality with a sufficient margin.

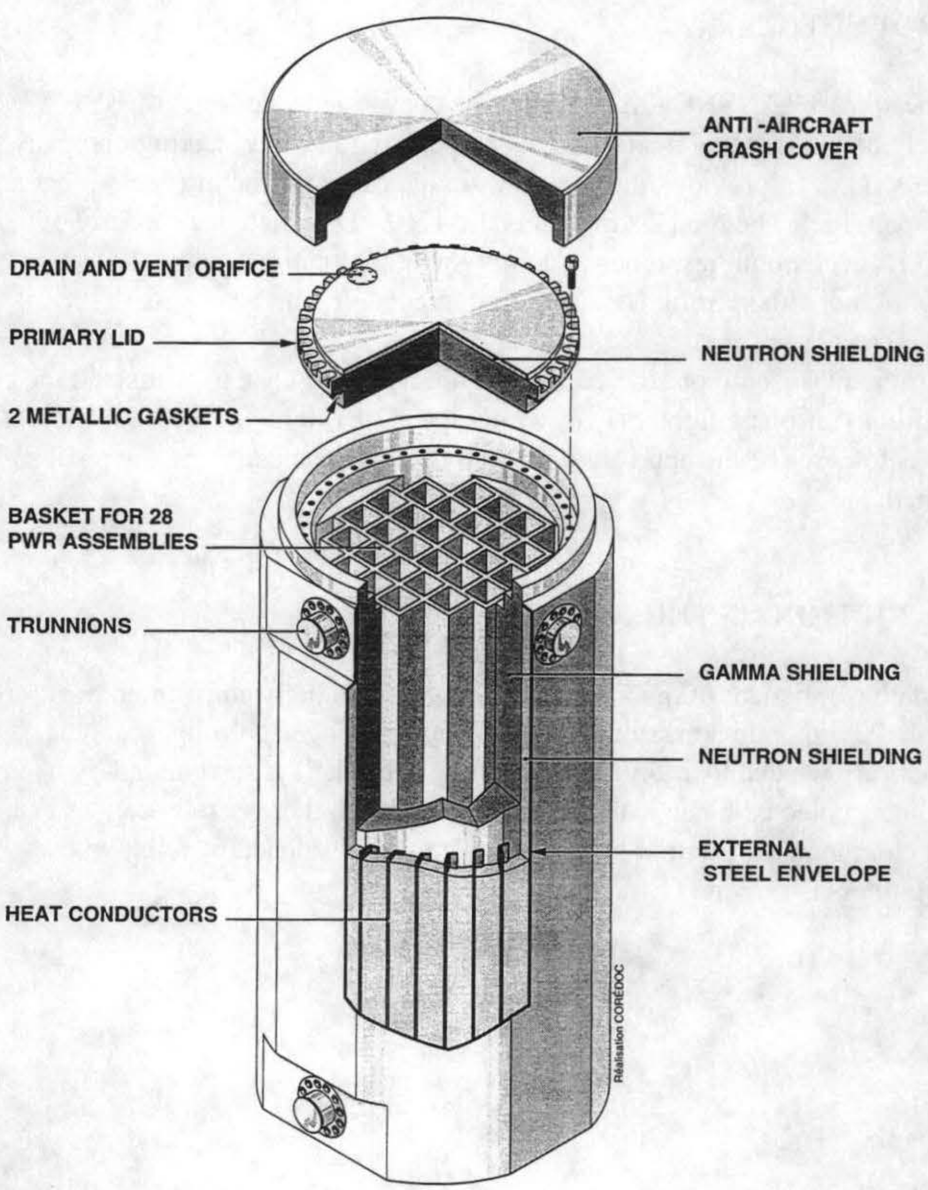
During transport, the cask is protected by two shock absorbing covers fitted at both ends, while during storage, the closure system is protected by an anti airplane crash cover.

The total mass of the cask during transport is 112 tons.

The TN 24 D cask (Fig.1) has been designed to accommodate 28 PWR spent-fuel assemblies (17 x 17, 12 ft active length) with an initial enrichment of 3.4%.

The burnup may be as high as 36,000 MW.d/tU and the cooling time as low as 8 years.

Figure 1. TN 24 D packaging.



TRANSPORT QUALIFICATION

Qualification of the design of this cask, concerning transport aspect, is based as usual on the Regulations established by the International Atomic Energy Agency (IAEA) (Safety Series N°6 : Regulations for the Safe Transport of Radioactive Material) and associated tests.

To show the ability of the cask to withstand accident conditions in transport, it must be demonstrated that it can resist the following sequence :

- 9-m drop test on an unyielding target, with the worst orientation;
- 1-m drop test, on a steel punch with a diameter of 150 mm;
- 800°C fire test for 30 minutes.

The demonstration was provided, as concerns drop tests, using a one-third scale model, which successfully resisted six 9-m drop tests and one punch test.

As for the fire test, calculations, correlated with numerous experiments, show that all the temperatures are acceptable and do not impair the cask leaktightness.

Licenses were issued by French Competent Authority in February 1994 and by Belgian Competent Authority in February 1995.

STORAGE QUALIFICATION REQUIREMENTS

Unlike the case of transport, there is no international standard concerning storage qualification, for which the requirements are related to the storage site.

In our case, the main tests are:

- a 2.5-m drop test on a concrete floor, with the worst orientation on the bottom side;
- a 600°C fire test for 1 hour; and
- an airplane crash test.

The latter corresponds to the impact of a military fighter (F16) with a total mass of 14,600 kg and a speed at the moment of impact of 150 ms^{-1} (540 km h^{-1}). The impact surface of the projectile is 2.6 m^2, corresponding to a diameter of 1.8 m. Our customers specified the evolution of the force versus time, corresponding to a crash against an unyielding wall. This curve is considered as the basic data.

Concerning the drop test and the fire test, the methodology is the same as for transport, i.e., use of a one-third scale model test for 2.5-m drop tests, and calculation for the fire test.

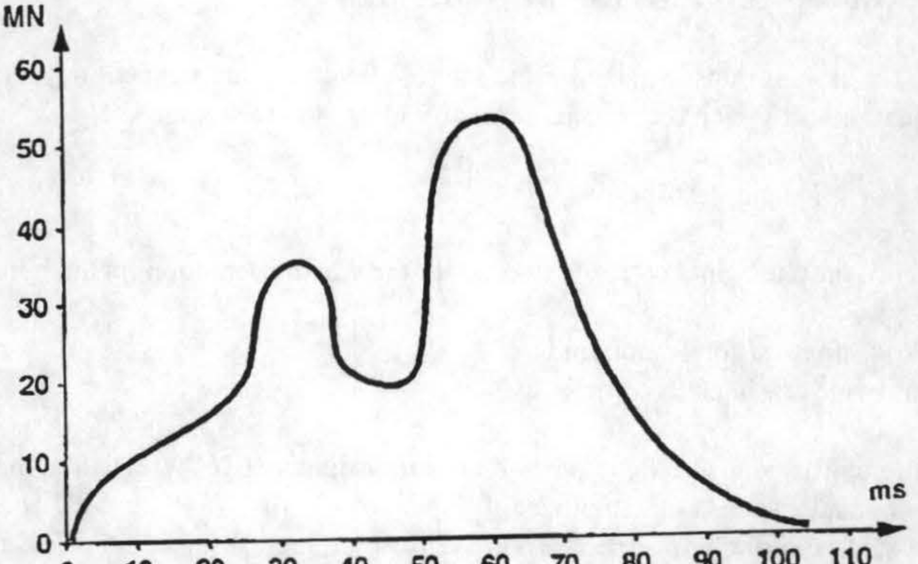
For airplane crash resistance, we considered the only way to provide a quantitative demonstration that the required level of leaktightness was reached was by actual testing. Therefore, the one-third scale model used for drop tests was subsequently submitted to an additional air-crash test.

Preliminary calculations were nevertheless necessary to determine first the features of the missile to be shot, and, secondly, the orientation of the test, taking into account potential scale effects and realization of the test constraints.

CALCULATIONS: DETERMINATION OF THE MISSILE AND ORIENTATION OF THE IMPACT

As explained previously, the basic data were the curve describing the evolution of the impact force (on an unyielding wall) versus time (Figure 2).

Figure 2. Force versus time.



Full-Scale Missile

The first step of the method consisted in the design of a full-scale missile. This was performed with the help of a code specially developed to study the effects of crashes. The distribution, along a fictitious cylinder, of mechanical and mass characteristics was determined until the calculated forces corresponded to the specified impact curve. Since this missile did not have to be shot, it was possible to use theoretical characteristics of materials.

Orientation of the Impact

The second step of the method consisted in the choice of the most damaging orientation for the impact. Tests already performed, particularly in Germany, had shown that a direct impact on the central part of the body did not create significant damages. This is the reason why we decided to focus the qualification on impacts on the closure system.

Two orientations were recognized as particularly harmful. For the first one, the projectile hits the cask axially at the center of the anti-airplane crash cover; for the second one, it hits the cask in the plane of the closure system.

To conclude about the worst orientation for the impact, calculations were performed using the finite elements models of the scale 1 projectile and cask with their material characteristics and geometries (as determined in the first step for the projectile).

The results of the calculated axial impact show that the whole impact energy is absorbed by the deformation of the missile and of the anti airplane crash cover, without any incidence on the containment vessel (no deformation, no displacements).

The results of the radial impact show :

- negligible deformations in the forged shell of the containment vessel;
- temporary displacement of the closure lid against the upper part of the forged shell;
- temporary elongation of the bolts near the impact;
- tilting of the cask.

Since the anti-airplane crash cover provides a fully efficient protection of the closure system in the case of an axial impact, it was established that a radial impact on the upper part of the cask, in front of the closure lid gasket seats, would be the most damaging.

Determination of the Projectile to be Shot

The third step was the design of the missile to be shot. This missile had to recreate the same phenomena when impacted on a 1/3 scale model of the cask, as described previously at scale 1. The deformations and displacements had to be recreated with a 1/3 scale ratio factor.

It had also to be manufactured out of easily procured materials. The last conditions was that it had to be compatible with the diameter of the air gun used to shoot the missile: this imposed a diameter for the projectile of 270 mm. Therefore, the scale of the diameter of the missile is between 1/6 and 1/7, while the scale of the packaging is 1/3.

The calculations were iterated, adjusting the scale projectile characteristics (material, mass distributions, geometries, and lengths) until the required results were obtained.

The results have been checked for the two cases of impact previously detailed, axial and radial.

The projectile is a steel pipe with a thickness ranging from front to the end, from 2 mm to 16 mm and a total mass of 350 kg.

IMPACT TEST

General

The fourth step of the demonstration was the impact test of the projectile on the one-third scale model of the packaging. This was necessary to show that the displacements of the closure lid were compatible with the required criteria for leaktightness (3×10^{-3} Pa m^3 s^{-1}).

The test was performed in June 1993 in a CEA test center in the southwest of France. The missile (outer diameter, 270 mm; mass, 350 kg) was shot using a compressed air gun equipped with accurate speed measurement devices.

Result

The missile was shot at a measured speed of 147 m s^{-1}. There was, therefore, a small lack of kinetic energy, limited to 4%, a value which is not significant for this kind of test.

No permanent elongation of the bolts was measured by the strain gauges.

As concerns the main purpose of this test, which was to measure leaktightness, the leak rate before the test was lower than the sensitivity of the helium mass spectrometer used, i.e. lower than 5×10^{-10} Pa m^3 s^{-1}. After the test, the measurement remained lower than the detectable threshold of 5×10^{-10} Pa m^3 s^{-1}.

The experiment therefore can be therefore considered as totally successful.

COMPARISON BETWEEN TEST AND CALCULATION

The purpose of this experiment was not to make a full comparison between tests and calculations. The function of each element has been explained previously: calculation to determine the missile and the most damaging orientation and test to show the ability of the cask to withstand the crash.

Nevertheless, it is interesting to note that the calculation can predict reliable information. We give hereafter some elements to confirm this matter, among many others included in the detailed analysis.

- Strain in the bolts increases during the impact, and the initial value is recovered afterward: the same observations may be done for calculation and test.

- Kinetic energy of the projectile is calculated to be absorbed at a rate of 84%, as a result of the missile crushing and setting the model in motion at the end of the impact according to the calculation of the one-third scale model (at 24-25 ms); the test shows that, at 24 ms, the kinetic energy of the projectile is dissipated at a rate of at least 80%.

CONCLUSION

The TN 24 D cask can withstand an airplane crash without alteration of its leaktightness, maintaining a leak rate lower than 5×10^{-10} Pa m^3 s^{-1} and several orders of magnitude better than required. Demonstration has been fully provided by a rigorous combination of calculation and testing. It allowed us to obtain a license for the storage of spent fuel at the Doel site. Loading of spent-fuel is now achieved: the first operation was performed in November 1995.

The results have also been extrapolated to another cask of the same family: the TN 24 XL, which has a capacity of 24 PWR longer fuel assemblies (14 ft active length).

The same extrapolation also could have been easily extended to other models: the TN 24 cask family can withstand the most severe airplane crash.

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