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TYPE C PACKAGE DESIGN REGULATORY IMPACT TEST EXPERIMENTAL AND ENGINEERING PROCESS

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ABSTRACT

Since the introduction of the Type C package model in the 1996 TS-R-1 edition of the Regulation for safe Transport of Radioactive Material, only few package models have been approved throughout the world.

As soon as 1998, CEA was requested to define and undertake a qualification test program leading to commission a new package designed for transportation of radioactive material by air, following all 1996 TS-R-1 regulation requirements. The “Type C” package was the response to this request. This new package design had to be designed from scratch because no experience feedback or reference design was available at this time. The design was entirely handled by CEA including the performance tests on a certified tests site. After number of studies and experiments, the type C package model has been finally authorized for transport by the French Competent Authority in 2006.

This papers deals with the challenge of designing such a package due to the severity of the regulatory requirements for Type C package. More specifically, this paper explains the engineering process leading to demonstrate that the Type C package design withstands the regulatory 90 m/s impact test.

The energy levels reached during the impact (nearly 50 times higher than during a type B drop), and the non-linearity of the behavior of the materials prevented most numerical simulations at the time of study to be accurate. The design has been based on a proven architecture, with no complex system insuring safety functions. Design constraints have also been considered, such as the use of a transport frame, limitation of mass and overall size. A dense wood protection was chosen, which offers a robust mechanical protection and efficient thermal protection. A number of preliminary tests were performed on scale models in different orientations of the package using air pressure cannon on the CEA Tests and Experiments Facility. The results show that the package behaved as expected and all the safety functions remained operational.

INTRODUCTION

The 1996 major update of the IAEA regulation has brought significant changes in the package categorization and the associated tests sequences. When previously a type B package model was sufficient for the air transport of high quantities following IAEA 1985 regulations, the new requirements requested the approval of a type C package.

Considering the range of speed at impact required for the impact test (90 m/s), gravity drops are not adequate to perform a regulatory impact tests. Three tests have to be performed:

- Longitudinal: impact test with the longitudinal axis of the package perpendicular to the target,
- Transverse: impact test with the longitudinal axis of the package parallel to the target,
- Oblique: the longitudinal axis of the package is oriented with an angle to the target, so that the center of gravity is aligned with the area of impact and perpendicular to the target.

An air pressurized cannon available for tests at the CEA’s Tests and Experiments Facility was modified and used for that purpose. This paper presents some specificities of this device. This speed range was the first to be reached on a package; therefore some preliminary tests were necessary to prepare the qualification tests.

After the tests an assessment of the mock-up showed that the package withstood the impact test.

TEST DEVICE

Facility

The facility used for the purpose of the impact test is the Tests and Experiments Facility and more specifically an Ø880 mm caliber cannon.

Figure 1. External view of the facility showing the cannon muzzle and the blow deflectors

A diagram is shown here after:

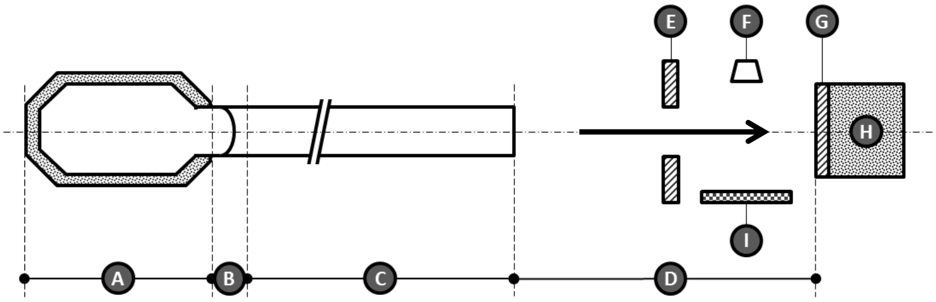

Figure 2. Diagram of the different parts of the test device

This device is made out of the following elements:

A. A 100 m^3 chamber pressurized with air up to 20 bars,
B. The triggering device composed of a pyrotechnic membrane,
C. A 60 m long barrel,
D. A 20 m distance of free flight zone,
E. Blow deflector or debris stopper,
F. High speed cameras with flash lights,
G. Target (steel plate),
H. Concrete reinforcement,
I. Sighting mark.

In preparation of the firing, the chamber is pressurized with air using a compressor. The maximal allowable pressure in the chamber is 20 bars. However in order for a package of approximately 700 kg to reach a velocity of about 100 $m.s^{-1}$, the pressure in the chamber is limited to 3 bars.

The firing mechanism mainly consists of a pre-cut metallic membrane provided with a pyrotechnic cordon used as a trigger.

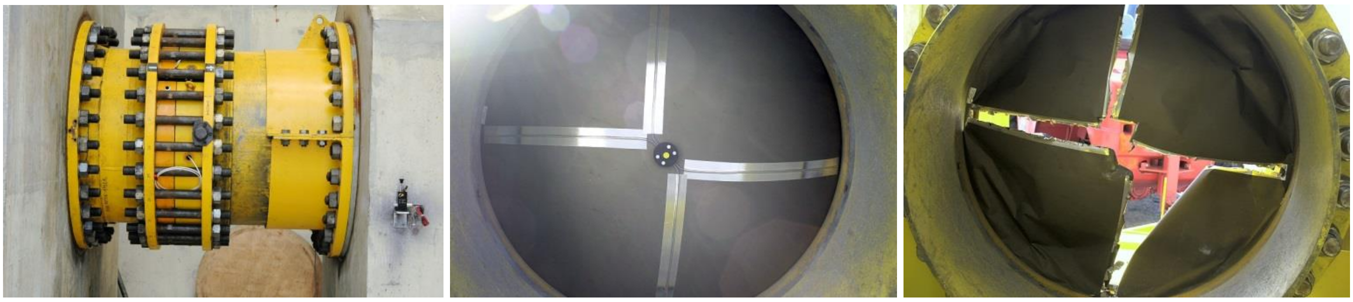

Figure 3. Views of the membrane.

Access from outside (left), before the firing (center), torn out after the firing (right)

When the cordon is ignited, the membrane is cut releasing the air pressure in the barrel thus giving the thrust needed for the package to reach 100 $m.s^{-1}$.

When the package exits the barrel, the air promptly expands originating in a steam cloud that may obstruct the view of the package from the cameras. This steam cloud has to be deflected by the deflectors.

Although the muzzle velocity of the package is significant, it has been observed that the velocity is still increasing because of the remaining pressure of the air/steam.

Target

The unyielding target is made of a 50 mm thick steel (A) plate and concrete reinforcement blocks (B) assembled together using tied beams (C). The whole assembly weighs 250 tons and lies on the ground in a pool (D). The advantage of using a non-fixed construction is to bring the possibility of rearranging the blocks to give an angle to the target (see para Orientations\Oblique test).

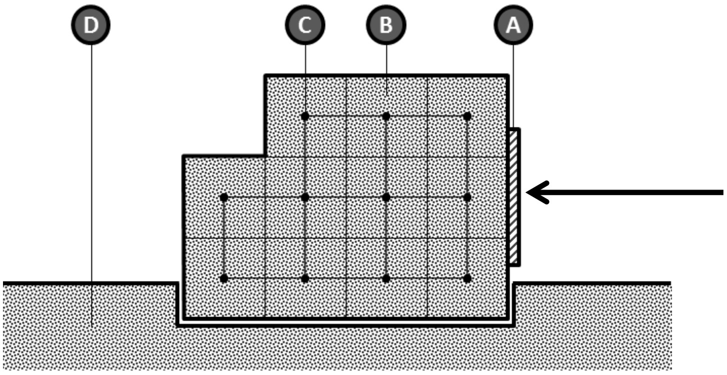

Figure 4. Diagram of the different parts of the unyielding target

After each sequence, the target was inspected and checked out for any displacement.

Figure 5. Views of the unyielding target (steel plate in black), sighting marks and debris stopper (right)

PRELIMINARY TESTS

Characterization of the cannon device

The cannon has not been built for the purpose of this tests and has been renovated shortly beforehand. It was necessary to characterize its capacity or the way it responds to the pressure. More importantly, it was to be evaluated the pressure to be necessary to launch the package with the proper velocity.

In order to evaluate the necessary pressure, a homemade code was used, dedicated to the launchers using pressurized inert gas and mainly based on a state equation of real gas.

Fed with the characteristics of the canon and the distance to the target, the code estimated the following results which were then confirmed by a test. A velocity radar was placed under the muzzle and measured the velocity of a 700 kg mass at impact.

Table 1. Comparison between the code and the experiment on the relation between the chamber pressure and the muzzle velocity

	Test	Code
Chamber pressure (bars abs)	3.2	3.25
Muzzle velocity (m.s^{-1})	137	133
Time for exit – 60 meters (ms)	780	780
Time for impact – 82 meters (ms)	940	970

A mass of 700 kg needs the chambers of the cannon to be pressurized at 2.65 bars abs in order to reach a velocity of 95 m.s^{-1} on the target.

An additional test was performed later where the velocity of a mockup was measured all along the launch including the inner part of the cannon and the free flight. The velocity radar was placed on the target in the area of the axis of the cannon.

On the Figure 6 below, the phase A is the thrust of the mockup under pressure. The velocity increases almost linearly. The phase B corresponds to the free flight, where the velocity remains constant. However it can be raised that shortly after the exit of the barrel, the velocity keeps increasing due to the blow that stills pushes the load. The impact velocity reaches 105 m.s^{-1}.

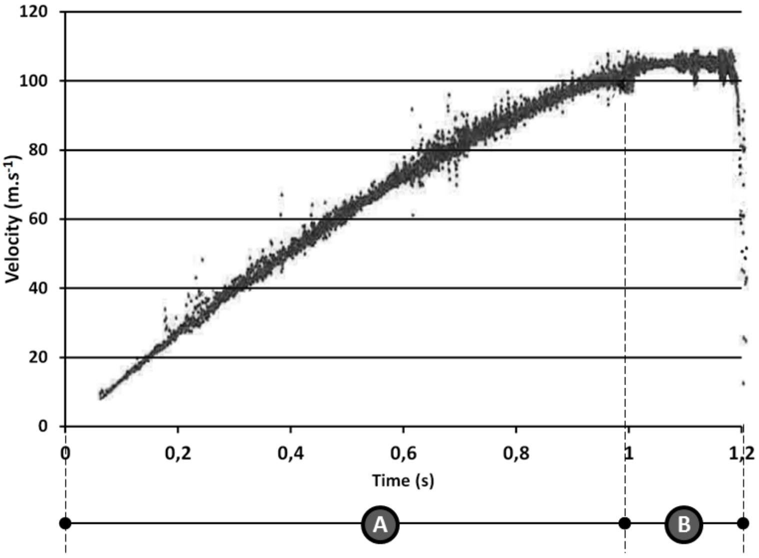

Figure 6. Evolution of the velocity of a mass of 670 kg launched with a pressure of 2.73 bars abs

Characterization of the package shock absorbers

Despite the massive experience of the CEA in the wood behavior towards crash, only few data were available for this range of deformation speed.

Some test sequences were performed. Several species of wood were launched at a velocity of 90 m.s^{-1} in different orientations (parallel to the wood fibers, transverse to the fibers and with an angle of 45°).

Figure 7. Three mock-up containing different type of wood (sequoia, deal, poplar) after a launch with an angle of 45°

The observations after the tests show that the sequoia was the best choice for the impact test because it has higher density and energy absorption capacity (maximal deformation ratio, crushing stress). The crushing of the wood is reduced: the impact energy is dissipated with a smaller volume of wood. Furthermore, the cohesion of the wood fibers remains, contrary to the other types of woods where the structure tends to be dispersed at impact.

ORIENTATIONS

The 1996 AIEA regulation states that the orientations for the impact test have to be chosen such as the package to suffer maximum damage.

The package being roughly a cylinder supported by a frame, three different orientations are obviously preferred: longitudinal (A), transverse (B) or oblique (C).

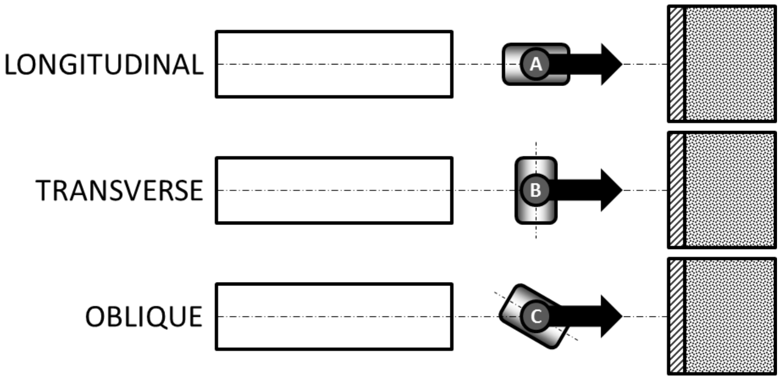

Figure 8. Three preferred orientations for impact tests

Considering that the impact test device does not allow the use of the transport frame, the deficit in energy of the package without it is converted into additional velocity. Thus the impact speed for the regulatory test is brought to 97 m.s^{-1}.

Figure 9. Equivalence in energy between mass and velocity

Longitudinal test

The impact test in longitudinal orientation is the simplest test to perform as the package shape fits perfectly to the barrel of the cannon. However the external diameter of the package being bigger than the inner diameter of the cannon, a 0.8 scale model was used.

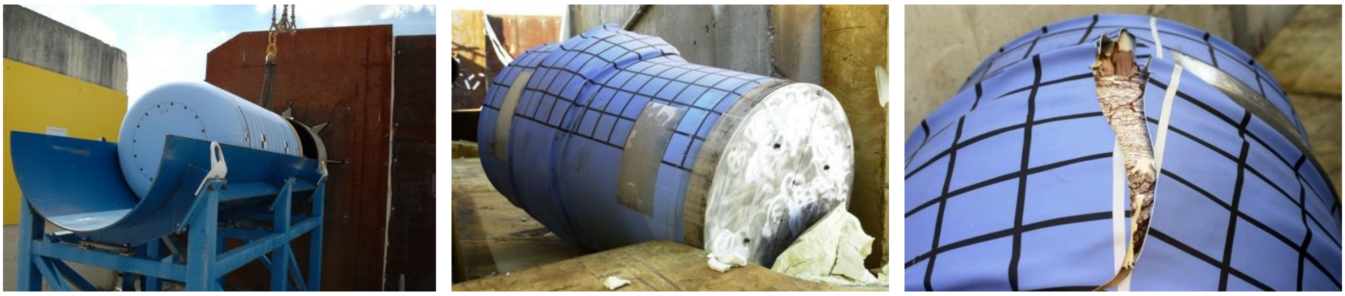

Figure 10. Package before (left) and after (center and right) the impact test in axial orientation

Transverse test

The impact test in transverse orientation is more difficult to perform as the shape of the package has to be transverse to the axis of the barrel of the cannon.

A 0.4 scale model was used and a plaster cast was designed (see Figure below). This plaster cast is made of 4 independent plaster petals. When still in the barrel, the assembly is naturally maintained. During the free flight, an aerodynamic effect spreads the petals apart and frees the package. Additionally a debris stopper (see Figure 5) was used to prevent any debris of plaster to obstruct the camera field.

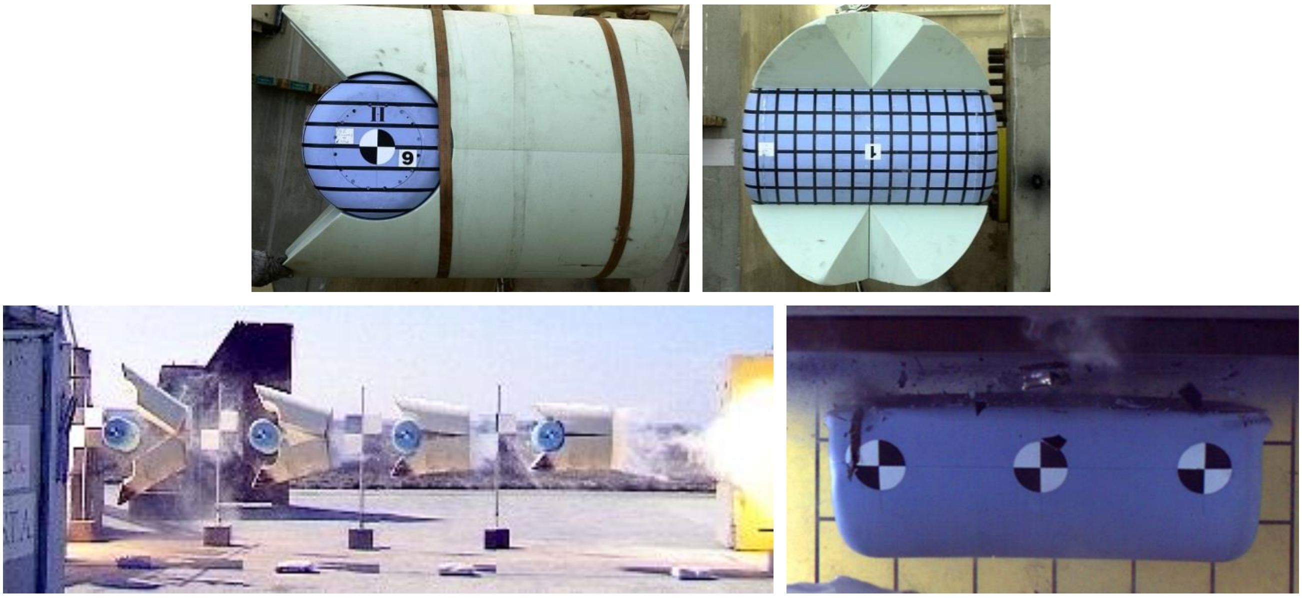

Figure 11. Package before the impact test (top), chronophotography during the free flight (bottom left) in transverse orientation and just after the impact (bottom right)

<u>Oblique test</u>

The impact with the package in oblique orientation is also challenging. Three options are discussed:

- Direct impact on the target (C): the package (B) is in an attitude that maximizes the damages. The axis of the barrel is perpendicular to the target,
- Reverse impact: a load (D) is launched onto the package (B) standing in the proper orientation,
- Direct impact on an oriented target: the package (B) is launched in the same attitude as longitudinal impact test, but the target (C) is oriented with an angle.

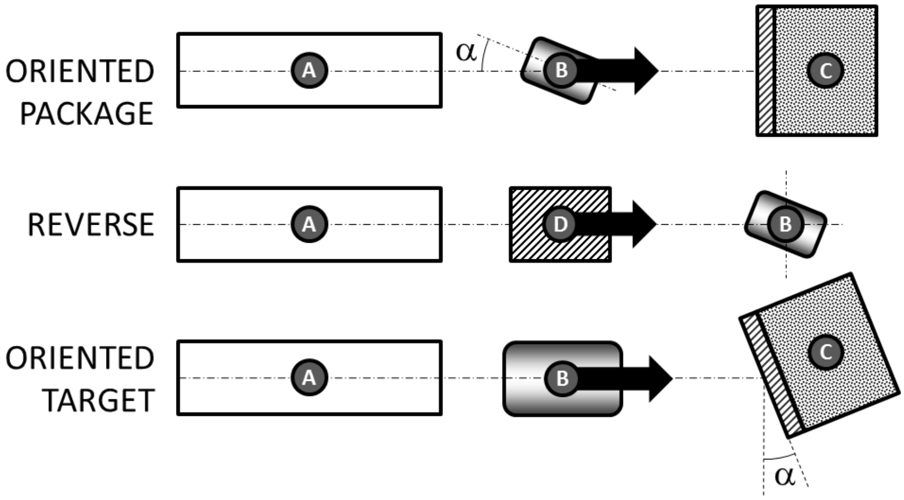

Figure 12. Three solutions for oblique impacts test: direct impact (top), reverse impact with the target rotated (down)

Oriented package

This configuration needs the use of a 0.4 scale model placed in a plaster cast. The velocity is adjusted to 97 m.s^{-1} to cover the deficit of the transport frame's mass. A debris stopper is placed to prevent pieces of plaster to obstruct direct views from the camera.

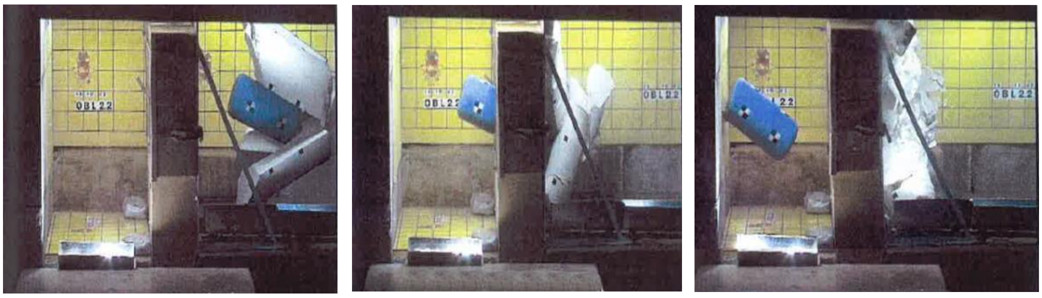

Figure 13. Oblique impact test using the plaster cast before(left), through (center) and after (right) the debris stopper

The damages on the package are located on the corner. The external shell remained unperforated.

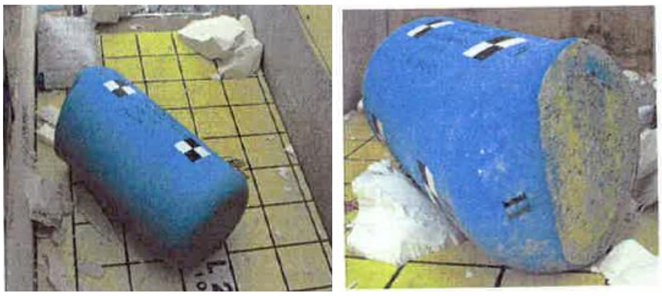

Figure 14. Damages observed on the package after the oblique impact test using the plaster cast

This configuration is simpler to set up compared to the reverse configuration. However the analysis of the video showed that the package has lost its orientation during the free flight. It is probable that the package is aerodynamically unbalanced inducing a rotation leading to a loss of the proper positioning at the impact. Unfortunately, this effect was not sufficiently controlled to provide confidence in this configuration.

Reverse configuration

In the reverse configuration, the package is not launched directly from the cannon but is hit by a load. The projected load has to be heavy (approx. 10 times) compared to the package. However the cannon has the capacity to launch heavier loads at regulatory velocity. This configuration allows some flexibility in the positioning of the package.

Several tests were performed in that configuration. In the first one, the package was freely positioned on a stool. The results showed that the blow of the load induce a rotation of the package before the impact, leading to a loss of precision in the angle.

It was then necessary to tie down the package on the stool. A second test was performed, which showed that the impact induced a rupture of the slings, meaning that not the whole energy of the load was transferred to the package. An additional device had to be designed to break the link between the stool and the package right before the impact. It was decided to abandon this configuration which showed high operational complexity added to a poor precision in the positioning at the moment of the impact.

Oriented target

In the “oriented target” configuration, the target is rotated so that the steel plate is oriented with an angle with the axis of the cannon. The concrete reinforcements design (see para Test Device\Target) enables the whole assembly to be precisely rotated with the proper angle.

In order to keep the same velocity at impact in the perpendicular axis of the target, the muzzle velocity has to be increased by a factor related to the angle ($1/\cos \alpha$). This leads to a muzzle velocity of 105 m.s^{-1}. This also increases the amount of energy to be dissipated at impact.

Figure 15. Impact test (105 m.s^{-1}) on a oriented target

It appears that the test on the oriented target caused much more apparent damage than the direct impact test. The external shell was torn apart and approximately 30% of the wood was ejected. However, a remaining layer of wood was still in place protecting the internal structure of the package. In all cases the closure system was not impaired and containment envelopes remained leaktight.

NUMERICAL CALCULATIONS

In order to perform some sensitivity studies, it was necessary to create a numerical model of the package. This was done using LS-Dyna code.

A first calculation was performed in order to match the observations made during the impact tests. The challenged lied into the capacity of the model to represents the test results in every orientation. Thus the following aspects were followed:

- Crushing of the wood,
- Deformation of the containment envelopes,
- Shape (length, diameter) of the containment envelopes.

This first calculation showed a good correlation between the model and the test although the first did slightly overestimate the stresses.

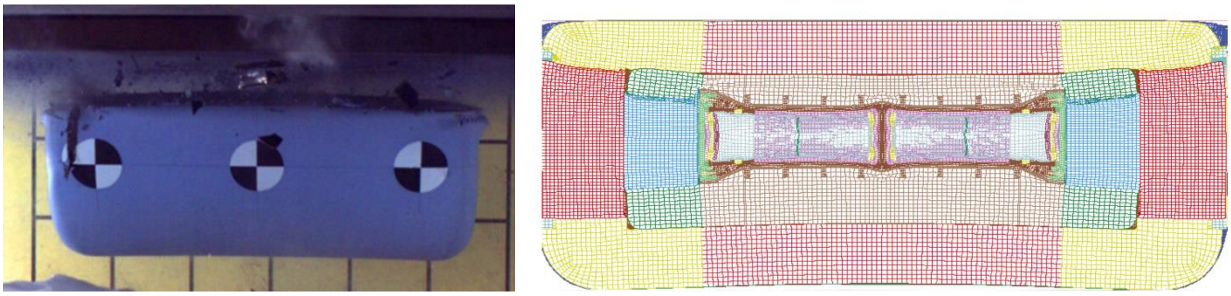

Figure 16. Example of good correlation between the calculations and the impacts tests

Secondly a sensitivity study on the angle shows that no slap down effect is to be expected for angles from 0° to 30°.

Additionally, this model was also used to show that the conclusions of the tests were robust enough. Considering any variability of the mechanical properties of the components in line with temperature variations did not show any adverse effect on the tests results.

CONCLUSIONS

This paper has shortly described the challenged of designing a package so that it withstands a regulatory impact test.

Many experiments have been conducted using different configurations, orientations and material. In all presented configurations the type C mockup remained leaktight. Calculations showed a good correlation with the tests and extended the demonstrations to a wider range of temperatures and angles.

Finally test results and calculations have been assessed by the French competent authority for Defense ASND and its technical safety operator IRSN. The certificate of approval for the Type C package design in compliance with the 1996 regulations for the safe transport of the Type C package containing radioactive material was issued in 2006.

REFERENCES

"Regulations for the Safe Transport of Radioactive Material", 1996 Edition (Revised), No TR-S-1 (ST-1, Revised)