# Radioactive material packages: accounting for the transport frame in regulatory drop scenarios

## G. MARCHAUD[a], V. SAINT-JEAN[b]

a. AREVA TN, gilles.marchaud@areva.com
b. AREVA TN, valerie.saint-jean@areva.com

## Résumé :

*Le transport de matières radioactives sur la voie publique est soumis à une réglementation nationale et internationale qui vise à assurer la protection des personnes et de l'environnement contre les effets dommageables des rayonnements ionisants. L'AIEA, Agence Internationale de l'Energie Atomique, a établi une norme, le « Règlement de transport des matières radioactives », qui notamment spécifie des épreuves mécaniques auxquelles doit résister un colis de matières radioactives, par exemple une chute de 9 mètres sur une cible indéformable ou une chute de 1 mètre sur un poinçon. Ces épreuves normalisées couvrent une vaste étendue de situations accidentelles réalistes. Le paragraphe 612 de l'édition 2012 de la norme précise que « les adjonctions au colis apportées au moment du transport et qui ne font pas partie intégrante du colis ne doivent pas en réduire la sûreté. » Cela implique que les composants assurant l'interface entre le colis et le moyen de transport sont à prendre en compte dans les études de chute. Cet article présente les différentes méthodologies adoptées par AREVA TN pour analyser l'influence du châssis de transport sur le comportement mécanique du colis. Des simulations numériques réalisées avec LS-DYNA® illustrent les différents phénomènes mis en jeu : absorption d'énergie, rupture, transmission d'effort vers le colis.*

## Abstract:

*The transport of radioactive material on a public road shall comply with national and international regulations that are intended to protect people and the environment from the harmful effects of ionizing radiation. The IAEA, International Atomic Energy Agency, established a standard, the "Regulations for the Safe Transport of Radioactive Material", that notably specifies mechanical tests a radioactive material package shall withstand, for instance a 9-meter drop onto an unyielding target or a 1-meter drop onto a pin. These standardized tests cover a wide range of realistic accidental situations. Paragraph 612 of the standard says that "Any features added to the package at the time of transport that are not part of the package shall not reduce its safety." This implies that the components that act as an interface between the package and the vehicle shall be taken into account in drop studies. This paper presents the different methodologies adopted by AREVA TN in order to analyze the influence of the transport frame on the mechanical behavior of the package. Numerical simulations performed with LS-DYNA® illustrate the different phenomena at stake: energy absorption, rupture, force transmission toward the package.*

**Mots clefs : transport, colis, matières radioactives, châssis, chute, simulation, LS-DYNA**

**Keywords: transport, package, radioactive material, frame, drop, simulation, LS-DYNA**

# 1    Introduction

The transport of radioactive material on a public road shall comply with national and international regulations that are intended to protect people and the environment from the harmful effects of ionizing radiation.

The IAEA, International Atomic Energy Agency, established a standard, the "Regulations for the Safe Transport of Radioactive Material" [1], that notably specifies mechanical tests a radioactive material package shall withstand, for instance (Fig. 1):

- a 9-meter free drop onto a flat unyielding target,
- a penetration test defined as a 1-meter free drop onto a mild steel bar.
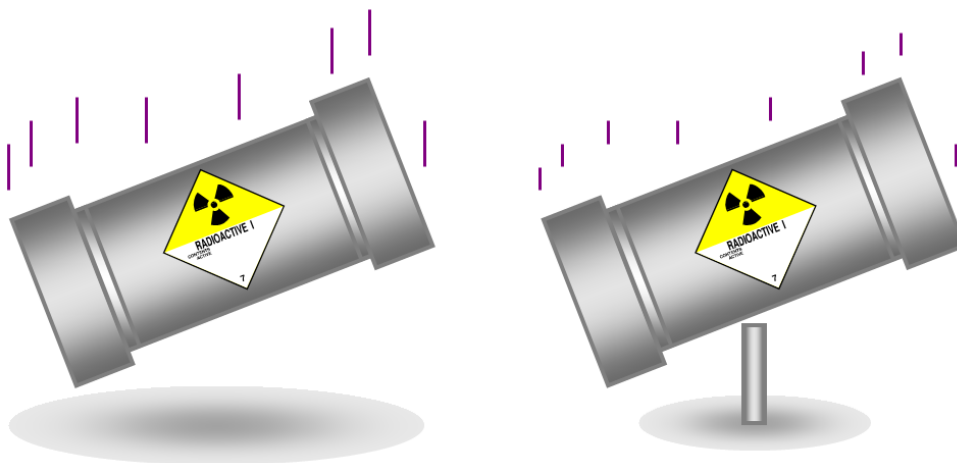


Figure 1: (left) 9m drop test onto an unyielding target, (right) 1m drop test onto a bar.

These standardized tests cover a wide range of realistic accidental situations. For instance, the 9m drop onto an unyielding target covers drops onto a real ground from a height of tens of meters.

Paragraph 612 of the standard says that "**Any features added to the package at the time of transport that are not part of the package shall not reduce its safety.**"

Paragraph 612.1 of the advisory guide [2] associated with the standard provides further explanations: "This requirement is intended to prevent such action as placing handling tools, auxiliary equipment, **transport frames** or spare parts on or near the package in any manner such that the intended functions of packaging components could be impaired, either during normal transport or in the event of an accident."

This implies that the components that act as an interface between the package and the vehicle shall be taken into account in drop studies.
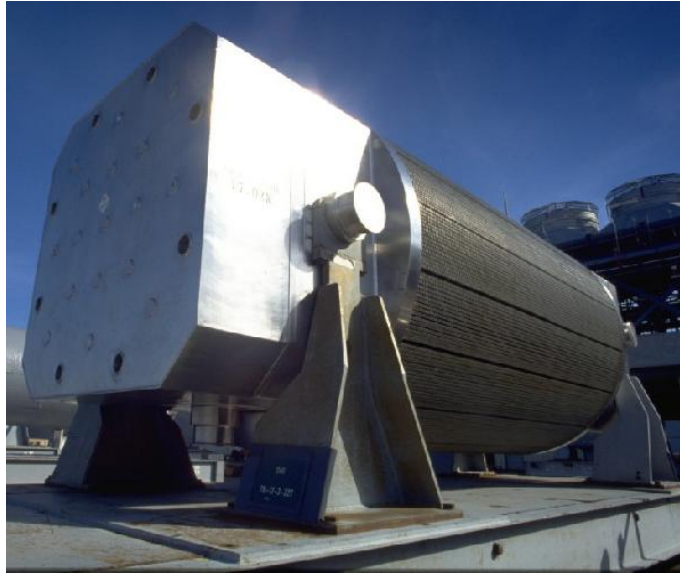


Figure 2: package lying on its storage frame – © AREVA TN.

This paper presents the different methodologies adopted by AREVA TN in order to analyze the influence of the transport frame on the mechanical behavior of the package.

Numerical simulations performed with LS-DYNA® illustrate the different phenomena at stake: energy absorption, rupture, force transmission toward the package.

The simulations are all based on an explicit time integration scheme.

## 2    Safety functions of a package

The package, composed of a content inside a packaging, shall fulfill the following safety functions:

- **Confinement**: the package shall remain leak-tight to avoid the exit of radioactive material;
- **Shielding**: the package shall protect people and the environment from ionizing radiation emitted by the radioactive content;
- **Subcriticality**: the package shall limit neutron multiplication in the content (if it is fissile);
- **Thermal dissipation**: the package shall dissipate the content thermal power in the environment without exposing people to burn injuries.

These safety functions shall be ensured even if the package is subjected to the regulatory drops.

# 3    Demonstrating the safety of a package with its transport frame

## 3.1    Simple reasoning, or avoiding unnecessary simulations…

The safety demonstration may partially rely on the simple comparison of the thicknesses of the subcomponents of the transport frame with respect to the diameter of the bar (150 mm) of the regulatory penetration test. In such a case, demonstrating that the transport frame will not penetrate the package boils down to demonstrating that the package withstands the regulatory penetration test, which has been already done, for instance with a numerical simulation and/or a real test with a mock-up.

## 3.2    Simulating…

Numerical simulations based on the Finite Element Method are of great help for analyzing complex phenomena that may occur when the package and its transport frame are coupled during a regulatory drop.

It is possible to evaluate:

- The maximum force exerted by the transport frame onto the package,
- The maximum deceleration of the package and its content,
- The stresses in the package body (useful for a brittle fracture analysis),
- The leak-tightness of the package (in terms of stresses and strains in the lid screws, residual opening between the lid and the body near the gasket, ovalization of the gasket plane),
- Or any other relevant result.

Such simulations are helpful for optimizing transport frames with "weak-link" components, such as shear pins, that are designed as force limiters and thus protect the supported packages from excessive loads in the event of a drop.

In the next section, numerical simulations performed with LS-DYNA® are presented and illustrate the main assumptions taken and the different phenomena at stake: energy absorption, rupture, force transmission toward the package.

# 4      First example of simulation
## 4.1   Presentation of the model

The 114.5-ton package is lying horizontally with its four trunnions supported by a road transport frame.

One fourth of the package has been modeled, only considering the end fitted with two lids, with two vertical symmetry planes (see Fig. 3 and 4).
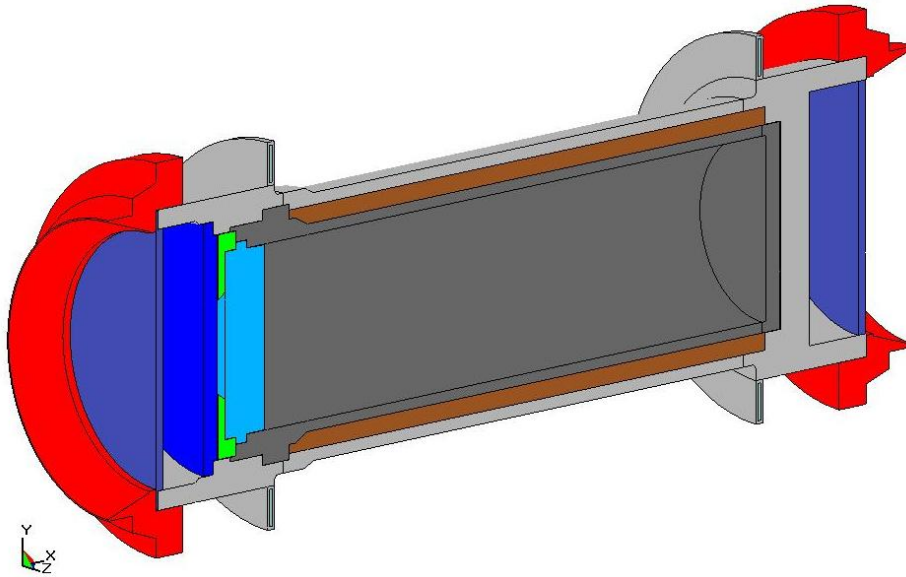


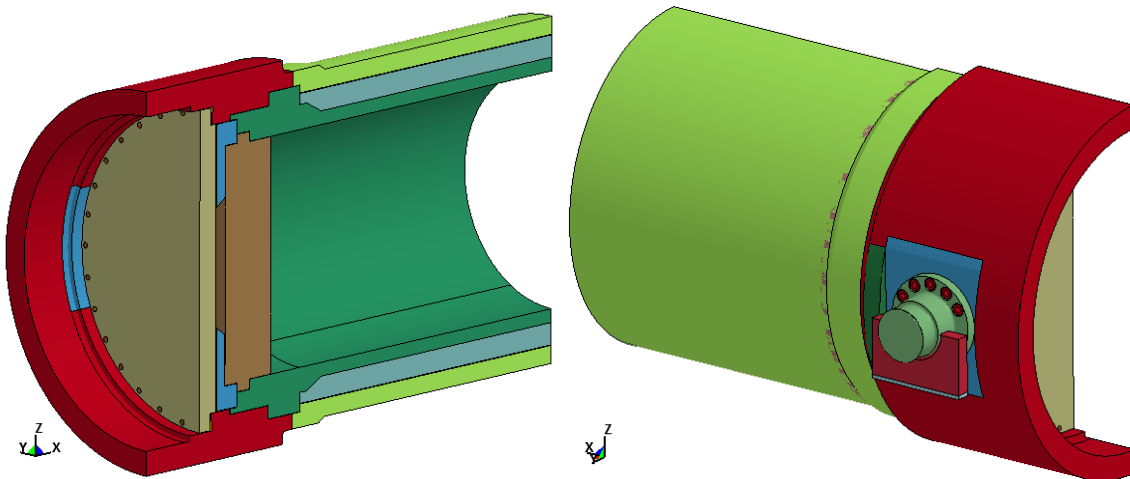Figure 3: geometry of the original FE model of the package.



Figure 4: geometry of the FE model of the package on its frame.

The geometry is meshed with 186,000 hexahedra. Depending on the area, the FE formulation is either one-point integration or eight-point, full, selectively reduced integration.

The metal parts are attributed an elastic-plastic constitutive law (*MAT_PIECEWISE_LINEAR_ PLASTICITY in LS-DYNA<sup>®</sup>).

The screws are tightened by artificially cooling down a layer of elements where a specific material is defined: an orthotropic material that has a non-zero thermal expansion coefficient only in the screw-axis direction.

Another layer of elements in each screw is attributed a rupture criterion (*MAT_ADD_EROSION): an element is eroded if the Von Mises stress reaches the true ultimate stress of the screw material. This criterion proved to induce the most delayed rupture with respect to other available criteria, which is conservative in terms of the force transmitted to the package.
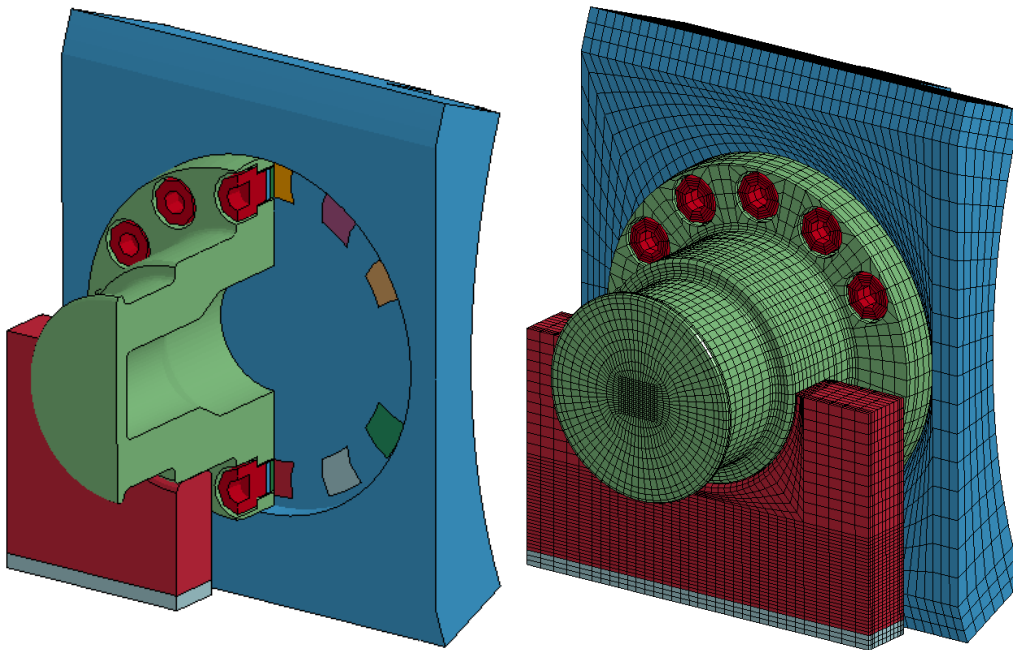


Figure 5: mesh of the trunnion (green), bolted on the package body (blue)
and lying on the upper end of the transport frame (red).

Only the upper end of the frame support is modeled, in contact with the trunnion. The rest of the frame is assumed to be rigid, conservatively overestimating the frame stiffness. It may also avoid the necessity of an exhaustive study of other frame designs, provided that their upper ends are similar to the one being studied.

The package is subjected to an artificial gravity field that increases linearly as a function of time until the rupture of the screws.

## 4.2   Main results

The rupture of trunnion screws (Fig. 6) limits the force and the moment transmitted to the package body. The force is illustrated by the vertical deceleration of the center of gravity (CG) of the package body, calculated as the difference between the body CG acceleration and the artificial gravity load (Fig. 7).

Acceleration peaks due to vibrations and gap opening/closing have a very short duration and the average deceleration is 38 g (plateau for 50 ms), much lower than the average deceleration in a regulatory 9m drop onto an unyielding target (order of magnitude: 160 g for 10 ms).
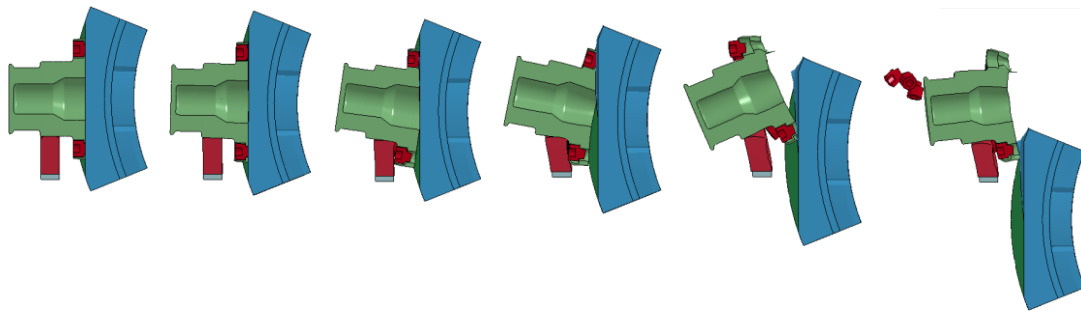
Figure 6: deformed mesh at times
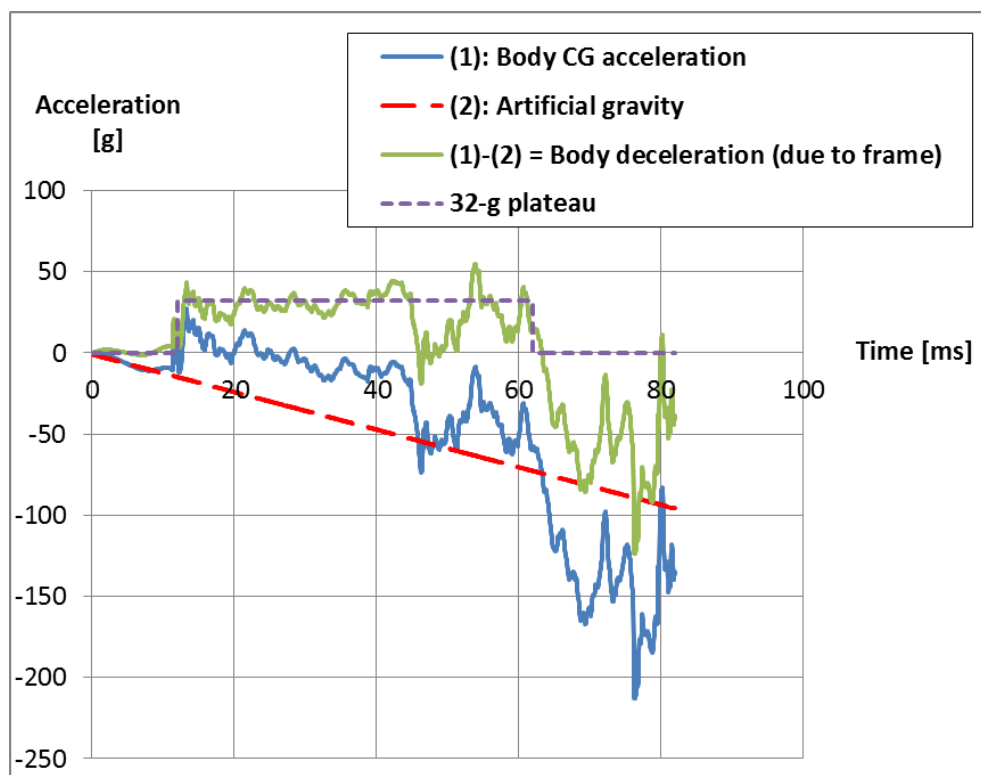0 ms, 44 ms (screws start breaking), 50 ms, 60 ms, 70 ms, 80 ms.



Figure 7: vertical deceleration of the body CG.

As a result of this low deceleration, the residual opening between the most internal lid and the body was found to be negligible.

The necessity of studying the drop of the package with its frame stems from the way the impact force is transmitted to the package: it is significantly different from the way the impact force is transmitted by the shock absorbers when the package is dropped onto a flat unyielding target. In particular, the frame applies onto the trunnion a force that induces a longitudinal bending moment in the side of the package body (see Fig 8).
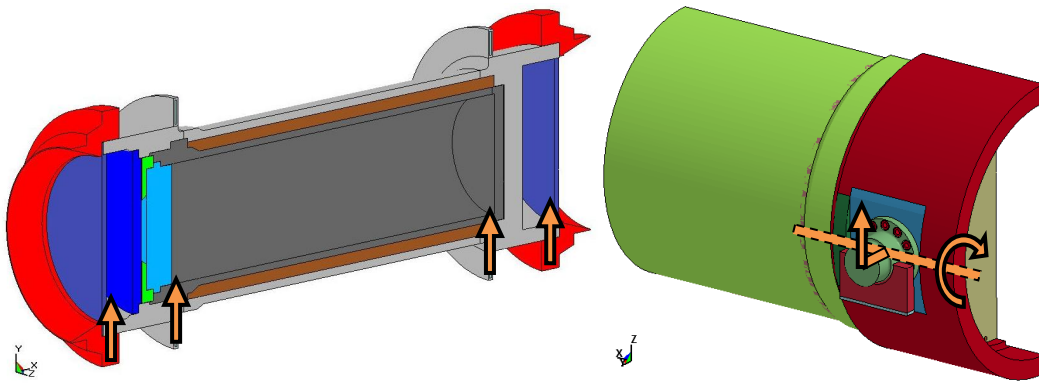
Figure 8: impact force transmission to the package – comparison between
a 9m drop of the package by itself (left) and a drop of the package with its frame (right).

# 5     Second example of simulation
## 5.1     Presentation of the model

The 80-ton package is lying horizontally with its four trunnions supported by a road transport frame.

One fourth of the package has been modeled, only considering the end fitted with two lids, with two vertical symmetry planes (see Fig. 9).
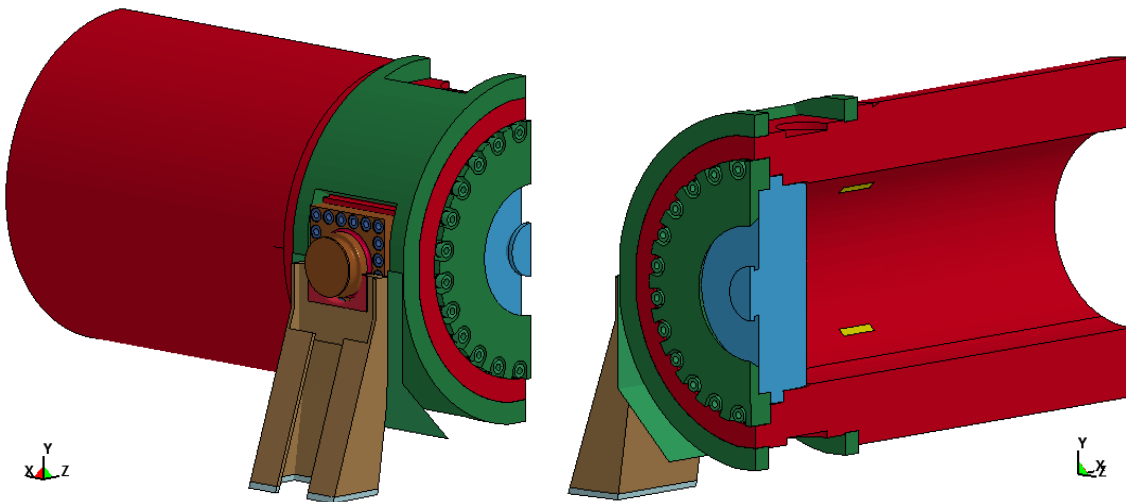


Figure 9: geometry of the FE model of the package on its frame.

The geometry is meshed with 201,000 hexahedra. Depending on the area, the FE formulation is either one-point integration or eight-point, full, selectively reduced integration.

The metal parts are attributed an elastic-plastic constitutive law (*MAT_PIECEWISE_LINEAR_ PLASTICITY in LS-DYNA®).

The 20 trunnion M42 screws are tightened by artificially cooling down a layer of elements where a specific material is defined: an orthotropic material that has a non-zero thermal expansion coefficient only in the screw-axis direction.

Another layer of elements in each screw is attributed a rupture criterion (*MAT_ADD_EROSION): an element is eroded if the Von Mises stress reaches the true ultimate stress of the screw material.

A rupture criterion (*MAT_ADD_EROSION) is also defined in an annular area of the trunnion and in its shear disk (Fig. 10). FE benchmarks of trunnion rupture tests concluded that this criterion is relevant.
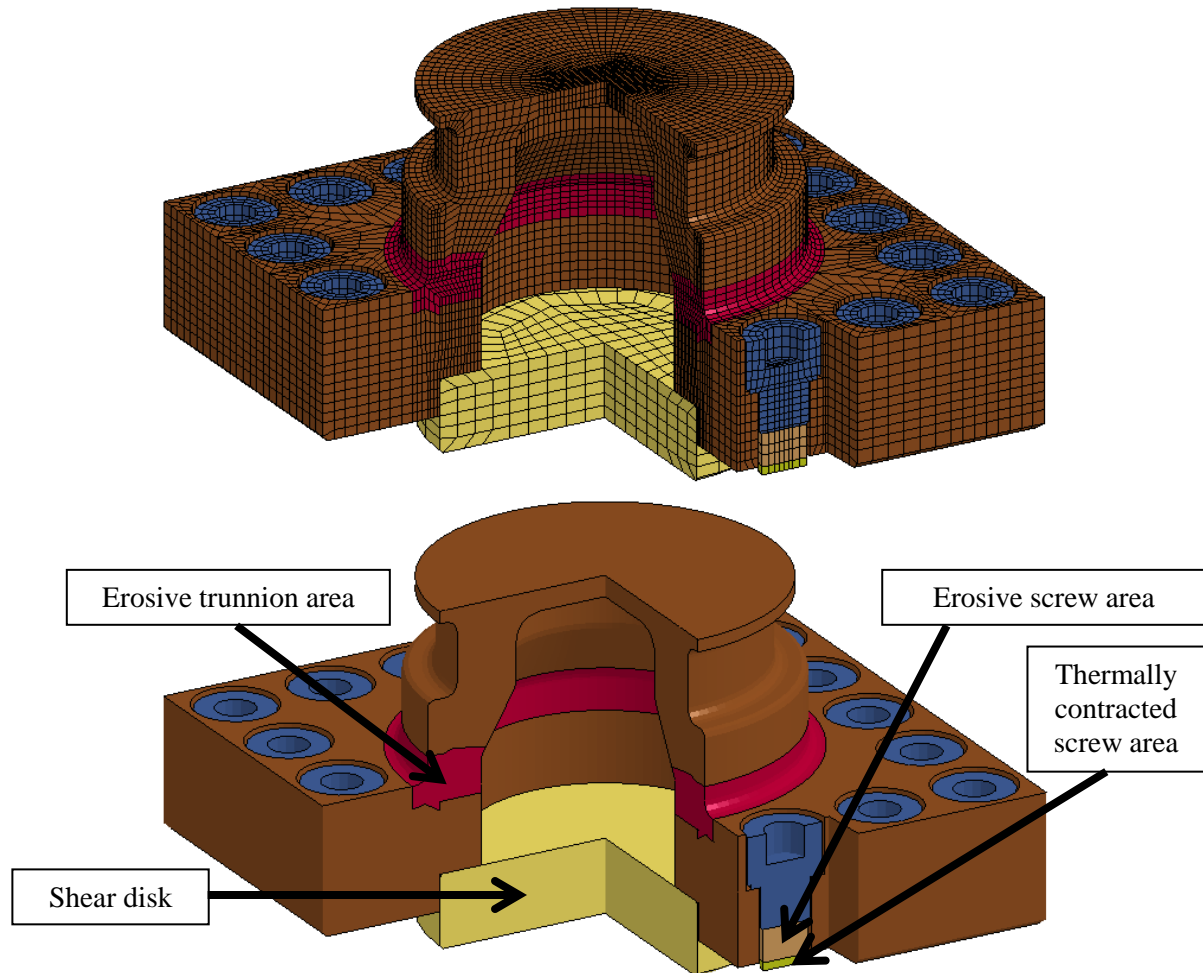


Figure 10: mesh of the trunnion, its shear disk and its screws.

The lower end of the frame support is clamped.

The package has an initial downward velocity of 13.3 m/s due to a 9m free drop.

## 5.2   Main results

No rupture is observed in the trunnion or in its screws.

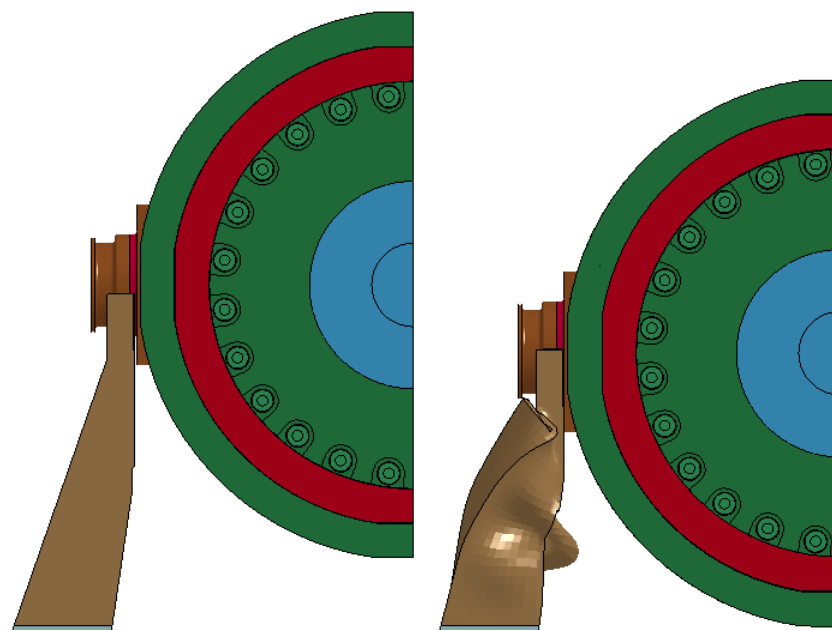The frame support is crushed (Fig. 11) and absorbs most of the energy (Fig. 12).

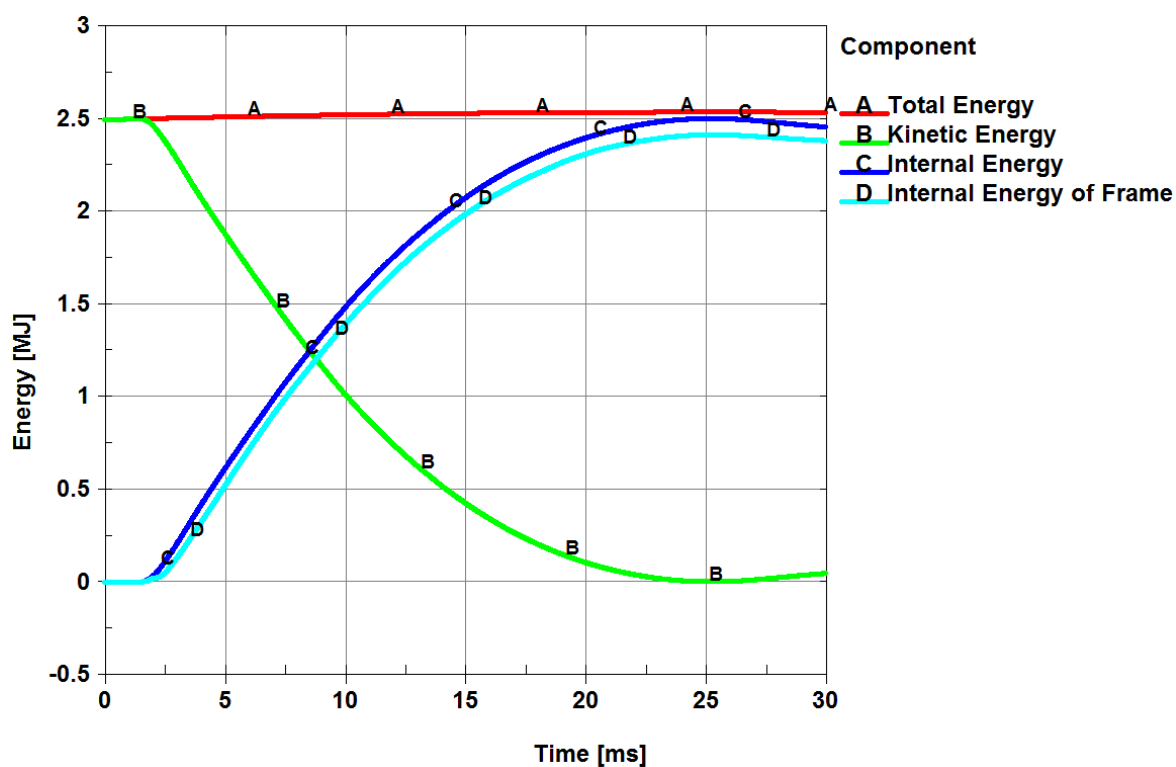Figure 11: initial and deformed mesh of the model.



Figure 12: time history of energies.

The frame acts as a force limiter.

As a result, the package deceleration is lower than in a regulatory 9m drop onto a flat unyielding target. The lid screws remain elastic. The maximum principal stress in the forged steel body is low enough as to exclude any risk of brittle fracture.

# 5      Another example of simulation… in a nutshell

In this simulation (Fig. 13), an oblique drop is studied. The lower ends of the two frame supports are linked to each other thanks to a rigid body.
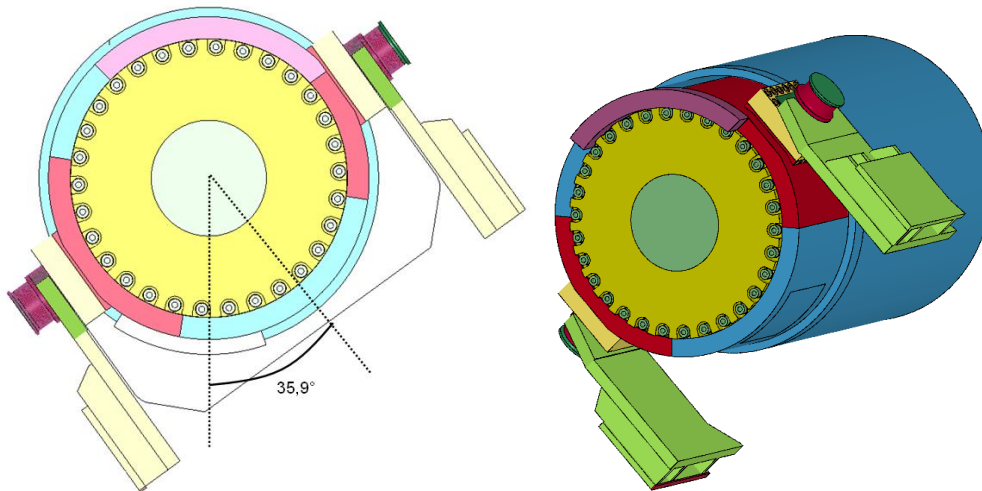


Figure 13: oblique drop – geometry of the FE model of the package on its frame.

Modeling the support opposite to the impacted side is necessary in order to account for its guiding role, as long as the trunnion does not slide off it, as shown in Fig. 14.
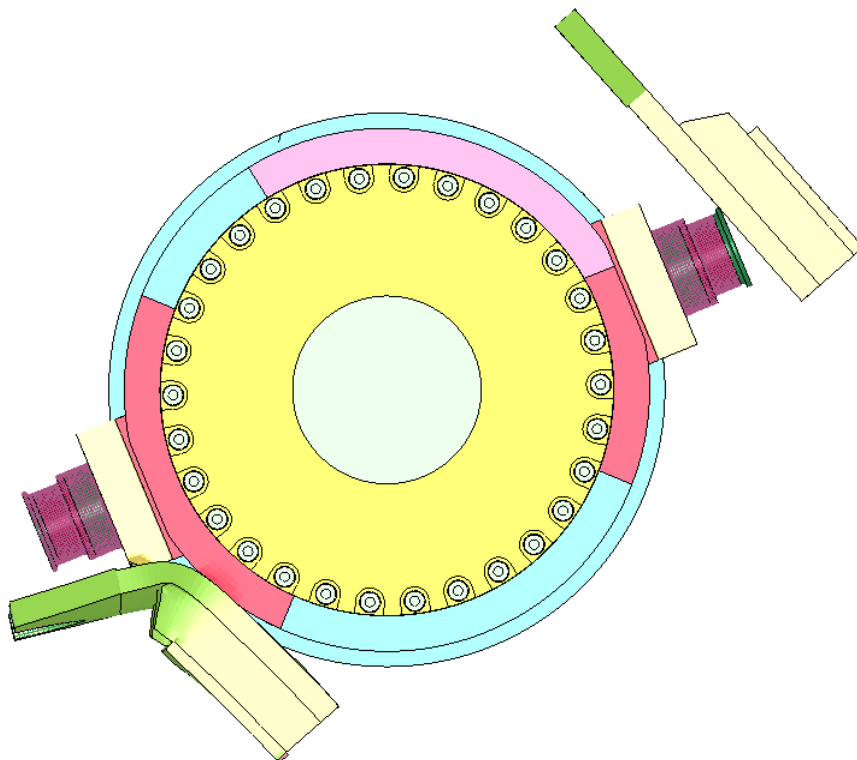


Figure 14: deformed mesh of the model.

# 6      Conclusion

When demonstrating the safety of a radioactive material package according to the IAEA "Regulations for the Safe Transport of Radioactive Material", it is required to account for transport frames in the drop scenarios specified by these regulations. Indeed, the transport frames might impair some safety functions of the package, even if the package by itself withstands the drop scenarios.

For that purpose, AREVA TN applies a long-proven methodology based on simple reasoning as well as numerical analyses with LS-DYNA®, along with conservative assumptions.

# References

[1] International Atomic Energy Agency (IAEA), Regulations for the Safe Transport of Radioactive Material (2012 Edition) – Specific Safety Requirements – IAEA Safety Standards Series No. SSR-6, Vienna, Austria, 2012.

[2] International Atomic Energy Agency (IAEA), Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition) – Specific Safety Guide – IAEA Safety Standards Series No. SSG-26, Vienna, Austria, 2012.