LS-DYNA® APPLICATION TO DEVELOP A PACKAGE FOR AIR TRANSPORTATION OF FISSILE MATERIALS

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Object of computer study is a package for FM storage and transportation based on a container AT-400R [1].

Shock and fire resistant container AT-400R was designed at Sandia National Laboratories (USA) and was tested by US and Russian specialists in compliance with the IAEA regulations [2], including cases of flooding, falling of a slab with mass 500 kg from the height of 9 m, container dropping from the height of 1 m onto the pin 150 mm in diameter. In the frames of the ISTC projects # 1216 and 1449, performed computation proved that the IAEA regulations to safe transportation of FM are met. Besides, computation determined limited loading, when 500 kg slab falls from the height of 50 m and freefall of the container from the height of 50 m. When this limited value of loading is outranged, inner containment vessel looses tightness.

The objective of this work is to develop a package, based on this container, for FM air transportation, which will provide FM pressure-sealing in conditions that are regulated by up-to-date IAEA requirements – package collision with a target at a velocity 90 m/s.

Actual character of this problem solution is related to sufficient advantages of air transportation: low cost effectiveness in comparison with other types of transport and higher safety, which is provided by corresponding selection of air routes, quick transportation, better protection against terrorism.

For solving the problem of FM air transportation meeting safety requirements, a package was developed on the basis of protective container AT400R, using numerical modeling. In case of transportation by a vehicle or by rail way, for the sake of protection against fire, bullets and fragments, the package is put in transport protective block (TPB). TPB was built in the frames of an "Agreement between RF Government and US Government regarding safety and reliability of FM transportation and storage" (1992) and "Memorandum on cooperation of RF Minatom and US DOE National Laboratories" (1997) [3].

Using calculation and experiment, US and Russian specialists confirmed that container AT400R meets practically all safety requirements: it provides heat protection, moisture protection, protection against vibration impacts under normal conditions of transportation; it provides tightness of protected cargo (PC). PC is FM (MOX fuel), which is transported under regulated emergency impacts such as falling from a height 9 m, dropping of a slab on the package, falling on a pin, flooding [4].

In the frames of the ISTC project # 1216, limited loading, whose exceeding leads to inner containment vessel depressurization, were determined. Using numerical modeling and LS-DYNA [5], it was shown that 500 kg slab falling from the height of 50 m and container free falling from a height 50 m (shock velocity 31,3 m/s) leads to inner containment vessel seal failure. Containment vessel lid opens, strength of container body is violated, FM pressurizing shell (armour) is broken (Fig. 1).

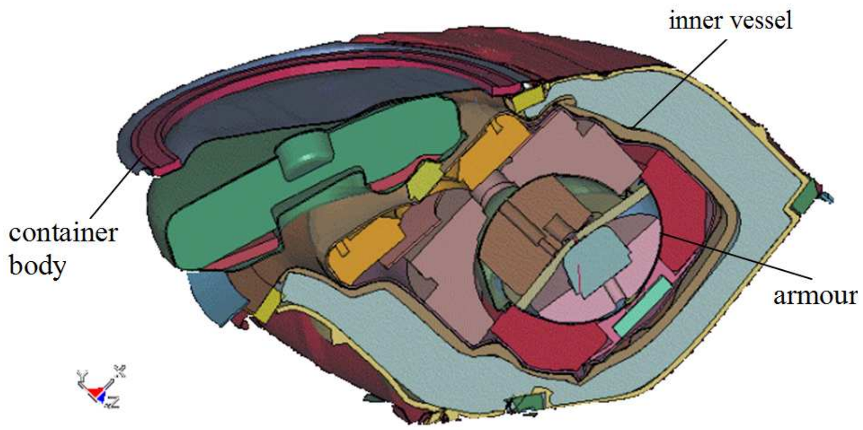


Fig.1 Deformed state of container, when a slab falls from the height of 50 m

In earlier days, the problem of providing FM tightness under package collision with a barrier at a velocity 90 m/s was not solved.

In performed activities for providing AT 400R-based packages meeting the requirement of FM tightness under collision with a target at velocity 90 m/s, we undertook measures to improve resistance to shock impacts.

The first direction of our measures is related to modernization of TPB, which plays the role of external damper in impacts under study. Free space of TPB internal cavity was filled by elements out of wood and foam plastic. This leaded to restriction of package free movement and absorption of shock impacts under emergency situations (Fig. 2).

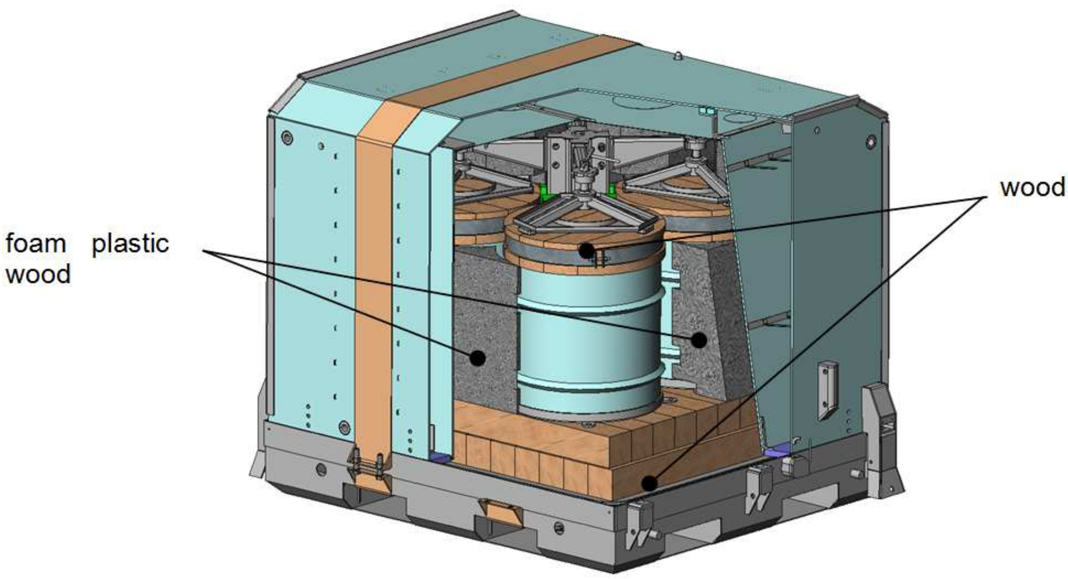


Fig.2 Scheme of TPB with packages

The second direction of design resistance improvement was related to modernization of a package. It was proposed to put FM in capsule – additional pressurizing element. Between a inner containment vessel and protective layers, as well as between FM and capsule, force layers are put, which strengthen pressurizing shells (Fig. 3). Selection of force layers (materials and shell thicknesses) was made from condition of package strength balance under falling in various directions.

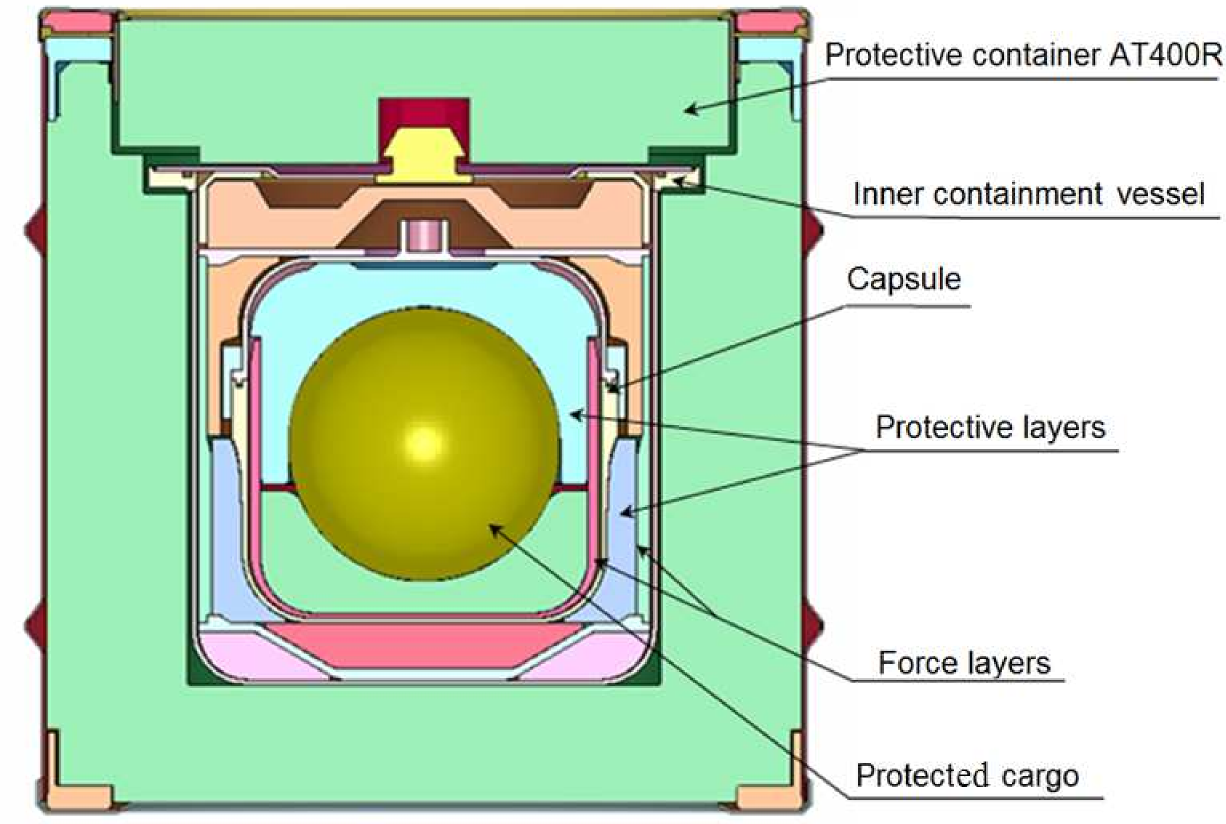


Fig.3 Scheme of the package with FM

It is necessary to note that introduced changes deal only with modernization of protective layers, i.e. they do not touch container design and do not influence its protective functions.

Using LS-DYNA, full-size modeling of design behavior for all types of impacts was run. Finite element mesh was formed with 8 node volume elements *ELEMENT_SOLID and shell elements *ELEMENT_SHELL were used for the cask and the lid. Contacts between parts were treated by setting up surface-to-surface interfaces. Elastic-plastic properties of the materials were defined by *MAT_PLASTIC_KINEMATIC model with bilinear diagram.

Fig. 4 shows our finite-element model of the package.

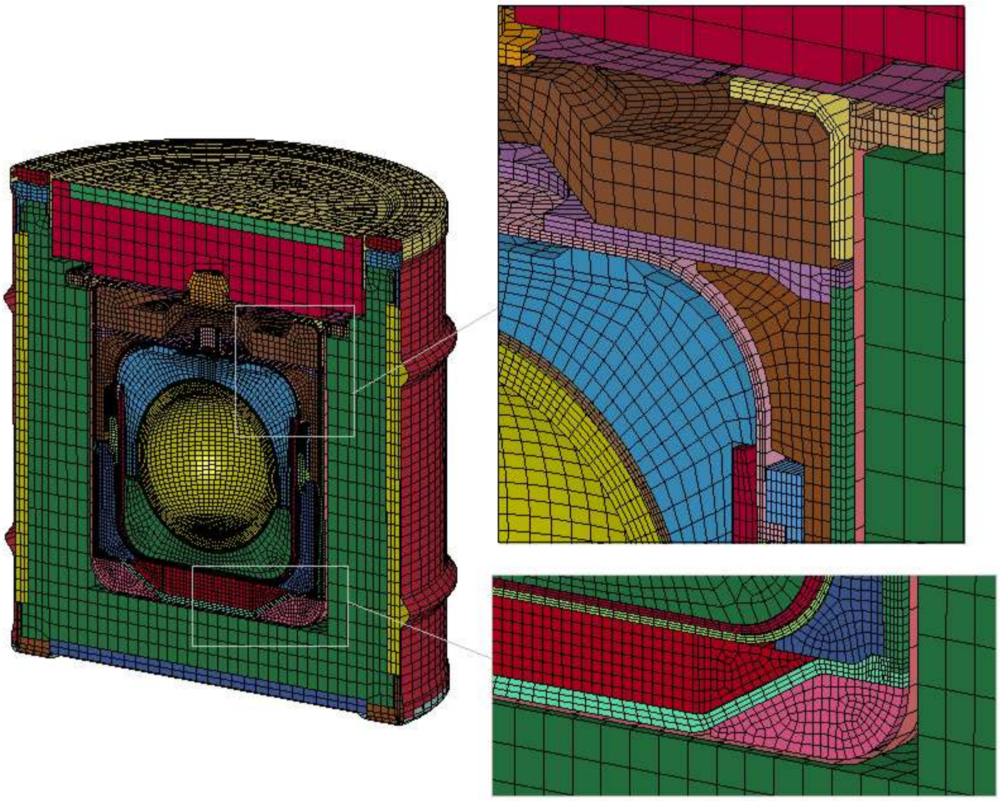
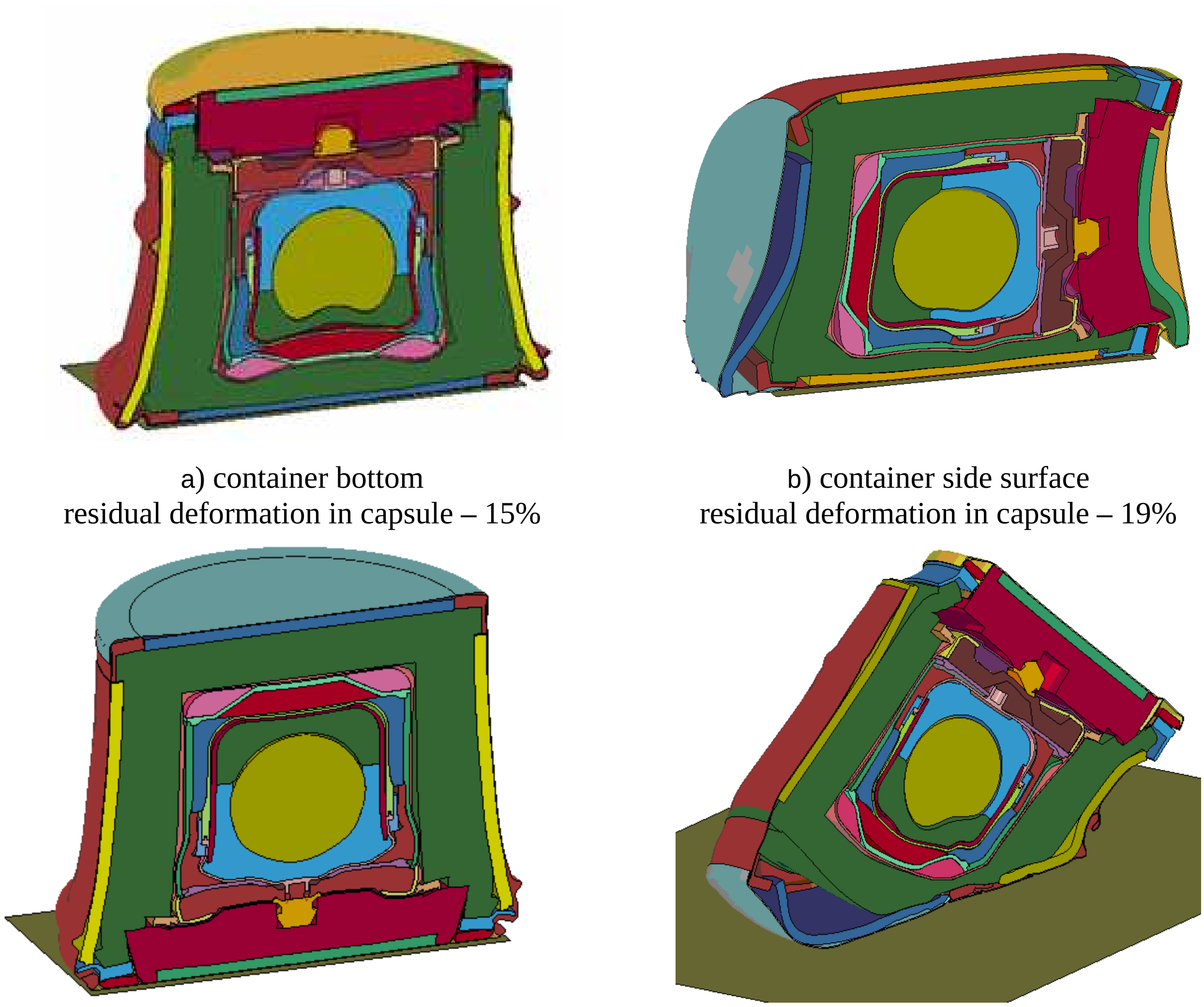


Fig.4 Finite-element model of the package

Fig. 5 shows deformed states of the package, which were obtained by the results of numerical modeling, after collision of package with a target at a velocity 90 m/s in various direction of a shock.

Graphs of predicted accelerations of protected cargo under package collision with a target at a velocity 90 m/s are shown in Fig. 6.



a) container bottom
residual deformation in capsule – 15%

b) container side surface
residual deformation in capsule – 19%

c) container lid
residual deformation in capsule – 20%

d) container corner
residual deformation in capsule – 20%

Fig. 5 Package collision with a target at a velocity 90 m/s

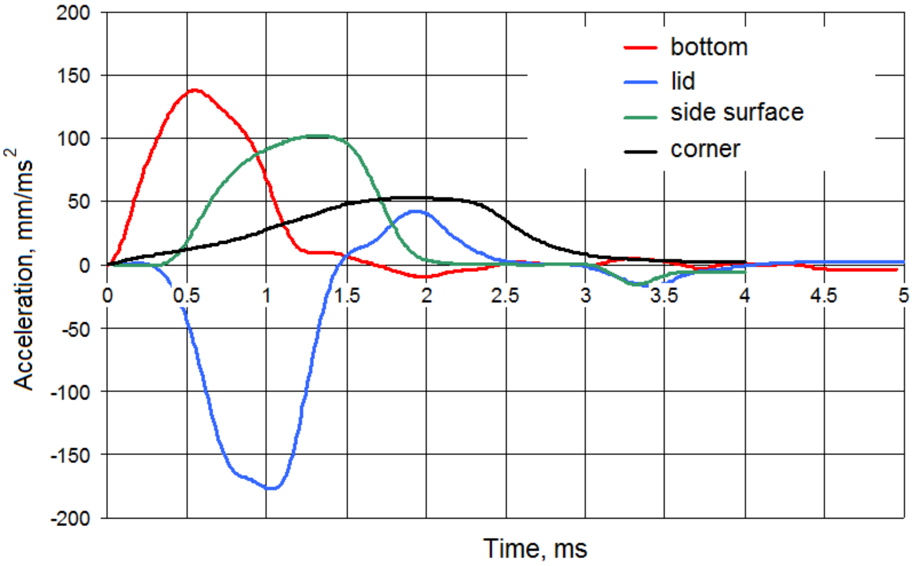
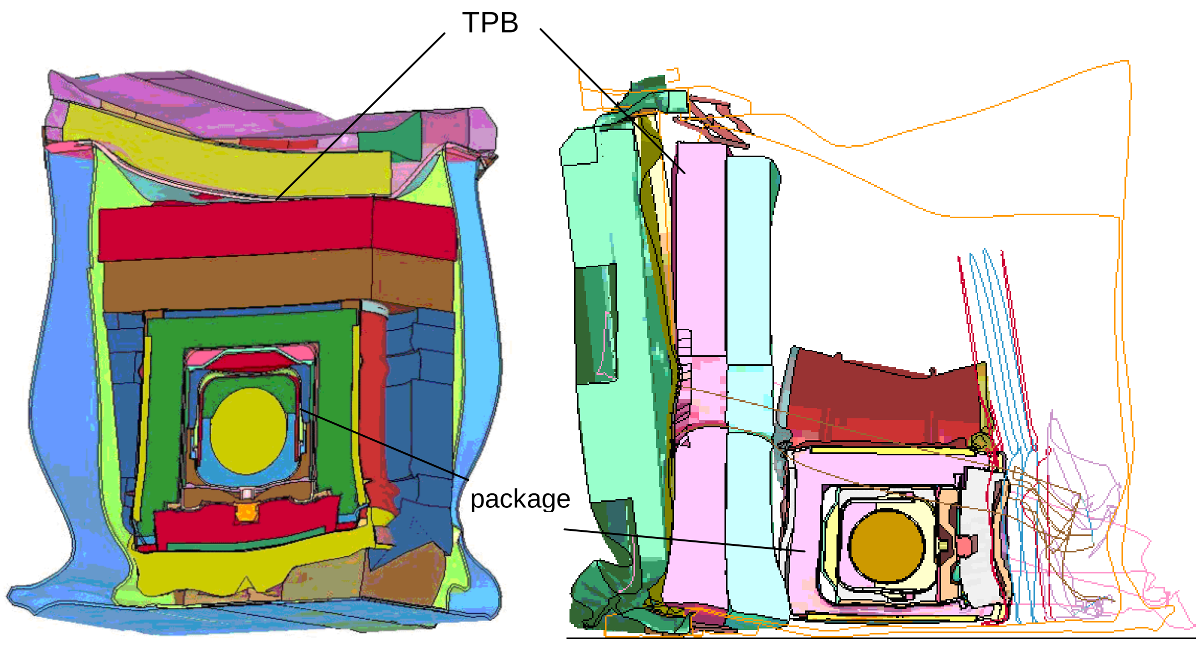


Fig. 6 PC accelerations under package collision with a target at a velocity 90 m/s

According to the results of numerical modeling, a conclusion was made that maximum damage of package sealing system is made in case of target contact with container side surface. Maximum deformations in capsule are concentrated in the region of pressurizing joint – in lock joint zone.

Analysis of performed calculations of packages in TPB content showed that TPB sufficiently decreases loading of packages with FM in the conditions of emergency impacts (Fig. 7).



a) falling on the roof

b) falling on the side

Fig. 7 Deformation of TPB elements and package

Studies made in LS-DYNA permitted to optimize package location in TPB. In order to exclude impact of packages one on another, in one TPB, instead of four packages, only two were located along diagonal line (Fig. 8).

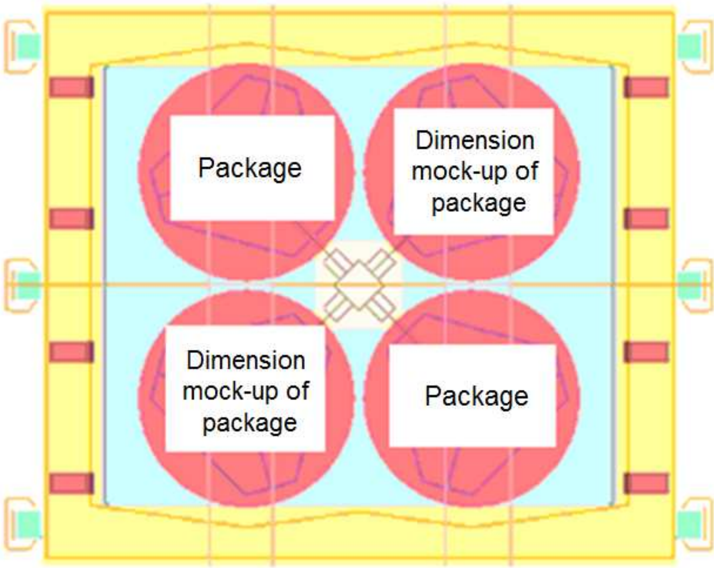


Fig.8 Scheme of package location in TPB

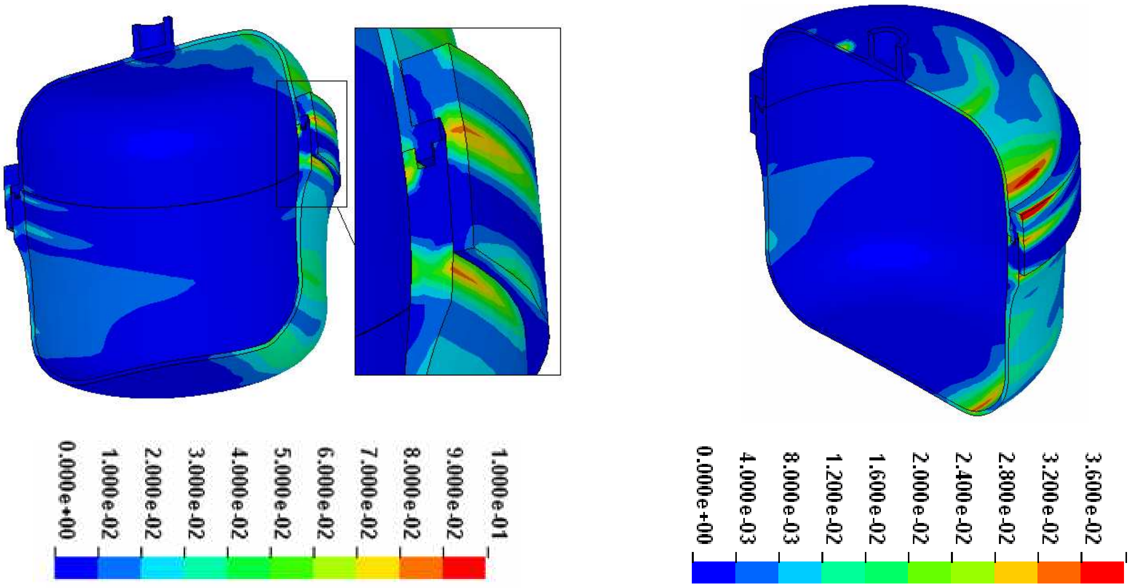
According to the results of numerical modeling, states of TPB with packages under various directions of contact with target (falling on the bottom, on the lid, on the corner and on the side) the following conclusions were made:

— the worst version is side loading of TPB;

— maximum residual deformations in capsule ε = 5%- 10% (depending on a shock direction) do not exceed limit of uniform deformation of material;

— capsule and inner containment vessel is preserved;

— availability of all sealing elements is also preserved.



a) package is located from the side of a shock b) package is located from the opposite side of a shock

Fig.9 Plastic deformations in the capsule

As far as maximum loading of packages and their sealing systems takes place upon TPB side contact with a target, for this case of loading, experiment was performed for TPB collision with a target at a velocity 90.2 m/s. (Fig. 10).

Fig. 10 Appearance of packages in TPB content after experiment

Survey of defects showed that pressurizing joint of inner vessel and capsule was not deformed. Capsule is slightly deformed (Fig. 12).

a) package is located from the opposite side of a shock

б) package is located from the side of a shock

Fig. 11 Appearance of packages after experiment

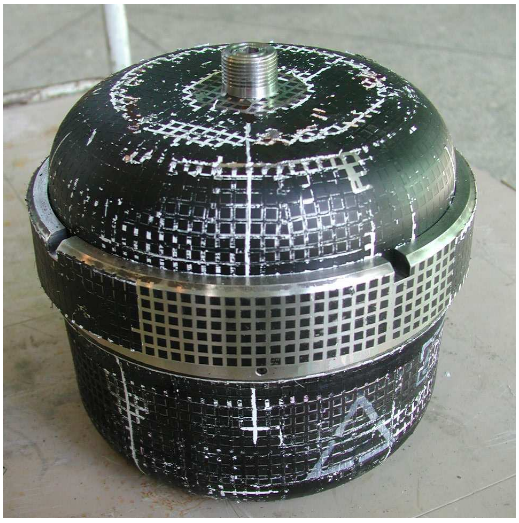


Fig. 12 Appearance of the capsule after experiment

While checking inner vessel and capsule tightness by residual pressure 0,03+0,01 MPa, there was no pressure drop.

Survey of defects after experiment showed that all force and pressurizing layers under deformation preserve their strength (integrity). Performed studies proved inner vessel and package capsule tightness after shock.

On the basis of performed computation and experimental activities, it is possible to make the following conclusions:

- This approach to the development of a package design supported by numerical simulation using LS-DYNA permitted to build a structure that provides meeting the IAEA regulations in case of FM air transportation.
- The results of numerical modeling are in good agreement with experimental data (Fig. 13 and Table 1).

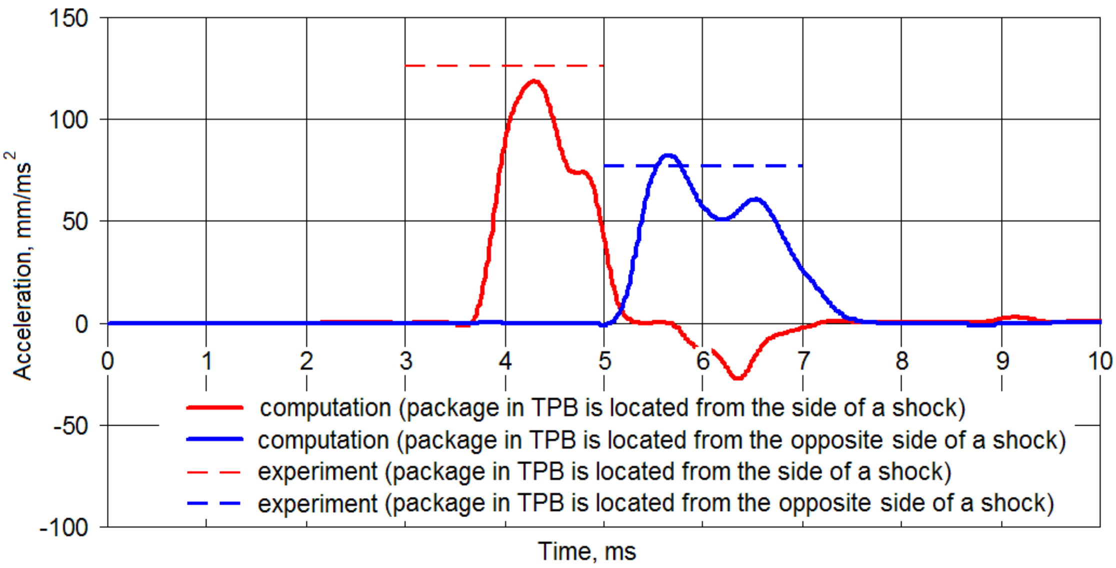


Fig. 13 Accelerations of protected cargo under TPB side collision
with a barrier at a velocity 90 m/s

Table 1

	Experiment	Calculation	Difference
Package in TPB is located from the side of a shock	126 mm/ms^2	117 mm/ms^2	7.1%
Package in TPB is located from opposite side of a shock	77 mm/ms^2	81 mm/ms^2	5.2%

Thus, using calculation, a package was designed, which meets all the IAEA safety regulations, including requirements to air transportation.

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