Estimation of terrorist attack resistibility of dual-purpose cask TP-117 with DU (depleted uranium) gamma shield

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Abstract

Report is devoted to numerical research of dual-purpose unified cask (used for SFA transportation and storage) resistance to terrorist attacks. High resistance of dual-purpose unified cask has been achieved due to the unique design-technological solutions and implementation of depleted uranium in cask construction. In suggested variant of construction depleted uranium fulfils functions of shielding and constructional material. It is used both in metallic and cermet form (basing on steel and depleted uranium dioxide). Implementation of depleted uranium in cask construction allows maximal load in existing overall dimensions of the cask. At the same time: 1) all safety requirements (IAEA) are met, 2) dual-purpose cask with SFA has high resistance to terrorist attacks.

1. Introduction

In spite of all precautionary measures during transportation of cask loaded with SFA we can not exclude the possibility of terrorist attacks against them.

Currently, alongside with usual weapon (submachine guns AKM, sniper rifle), terrorist groups can also have hand antitank grenade cup discharge (RPG) with depth of penetration through armor up to 400mm, as well as chemical explosives.

In that case transporting packages for transportation and storage of SFA must provide necessary resistance to action of usual weapon, hand antitank grenade cup discharge and chemical explosives.

The main aim of conducted investigations is to estimate resistance of dual-purpose unified cask TP-117 to specific influences (terrorist attacks) The following initial effects were considered during performing numerical researches of TC-117 resistance against terrorist attacks:

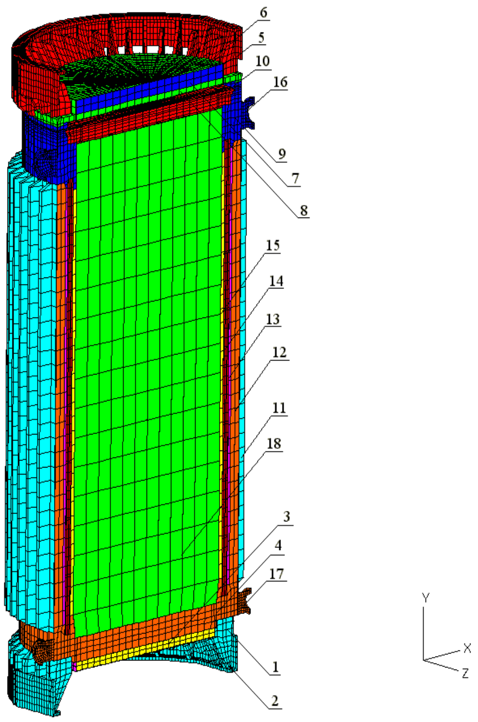
- Collision of the falling airplane with vertically standing container at angle of 10^0 and velocity V=100m/s.

Loading of vertically standing container with fragments of the falling airplane was assumed as beyond-design-basis accident. In numerical calculations air-engine module (the most massive element of airplane) was selected to play a part of airplane fragments:

- Shooting through vertically-staying cask from sniper rifle by incendiary bullet BZ-2 of caliber 12.7mm. The bullet interacts with side surface of the cask along the normal. We consider only armor-piercing effect of the bullet heart. This case is the most severe, when the highest depth of punching through cask casing is reached;
- Shooting through vertically-staying cask from hand antitank grenade cup discharge by cumulative grenade of caliber 90mm;
- Shooting through train car-cask loaded with TC from hand antitank grenade cup discharge by cumulative grenade of caliber 90mm;
- Detonation of explosive having weight of 50kg placed on lid of vertically-staying cask.

Conducted investigations of stress-strain condition of TP-117 construction and estimation of its resistance to terrorist attacks were carried out using numerical procedures developed at RFNC-VNIIEF. These procedures are based on Lagrangian and Eulerian methods.

Conducted investigations of stress-strain condition of TP-117 construction and estimation of its resistance to terrorist attacks were carried out using mathematical models shown on Figures 1-3.



TC-117 components:
1 – bottom damper;
2 – facing;
3 – bottom neutron shield;
4 – bottom;
5 – cover damper;
6 – facing;
7 – cover neutron shield;
8 – external shielding cover;
9 – coaming;
10 – internal sealing cover;
11 – external body coating with lateral damping ribs;
12 – lateral neutron shield;
13 – intermediate load-bearing coating;
14 – γ-shield (U^{238});
15 – internal load-bearing coating;
16 – lifting trunnion;
17 – tilting trunnion;
18 – basket with SFA.

Fig. 1. Summarized computer model of TP-117 for air accident modeling

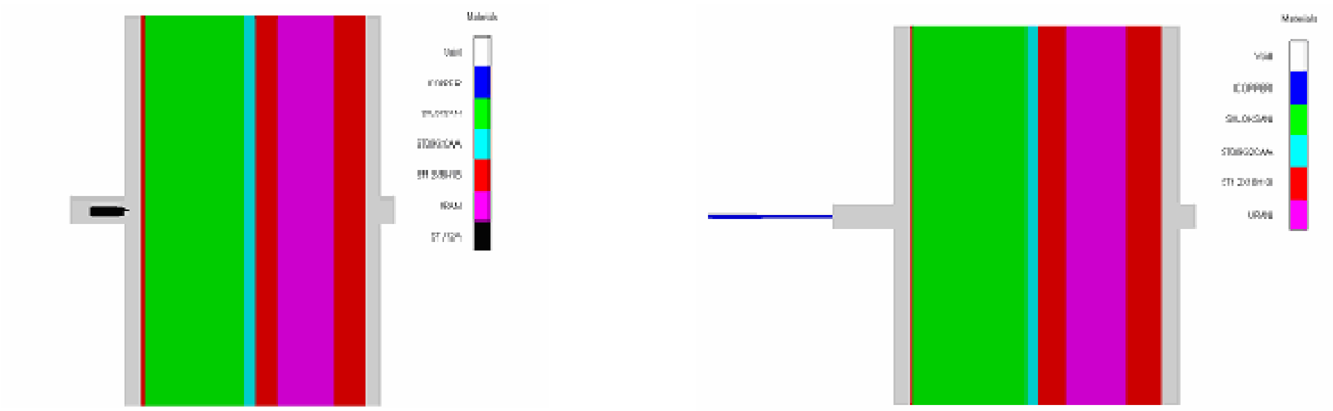


Fig.2. Computer model of TC-117 fragment for case of shooting through it by bullet BZ-2 and grenade cup discharge RPG

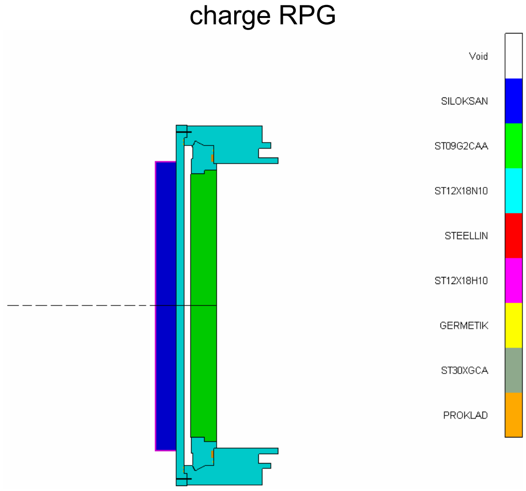


Fig.3. Computer model of TC-117 fragment in zone of arrangement of coaming and lids for case of loading by explosion products of HE.

2. Numerical estimations of TP-117 construction resistance to terrorist attacks.

2.1. Numerical estimations of cask resistance (stability) to the falling airplane collision at angle of 10^0 and velocity V=100m/s.

As a result of airplane impact on vertically-staying cask, the last acquires forward speed in the direction of the impact. The average speed of cask movement (as a single whole) is near 8 m/s. Elasto-plastic deformation of shock absorbing system elements installed on the external lid occurs in the process of airplane collision. The level of plastic deformations in the external lid does not exceed 31%. At the same time plastic deformations are formed only in the area of impact at an angle of 53^0. Outside the area the elements of shock absorbing system and cask external deck are deformed elastically.

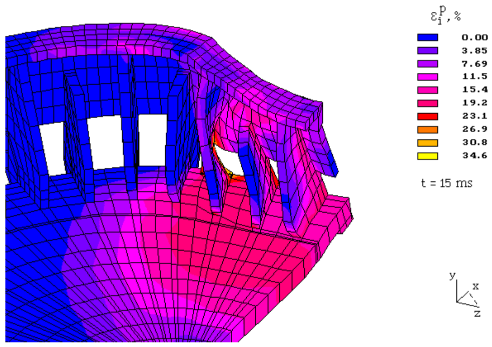


Fig. 4. Numerical field of plastic deformations intensity values distribution in the elements of container damping system and protection lid.

Coaming local contortion occurs in the area of impact, maximal value of plastic deformation intensity is 39%.

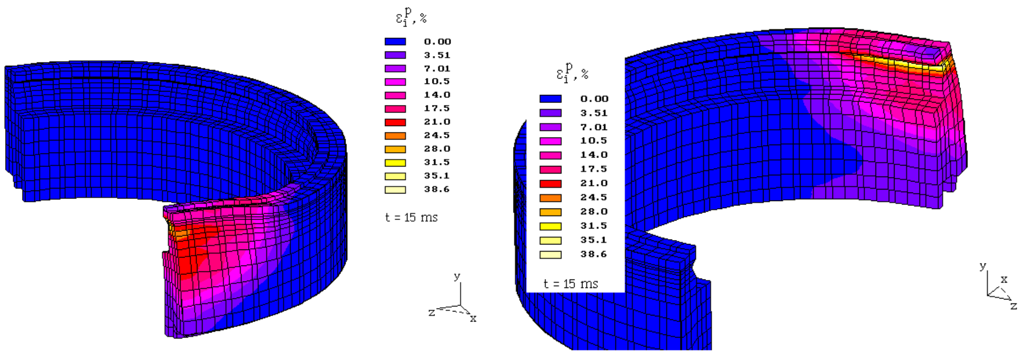


Fig. 5. Numerical field of distribution of plastic deformation intensity values in container coaming.

A local area of plastic deformations also forms in the cask internal lid, the level of plastic deformations reaches 26%. The maximal value is obtained close to the edge of the lid on the spot of its wedge strengthening at the angle of 30^0. Outside this area internal deck is deformed elastically.

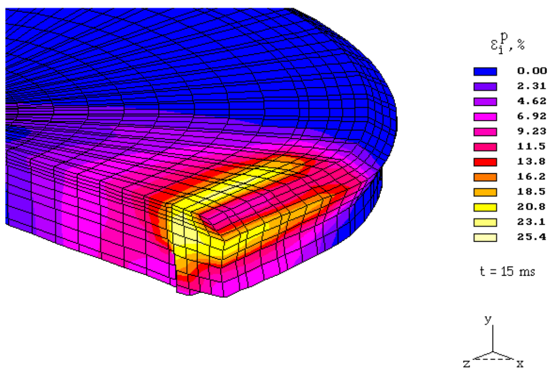


Fig. 6. Numerical field of plastic deformations intensity values distribution in the internal lid of the container.

Top value of g forces obtained on the basket with SFA was 300 units, this value is lower than the highest possible value of 400 units at which the process of fuel rods destruction begins. Thus on the basis of calculations it could be concluded that TP-117 is deformed elastoplastically without its basic construction elements destruction. The cask keeps its tightness.

2.2. Estimations of cask resistance to sniper rifle shooting by rifle by incendiary bullet of caliber 12.7mm.

Numerical researches of TC-117 deformation dynamics at shooting through by incendiary bullet were performed with use of computer model given in fig.2. Results of the calculations as deformed configuration of side wall of TC-117 casing are given in fig.7.

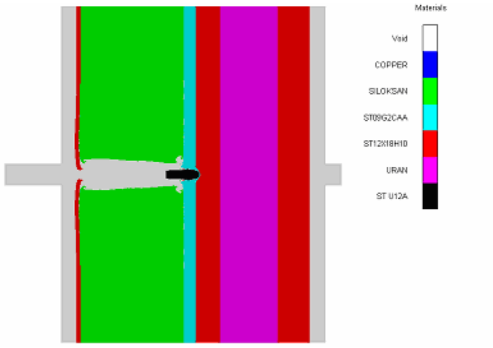


Fig.7. Final deformed state of side wall of cask at time of bullet stop.

The calculation results show that, at the first stage, actually without deformation, easily penetrates the outside shell of cask casing, forming a hole in it with radius of about 6mm.

Further, at the second stage, also actually without deformation, bullet penetrates solid neutron protection of the cask. Its initial velocity drops to ~ 653m/s (Initial speed 820m/s). In material of solid neutron protection (siloxane rubber), a cavity with radius of 20mm is formed along the bullet motion.

At the last stage the bullet having actually zero speed stops at the external cover of uranium casing without shooting through it. So, shooting through TC-117 from sniper rifle by armor-igniting bullet BZ-2 of caliber 12.7mm even in most severe case does not cause destruction of the load-bearing casing of TC-117, and the cask keeps its sealing.

2.3. Numerical estimations of cask resistance to shooting trough it by hand anti-tank grenade cup discharge of caliber 90 mm.

Numerical researches of dynamics of TC-117 deformation at shooting through it by cumulative grenade were performed using computer model given in fig.2. The following cases of possible shooting through the cask:

- Shooting through the cask from its side surface;
- Shooting through the cask from the bottom side;
- Shooting through the cask from the lid side;
- Shooting through the cask located in train car from its side surface.

Calculations show that shooting through the cask from its side surface is the most severe case. This is the reason why this case of cask loading is considered below. The calculation results in the form of deformed configuration of the TC-117 body side are shown for the case of shooting through the cask from its side surface in fig. 8, 9.

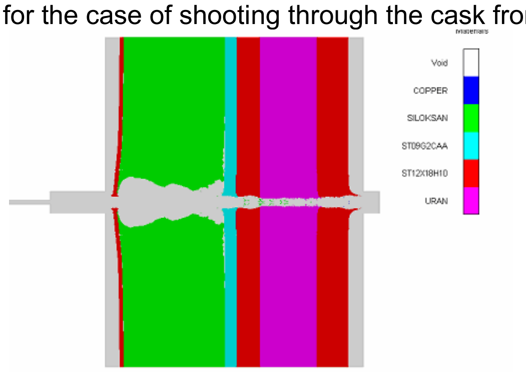


Fig.8. Final deformed state of side wall of cask at time of shooting through it by shaped jet.

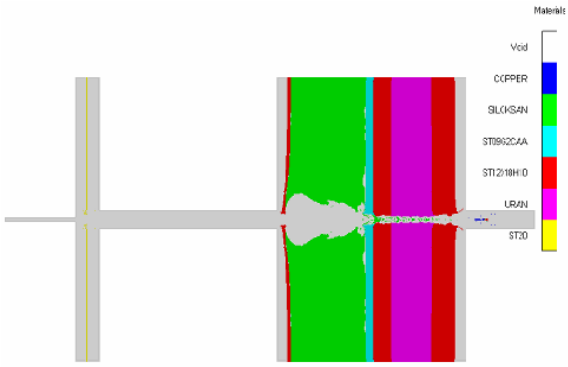


Fig.9. Final deformed state of side wall of cask at time of shooting through it by shaped jet.

As it follows from calculation results presented in fig.8, 9, during piercing the external shell of the cask and low-strength solid neutron protection, shaped jet gets heterogeneous structure both in length and radius. The internal boundary of the cavity formed in material of the neutron protection has the wave-like shape. Diameter of hole in the external shell of the cask casing is equal to ~ 13mm, diameter of the cavity in neutron protection is ~ 20-30mm. After shooting through the external shell of load-bearing casing of the cask, part of material of the neutron protection located on internal surface of the cavity moves to its center and effects on the jet causing perturbations and fragmentation in this zone (at distance of about 50 mm).

Fragmentation of shaped jet becomes stronger, as it approaches the internal shell of the load-bearing casing of the cask. It actually turns completely to dust at some sites, in particular, in the zone of shooting through uranium shell due to strong interaction of jet and uranium particles of comparatively small diameter (about 10mm). Due to fragmentation and loss of continuity of shaped jet, its piercing effect drops. Total shooting through all shells of cask casing occurs at time, when velocity of the rest of flying jet particles is less 2000m/s (Initial speed 7000m/s). So, small quantity of pulse energy is left in shaped jet at time of shooting through side wall of the cask. Diameter of hole made by jet in the internal shell of load-bearing casing of the cask is less ~ 13mm.

During effect of shaped jet, steel shells of the cask casing are plastically deformed. Zone of plastic strains in them occurs at diameter of ~ 200mm, deformations of all elements of the cask have elastic character out this zone. Shell made of uranium (gamma-protection) is plastically deformed. Zone of plastic strains in it occurs at diameter of ~ 50mm, deformations have also elastic character out this zone.

Presence of train car wall does not change the picture of loading and deformation of the cask casing itself (fig.9). The sidewall of the cask is also shot through by shaped jet of grenade. The only difference is that there is increase of length of shaped jet effecting on the cask due to initial gap between sidewall of train car and the cask. Increase of jet length results in that sufficient quantity of energy ~ 15.98kJ is left in shaped jet after shooting through sidewall of the cask. It corresponds to ~ 10.1% of initial energy for further deformation and destruction of heat-releasing assemblies placed in the cask.

2.4. Evaluation of radiological consequences of shooting through TC-117 loaded with SFA from reactor WWER-1000 by cumulative grenade of caliber 90mm.

According to results of the calculations, casing TC-117 is shot through for sure under effect of cumulative grenade of caliber 90mm. Shaped jet enters the internal cavity of the cask with velocity of ~ 2.0km/s is fragmented for many particles, which further effect on SFA from WWER-1000 placed in the internal cavity of the cask.

Due to this reason, we performed evaluation of radiological consequences of shooting through TC-117 loaded with SFA from WWER-1000 by cumulative grenade of caliber 90mm.

Radiation status of location, where terrorist act with shooting through TC-117 occurred, is determined by the following scales for long time after considered accident:

- scales of transuranium elements – isotopes of plutonium, curium-244, and americium-243. According to the level of territory pollution by these radionuclids, limitations are used concerning living of people at polluted territory, because of inhalation penetration of radionuclids into human organism not only during release cloud passing, but also due to resuspension (i.e. dusting of aerosols in the later time).
- scales of release of cesium-134 and 137, strontium-90 and americium-241. For evaluation, it is possible to be limited by account for releases of cesium-137. According to the level of territory pollution with radionuclid cesium-137, limitation is used concerning agricultural products of local production used for eating.

Results of the calculations are described below.

Evaluation of sizes of the zone, where limitations of agriculture activity should take place, was performed with account for the criterion applied after the accident at Chernobyl' NPP. It is forbidden to use locally cultivated products, if the level of territory pollution with caesium-137 exceeds $5.6 \cdot 10^5$ Bq/m^2 (0.17 micrograms/m^2). The size of the territory where this criterion is exceeded is equal to ~ 5.4 km^2, the size of polluted territory is equal to ~ 1.35 km^2.

Evaluation of sizes of the zone, where population should be removed from, was also performed with account for the criterion applied after the accident at Chernobyl' NPP. It is forbidden to live at polluted territory, if the level of territory pollution with plutonium-239 exceeds $3.7 \cdot 10^3$ Bq/m^2 (20 decays/min*m^2). According to this criterion, size of polluted territory, where terrorist act occurred with shooting through TC-117, is equal to ~ 3.8km in this case, and area of the polluted territory is equal to ~ 0.69km^2.

Table 1. Sizes of zones, where population should be removed from.

Parameter	Criteria according to accident at Chernobyl' NPP	
	Uranium fuel from WWER-1000	MOX-fuel from WWER-1000
Size of zone, where population should be removed from, km	~1.7	~3.8
Area of zone, where population should be removed from, km^2	0.15	0.69

Basing on the performed calculated researches, it is possible to make a conclusion that scales of radiation accident, which occurred due to terrorist attack with shooting through TC-117 by cumulative grenade of caliber 90mm from hand grenade cup discharge, are of local character. Size of polluted territory, where population should be removed from, and where reconstruction efforts should be performed, is ~3.8km, and its area is equal to ~ 0.69km^2.

2.5. Numerical estimations of cask resistance to explosion of 50kg of TNT placed at external lid of the cask.

Numerical researches of dynamics of TC-117 deformation due to effect by products of explosion of 50kg of TNT placed at external lid of the cask were performed using the computer model presented in fig.3. The calculation results are given in fig.10-12. The performed calculations show that explosion products cause intensive shock perturbations in the steel cover and the neutron protection mounted on the external lid. The perturbations form strong hydrodynamic flows in the steel cover and the neutron protection with scattering of these materials. Effecting on the external lid of the cask, compression wave causes high levels of deformation in it. However, they don't cause destruction of lid material.

Fig.10 show deformed configuration of TC-117 elements in the zone of location of the coaming and the lids due to effect of explosion products effecting on the external lid at times of 1.0ms and 5.0ms. Calculated field of distribution of states of TC-117 elements materials in the zone of location of the coaming and the lids at time of 1.0ms is given in fig.11.

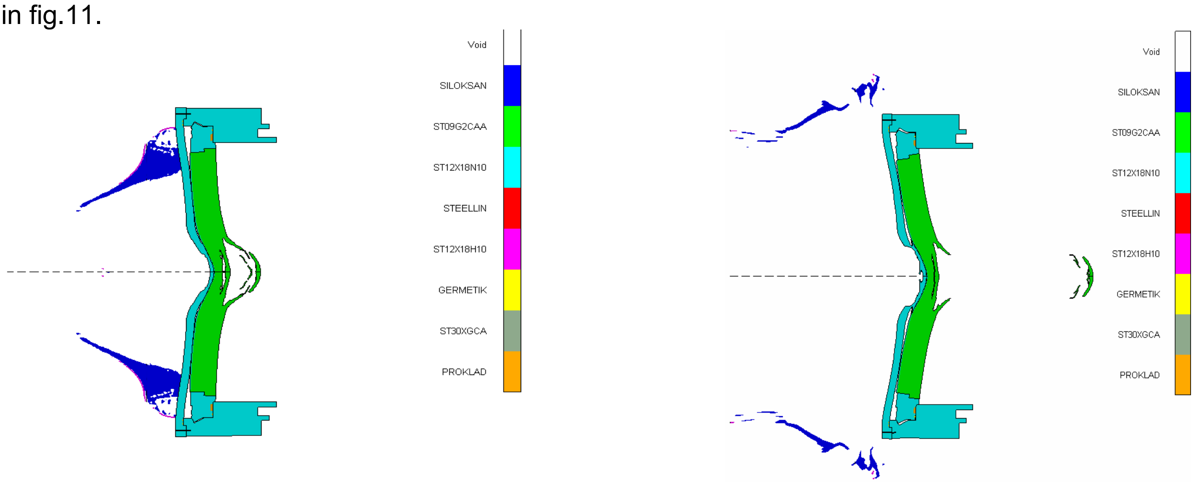


Fig.10. Deformed configuration of TC-117 elements in the zone of location of coaming and lids due to effect of explosion products effecting on external lid at time t=1.0ms and t=5.0ms.

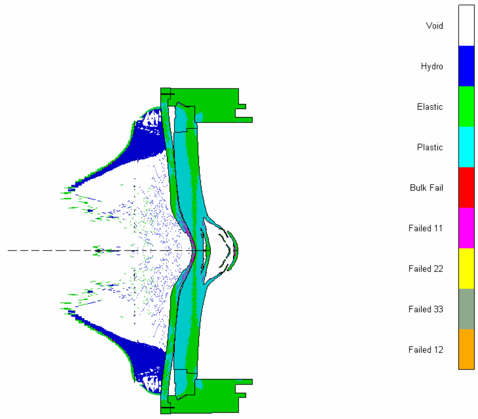


Fig.11. Calculated field of distribution of states of TC-117 elements materials in zone of location of coaming and lids at time t=1.0ms.

As one can see in fig.10-11, material of the central zone of the external lid of the cask is partially removed. However, no destruction of the external lid of the cask occurs. Though the internal lid of TC-117 has large area of plastic strains, it also keeps its intactness. At time t > 4.0ms, velocity of plastic flow in material of internal lid of the cask reduces actually to zero, and its deformed configuration becomes stabile. Fig.12 presents deformed configuration of TC-117 elements in the zone of location of tightly-sealed joints of the lids and the coaming, when explosion products effect on the external lid at time t=5.0ms.

The calculations show that joint opening occurs only in the zone of location of rubber sealing filling of the cask internal lid, but in the zone of spiral-wrapped filling (SWF) joint opening does not occur. The joint between the external lid and the coaming under the action of blast load is in compressive state.

Thus on the basis of the calculation results it could be concluded that in the case of explosion of 50kg of TNT placed at external lid of the cask TC-117 body destruction in zone of lids location does not occur, the cask keeps its tightness.

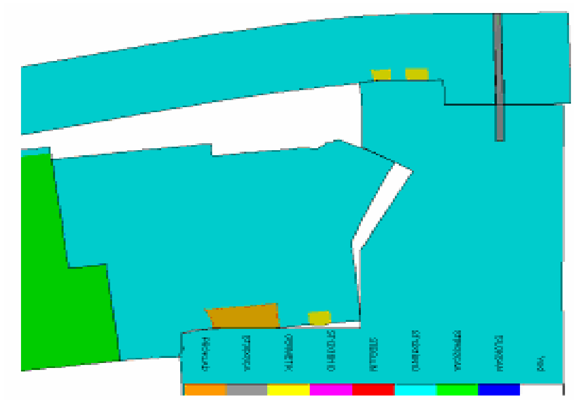


Fig.12. Deformed configuration of TC-117 elements in zone of location of tightening joints of lids and coaming at effect of explosion products on external lid at time t=5.0ms.

3. Conclusion

The following conclusion can be made basing on results of the performed numerical researches:

1. During the drop of a plane with velocity=100m/s onto the vertically standing container, it deforms elasto-plastically without destruction of its main reinforced elements. The container maintains its tightness.
2. For sure, TC-117 design cannot be shot through by incendiary bullet BZ-2 of caliber 12.7mm from sniper rifle. The cask keeps its tightness;
3. For sure, TC-117 design can be shot through (in any direction) by cumulative grenade of caliber 90mm from hand grenade cup discharge. However, the scales of radiation accident occurred because of terrorist attack with shooting through TC-117 by cumulative grenade of caliber 90mm from hand grenade cup discharge are of local character. Sizes of the polluted territory, where there is requirement for removing population and performing reconstruction efforts, is ~3.8km, and area of this territory is equal to ~ 0.69km^2;

4. At explosion of 50kg of HE consisting of trinitrotoluene mounted at external lid of TC-117 design, TC-117 design gets large plastic strains in the zone of location of the coaming and the lids. However, the cask keeps its tightness.