

Light reactive-passive armour

Lekki pancierz reaktywno-pasywny

Adam Wiśniewski

Military Institute of Armament Technology, 7 Wyszyńskiego str., 05-220 Zielonka, PL

Abstract: *In this work the examples of protection of light fighting vehicles armoured with additional reactive armours are described. The way of protection of light fighting vehicles with the use of composite-reactive armours against penetration with HEAT projectiles (with penetration ability of 300 mm RHA) and against armour-piercing bullets of small calibre (up to 14.5 mm) are shown on the example of BWP-1. Technical parameters of the CERAWA-1 armour, the kind of its assembly on BWP-1 and the results of firing of thin RHA armour (protected by the CERAWA-1 armour) with the use of PG-7 shape charge projectile are presented. There are also the results of static tests of three variants of reactive-passive panels against PG-7 projectiles' perforation.*

Key words: *reactive-passive armour, passive-reactive armour, light reactive armour, armour penetration.*

Słowa kluczowe: *pancierz reaktywno-pasywny, pancierz pasywno-reaktywny, lekki pancierz reaktywny, przebijanie pancierza.*

1. Armours applied on light armoured fighting vehicles

Armours of fighting vehicles [1÷5] nowadays reached the high degree of resistance to perforation of HEAT (*high explosive anti-tank*) hand grenades. Armours of such vehicles must effectively disturb the penetration of shaped charge jet and be resistant to the detonation of explosive, contained in the shaped charge projectile. Such quantity of explosive contained in such projectile, effectively destroy ERA reactive armour, usually situated as an additional protection [6]. Only a few constructions of reactive armours, eg. ERAWA-1 and ERAWA-2, are minimally sensitive to such destructive effect [6].

The armours of light fighting vehicles (LFVs) are usually not resistant to perforation even typical PG-7 projectiles firing from the most popular in the world hand grenade launchers, e.g. RPG-7. Armours of LFVs are protected with the use of lighter than RHA (*rolled homogeneous armour*) armours from the perforation of the PG-7 projectiles (with the penetration ability of $h = 300$ mm of the RHA) and against AP bullets of the calibre $d = (7.62 \div 14.5)$ mm.

The protection from the perforation of PG-7 projectiles is provided by reactive armours which different variants are used, among others, in fighting vehicles, for example, Bradley with different non modular cassettes, FV432 Mk3 BULLDOG with modular cassettes and the like.

In regards to the necessity for modernization of BWP-1 [7], the necessity for increase the protection level of this type of vehicles, among others with the CERAWA-1 composite-reactive armour [8,9], has been appeared.

2. Composite-reactive armour CERAWA-1

Typical reactive armour does not give any doubt regarding its high protective efficiency, but in spite of this many constructors and users presently are not convinced about usefulness of using reactive armours with explosive self-extinguishing material ESM (locally detonating). Mass efficiency of such armour is comparatively small, and area of surface of ESM deterioration is similar to area of surface of small cassette of typical ERA or e.g. ERAWA armour with the sizes of (150 x 150) mm. It results from the fact that too small quantity of ESM is not able to „energetically” destroy shaped charge jet. Besides, degree of mechanical deterioration of ESM and its casing (on surface several times bigger than (150 x 150) mm) is bigger or similar to degree of deterioration

of typical ERA or ERAWA cassettes. Instead, removal of damage of large surface of ESM casing, e.g. from tank and ESM, is incomparably more complex, time-consuming and more expensive than removal of damaged neighbouring ERA or ERAWA cassettes and renewed protecting of these surfaces.

Such easy and quick removal of only few neighbouring damaged ERA or ERAWA cassettes (created during firing such armour with projectile) does not create additional operating and repairing difficulties, etc.

Foregoing small protective abilities and usage inconveniences of ESM armours caused that the protection of BWP-1 light armour, with the use of cassette one-layered CERAWA-1 composite-reactive armour [8,9]. BWP-1 with additional CERAWA-1 armour maintains floating power, and its mass increases less than by 920 kg. Fulfilling this condition was obtained by protecting with CERAWA-1 armour with surface of 3.5 m², of front upper, bottom and side parts of hull and front and side part of tower. For comparison, it can be quoted that M113A1 and M113A2 reactive cassettes with surface of 3.6 m² and up to mass 980 kg, as well as passive cassettes ROMOR A with mass of about 1000 kg, cannot be used on BWP-1 because of their large mass. Western reactive armours with big thickness (100 ÷ 105) mm are used on vehicles with angle of inclination of front plate to horizontal 40° (e.g. M2 Bradley), much greater than in BWP-1 (10°). Similar construction of such thick reactive armour cannot be used on BWP-1 because it would significantly decrease field of view of a driver. Besides, some western reactive armours are assembled to hull in such a way (heads of screws are placed on external surface of ERA) that this makes covering of their surface with microwave absorber impossible, and on one vehicle there are several types of cassettes. These all faults are avoided in construction of CERAWA-1 armour because it has 100% modularity, and therefore optional replaceability, flat smooth surface and small thickness 44 mm.

Composite-reactive CERAWA-1 armour protects different surfaces of BWP-1 against perforation of shaped charge projectiles with average ability of RHA perforation $h = 300$ mm, perforation of armour-piercing bullets AP with calibre d : 7.62 mm, 12.7 mm and 14.5 mm and against detection by radar.

This armour should protect main surfaces of BWP-1 against perforation and detection by radar in sector of front horizontal fire and observation $\pm 70^\circ$ on the right and left from axis of vehicle, and it consists of cassettes of composite-reactive CERAWA-1 armour (72 pieces), hull holding CERAWA-1 armour and microwave absorber. CERAWA-1 armour consists of unified, mutually replaceable hermetic cassettes (modules) with the sizes of (306 x 156 x 44) mm, which in their passive layer contain, among other things, ceramics, and in their reactive layer - explosive. Cassettes are arranged on steel stands which are screwed to surfaces protected by screws. Stands, assembled on surface of tower, frontal upper and bottom plate of hull, have properly formed supports, which ensure inclination of CERAWA-1 surface in relation to horizontal at the maximum angle of 30°.

Stands are assembled on protected surfaces and together with CERAWA-1 cassettes are closed with cover. Such cover can be quickly connected with stand by screws permanently attached to frame.

Both CERAWA -1 armour and way of its assembly (stand, cover, possibly variable angle of inclination of stand, screws etc.) ensure efficient protection of main armour. During horizontal firing, CERAWA-1 cassettes inclined at an angle, efficiently cover whole front plate, in spite of fact that their surface is much smaller than surface of this plate.

On covers there can be microwave absorber in the form of gum with thickness of (2 ÷ 6) mm, which can be vulcanized, stuck or put in form of coverlet. Mass of microwave absorber placed on covers or coverlets, accounts for about (2 ÷ 6) kg m⁻². Total surface of microwave absorber, able to efficiently protect BWP-1 against detection with air radar in front sector of observation $\pm 70^\circ$, accounts for about 25 m².

Mass of cassettes of CERAWA-1 armour (52 pieces with surface of 3.5 m²) together with stands and covers accounts for about 900 kg, including microwave absorber (3.5 m²). Total mass of CERAWA-1 armour ensures floating power of BWP-1.

During military training, BWP-1 can be exploited without CERAWA-1 armour, but only with stands and covers (or even without them), in this way diminishing waste of fuel and vehicle. Such exploited BWP-1 during peace period "camouflage" their protective ability (resistance to perforation and detection by radar) in case of threat. Crew of BWP-1 can put quickly assembled CERAWA-1 armour within about 1 h, what is sufficient to prepare vehicle for fighting conditions.

This composite-reactive armour, fastened on BWP-1, was displayed on the III International Exhibition of

Defence Industry - Kielce' 95 (Fig. 1). In regards to full modularity, small thickness of CERAWA-1 armour and easy way of matching of length of stands and their angles of inclination to every shape of hull, this armour can be used on other fighting vehicles.

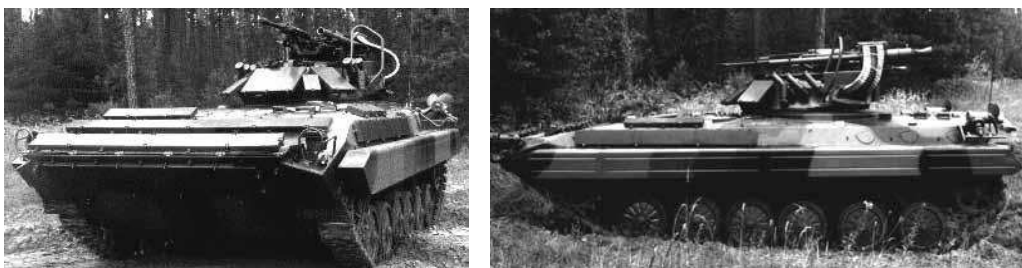


Fig. 1. BWP-1 with CERAWA-1 composite-reactive armour.

CERAWA-1 cassettes with ceramics showed good protective efficiency against penetration of RHA with thickness of $b = 10$ mm during firing with 12.7 mm and 14.5 mm AP bullets (Figs. 2, 3).

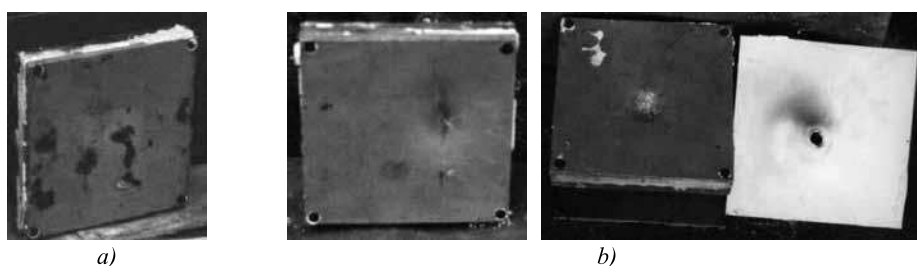


Fig. 2. Result of firing of CERAWA-1 cassettes with 12.7 mm AP bullets: a) reactive cassette which was not perforated after perforation of passive layer; b) reactive cassette which was not perforated and perforated passive layer.

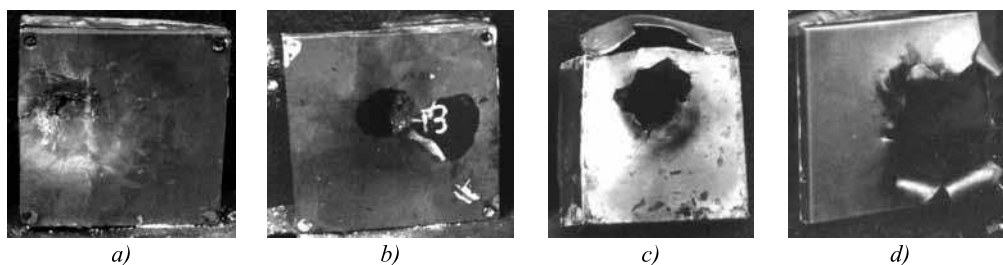


Fig. 3. Result of firing of CERAWA-1 cassettes - 14.5 mm AP bullets: a) reactive layer which was not perforated; b) perforated reactive layer; c, d) perforated and torn passive layer.

CERAWA-1 cassettes fastened on steel plate sized of (500 x 500 x 10) mm were additionally from the distance of 15 m treated the influence of fragments after explosion of 122 mm artillery projectile (Fig. 4). The projectile, placed vertically at a height of 100 mm above ground, was initiated statically and only casing of passive layer of CERAWA-1 cassette were destroyed as a result of hit (Fig. 4) without the damage of its reactive layer.

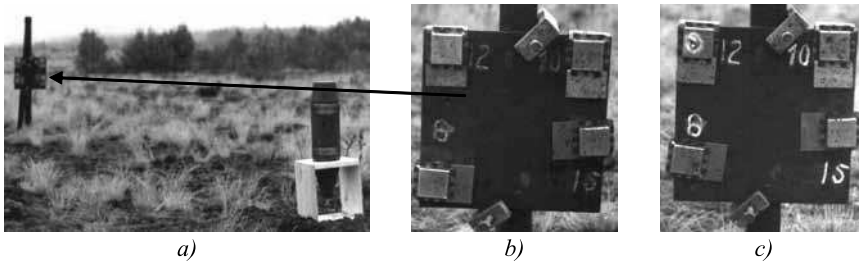


Fig. 4. Impact test of CERAWA-1 cassettes with the fragments of 122 mm projectile: a) projectile arrangement in relation to cassettes; b) steel plate with cassettes No 6, 10, 12 and 15 before initiation of 122 mm projectile; c) hit result of CERAWA-1 cassette No 12 with the fragment after explosion of 122 mm projectile.

It was considerably much more difficult to choose passive layer with ceramics in cassettes so that it would not disturb to protect thin RHA with thickness of $b = 10$ mm against perforation with PG-7 shaped charge projectile with penetration ability of $h = 300$ mm RHA, and against results of this cassette's explosion. An example of explosion results of this armour cassette placed on thin RHA with thickness of $b = 10$ mm, after hitting it with PG-7 shaped charge projectile, is presented in Fig. 5. This plate is perforated, when kind and thickness of material is chosen inadequately (Fig. 5a), and in the opposite case, plate is penetrated neither with shaped charge jet, nor as a result of cassette explosion, and it is only deformed (Fig. 5b).

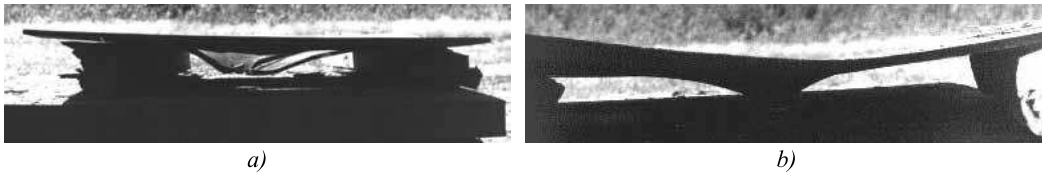


Fig. 5. Perforation of RHA plate of thickness $b = 10$ mm after hit of CERAWA-1 cassette of reactive armour with PG-7 projectile: a) only deep deformation; b) without perforation.

Composite-reactive CERAWA-1 armour can be modified and used to other kind of vehicle hull than RHA, e.g. RHA with double hardness, aluminium, titan, with an additional armour, spatial, ceramic, etc. Thickness of CERAWA-1 armour can be smaller in case of using it, e.g. on composite armour containing ceramics, which has large resistance to perforation with small-calibre AP bullets; there are works about it done in many countries, also in Poland [8,9].

Due to its original solution, CERAWA-1 composite-reactive armour, was described in Jane's Armour and Artillery [10].

3. Reactive-passive armour for protection against perforation with PG-7 projectiles

The static tests of protection abilities of panels of the reactive-passive armour with ERAWA -1 reactive cassettes from aluminium alloy during perforation with the shaped charge jet, generated by PG-7 projectile, were carried out [11].

Three different versions of armour's panels with the area of (500 x 500) mm (Fig. 6) have been used and on every panel shaped charge projectiles placed at an angles of $\alpha=60^\circ$ and $\alpha=72^\circ$ from normal to the surface of the cassette and also steel plates 1 (RHA - panel 1, 2, 5, 6 or St3 - panel 3, 4) have been used. Protection ability of panels [11], supported in two (version 1 and 2) and in three places (version 3) has been observed on the steel RHA plate 2 (called "witness") with the thickness of 8 mm (Fig. 6).

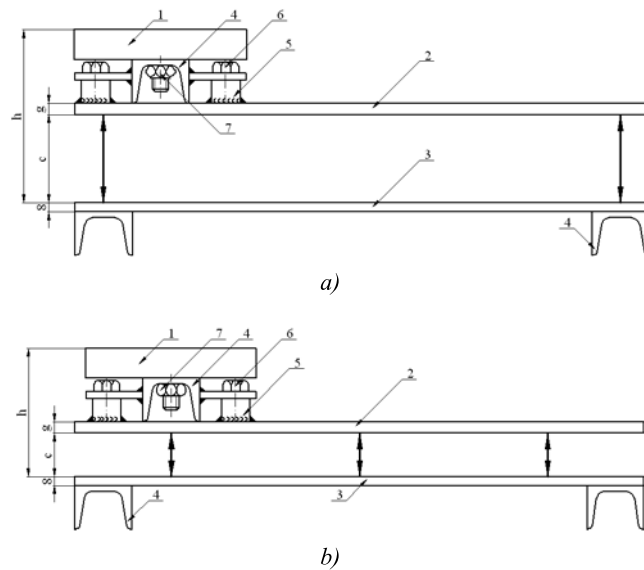


Fig. 6. Reactive-passive panels supported in two (a - version 1 and 2) and three (b - version 3) places: 1) ERAWA-1 cassette; 2) steel plate 1; 3) RHA witness plate 2; 4) steel channel section; 5) sleeve; 6) screw; 7) nut.

The views of panels in versions 1÷3 with ERAWA-1 cassettes before and after the initiation of the PG-7 projectile and witness plate 2 are shown in Figs. 7÷10.

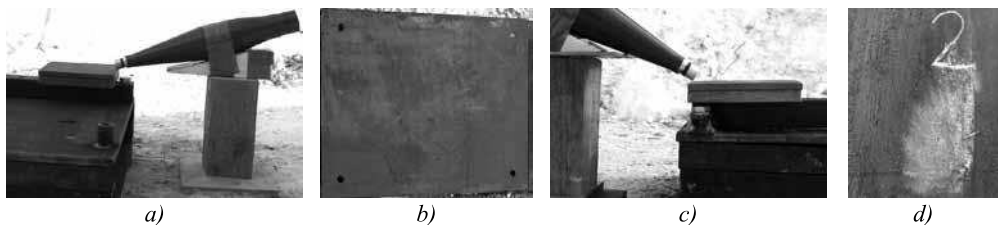


Fig. 7. Panels with ERAWA-1 cassettes from aluminium alloy before and after the initiation of the PG-7 projectile at an angles of α from normal to the cassettes: a) panel 1, $\alpha=72^\circ$; b) lack of copper trace on witness plate 2 (panel 1); c) panel 2, $\alpha=60^\circ$; d) $DP=1$ and copper trace on witness plate 2 (panel 2).

After perforation of panel 1 on RHA witness plate 2 no traces of copper were ascertained, i.e. the shaped charge jet was stopped by the ERAWA-1 cassette as well as RHA plate 1 which was damaged in the place where the cassette was fixed and after hitting of panel 2 only the trace of copper and the crater with the depth of $DP=1$ mm appeared on RHA witness plate 2.



Fig. 8. Panels with ERAWA-1 cassettes from aluminium alloy before and after the initiation of the PG-7 projectile at an angles of α from normal to the cassette: a) panel 3, $\alpha=72^\circ$; b) $DP=4.5$ mm and copper trace on witness plate 2 (panel 3); c) panel 4, $\alpha=60^\circ$; d) $DP=8$ mm perforation of witness plate 2 (panel 4).

In case of panel 3 the shaped charge jet pierced the St3 steel plate 1 and formed the crater with the depth of $DP=4.5$ mm, but in case of panel 4 it perforated the RHA witness plate 2 with the thickness of $DP=8$ mm. The maximum deflection of the metal sheet 1 as a result of the explosion of explosive, placed in the shaped charge projectile and in the reactive cassette, amounted 22 mm.

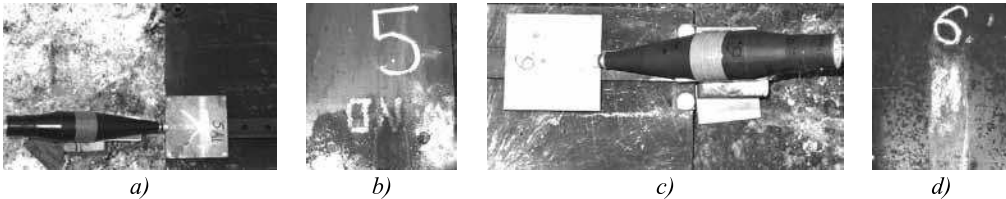


Fig. 9. Panels with ERAWA-1 cassettes from aluminium alloy before and after the initiation of the PG-7 projectile at angles of α from normal to the cassette: a) panel 5, $\alpha=72^\circ$; c) panel 6, $\alpha=60^\circ$; b) copper trace on witness plate 2 (panel 5); d) $DP=2$ mm and copper trace on witness plate 2 (panel 6).

The shaped charge jet in panel 5 pierced RHA plate 1, on the armour witness plate only the copper trace from the shaped charge jet appeared but in panel 6 the crater was formed with the depth of $DP=2$ mm and the maximum deflection of the armour witness plate 2 amounted 13 mm.

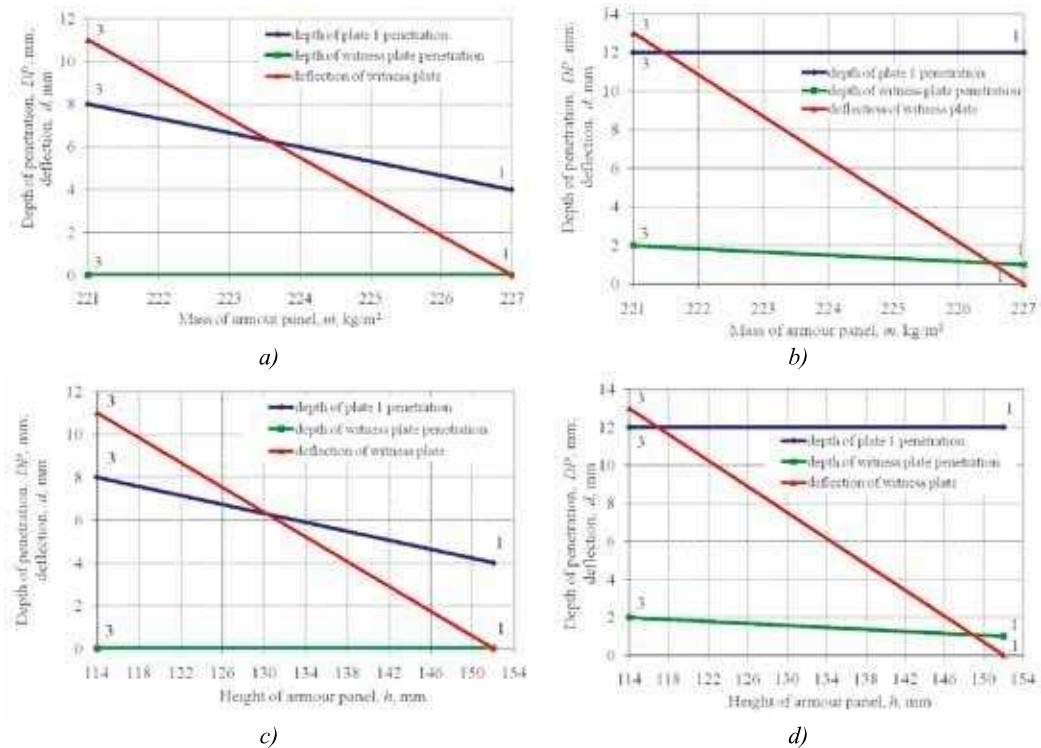


Fig. 10. The depth of penetration of the RHA plate 1, the steel RHA plate 2 (witness) and the deflection of the RHA plate 2 (witness):

- in the function of the mass of the armour panel for the angles of: a) $\alpha=72^\circ$; b) $\alpha=60^\circ$;
- in the function of the height of the armour panel for the angles of: c) $\alpha=72^\circ$; d) $\alpha=60^\circ$.

4. Conclusions

On the basis of carried out tests the following conclusions can be drawn:

1. Composite-reactive CERAWA-1 armour cassettes are the first solution of this type in the world. These cassettes are characterized by little thickness in relation to similar foreign cassettes and can be used on infantry fighting vehicle BWP-1 or on other light armoured vehicles. As a result of firing tests of CERAWA-1 cassettes it can be stated that:
 - Passive layer with ceramics in cassette of CERAWA-1 composite-reactive armour does not diminish protection ability of explosive of this cassette.
 - CERAWA-1 cassettes protect RHA with thickness of $b = 10$ mm against perforation with 12.7 mm bullets of B-32 type with penetration ability of RHA $h = 20$ mm and against PG-7 shaped charge projectiles with penetration ability of RHA $h = 300$ mm.
 - After the perforation of the reactive-passive armour on the surface of the hull of protected vehicle small craters with the depth of several millimeters and traces of dispersed copper of shaped charge jet of PG-7 can occur.
2. The panel of the reactive-passive armour with ERAWA-1 cassettes from aluminium alloy can protect light armoured fighting vehicles against the perforation of PG-7 projectiles hitting this armour at the angle of $60^\circ \leq \alpha \leq 72^\circ$ from normal to this armour.
3. The best protection was provided by the armour in version 1. In case of two angles of projectile setting the shaped charge jet did not pierce the RHA witness plate 2. There was also no deflection of the witness plate 2 as a result of the explosion of explosive from the shaped charge jet projectile and from the ERAWA-1 cassette.
4. The protection against the perforation of the shaped charge jet was also provided by the reactive-passive armour in version 3. However, the deflection of the armour witness plate 2 occurred for two angles of the PG-7 projectile, that was caused by the smaller distance between armour's plates, and also because of the greater stiffness of plate 1 as a result of additional supporting in three places.

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