

# **Investigation of Fragmentation and Damage Effects Caused by High-Energy Explosives**

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Within the second part of the 20th century local and military conflicts became the disappointing reality of the world life. Although each of those conflicts had its own character, the tendency towards the increase of the number of blast injuries from one conflict to another is being traced quite clearly. The most pronounced this tendency became apparent at the time of combat operations in Afghanistan and local military conflicts in North Caucasus [1,2].

Statistic data say that blasts and fires those result are on the top of the list of the man- made catastrophes [3,4].

The total number of explosions recorded in St. Petresburg over the period from 1998 to 2000 is 121, 52 people were injured, and 17 of them died. 75% of explosions resulted from the detonation of homemade blast devices equipped with TNT. The damage was caused by the initial blast effects and fragments.

In spite of the numerous publications devoted to blast wave effects, there are still many vague and doubtful things in mechanisms of harmful blast effects on human bodies. Most of the investigations have been studied such effects based on generalized wartime experience. Mortal and postmortem changes described in the investigations are practically not coordinated with physical parameters of the blast shock wave. The most common of contusion injuries is loss of consciousness. Sudden loss of consciousness clears the moment of contusion away from the memory, therefor only testing in animals can answer the question “what front shock wave overpressure values result in these or those injuries, from light to mortal”.

Studying protective effects of personal equipment and special means of blast protection (ballistic blankets, blast inhibition devices) on contusion injury degree is also of great interest.

As the biological specimens the following animals has been chosen:

- forty pigs of both genders weighing 65-70 kg;
- 130 rabbits of both genders of 1,5-2.0 kg weighing;
- Wister male rats of 230-260 g weighing.

Before tests the pigs were sedated with intramuscular doses of droperidolum and ketalarum, the rabbits and the rats were suspended resting on their stomach on special tables with their left side against the blast.

Detonations of explosives were performed in the open and inside 5.5 x 10.4 x 3.2.m structure with brick walls, concrete floor, ceiling, door and windows. Flat armor steel plates of

60x1,000x1,000mm were used as an underlying surface for the detonation of explosives. The plates provided the condition of the semi restricted space. The charge was placed in the middle of the plate.

In the open 5kg of explosive and inside the structure 1kg of explosive were detonated. Besides, 1kg of explosive in the open was detonated to compare the effect caused by the detonation of the same amount of explosive in the structure.

96 detonations were carried out.

In the open the animals were placed within 2.5, 3.0, 3.9, 5.0, 9.0 m from the blast epicenter.

To study protection effect of ballistic vests (BV), the pigs placed within 3.9 m and 5.0 m were clad in BV. The ballistic vests embedded armor plates made of SPS-43 steel 4.5 mm thick were used.

Inside the structure the rabbits and the rats were placed within 2.0, 2.25, 2.5, 2.75, and 3.0 m from the blast epicenter.

The swine were placed within 2 m at the wall and within 1.5 and 2.0 m in the way of the blast wave. Swine within 2 m from the blast epicenter at the wall, and within 1.5 and 2.0 m in the blast wave way were wearing BV and the effect of BV on the injury extent was evaluated.

Rats were chosen as an object of the investigation, because these animals are generally accepted for experiments concerning physio activity [5,6].

Shock wave injuries cause both stress and physio-activity effects. Adequate responses to the surroundings of the tested animals experiencing psycho emotional stress in extreme situation are different.

As is customary at present, bio-specimens' responds to the blast effects are considered to be a model of human responds to the same effects. The duration of swim is one of the main characteristics of a bio-specimen physical efficiency and physio-activity.

To evaluate physio-activity of the rats exposed to the blast wave, up-dated Porsolt test was applied. Rats with loads (8% of the average weight of the animal) fixed to their tails were forced to swim in the 22-24°C water "up to the end" [7].

Model of physical efficiency - "up to the end" can completely evaluate physio-activity of the biological object. Versatility of the model lays with the fact that practically every serious malfunction of any organ, system or the whole body adversely affect the physical efficiency.

The swim test was carried out in a special swimming pool. The depth of the water was such that the animals could not stand on their back paws. Drowning was considered to be real when after

the final plunge to the bottom, the animal did not surface for 10-15s, which corresponds to “real” drowning criterion.

Experimental investigations have shown that all organs and body systems can be damaged by the blast wave, but the eardrums and the lungs are the most sensitive to the blast effects.

The mechanism of lung damage caused by the blast wave is as follows: a sudden powerful compression of lungs contained in the chest, the ribs act as levers striking the lung surface or (at the opposite side) create a rigid backing for the compressed lung. As a result, the following mechanical damages of the lungs occurred: smashing and rupture of parenchyma and pleura, especially along the ribs and in the way of bronchial vascular bundle, occurred because of the difference in elasticity of the lung tissue and the bundle.

Other consequences of the blast effects are eardrum ruptures, injuries of various parts of human body: middle ear, larynx, nerves, abdominal cavity, spinal cord etc.

Autopsy showed edematous lungs, hemorrhages along the ribs, “rib prints”, in trachea and bronchus lumens foamy liquid was found.

Sectional investigation showed alveolus destruction, alveolus emphysema, hyperemia of alveolus capillaries, blood in the alveolus, numerous small and macro spotted hemorrhages, air embolism of coronary and cerebral vessels. All these resulted in the dysfunction of the lungs with the great lethality rate.

Based on microscopic investigation there were four injury degrees distinguished.

Mechanical injuries of the lungs up to their ruptures correlate with the degree of the general damage of the body.

Myocardium injuries in the form of intracardiac hemorrhages and hematomas were recorded at heavy contusion injuries.

Based on the general results obtained in the swine and rabbits, comparison of the blast injury degree and the overpressure level at the point of the tested animal’s location was done.

High meanings of correlation coefficients recorded in the testing with rabbits as well as in the testing with swine both inside structures and in the open have shown that the most damage is caused by the direct propagation shock wave. The intensity of the wave determines the degree of a blast injury.

Summarizing the testing results in rabbits we can conclude that the average overpressure value resulting in the barotrauma is 56 kPa, in the mild contusion - 134 kPa, moderate injury - 217 kPa, heavy injury - 280 kPa, lethal injury 490 kPa. The same parameters in swine were 130, 237, 371, 1074 kPa respectively.

Besides, the cut off  $\Delta P$  values causing the barotrauma, lung injuries and lethal injuries recorded during the testing should be noted (table 1).

Table 1

Cut off  $\Delta P$  values resulted in the blast injuries

Injury	Cut off $\Delta P$ values	
	rabbits	swine
barotrauma	33	113
lung hemorrhage	43	102
lethal	180	880

These data are in good agreement with those known from the literature [8-10].

Graphs of contusion injury degree dependence found in tested swine and rabbits of the blast wave overpressure were constructed with great values of approximation (0.85 for rabbits and 0.92 for swine), which allows using them for predicting possible injuries in bio-objects based on minimum values of blast wave overpressures.

The investigation was undertaken to evaluate the effect of ballistic vests embedded steel protective plates on limiting contusion injuries in swine.

Previous investigations with tested bio-objects have demonstrated no significant effect, even the increase in introthoracic pressure was recorded when the soft ballistic vest was worn. Based on the obtained data, we can assume that an animal wearing the vest with metal or ceramic plates should experience less degree of the blast injury in the chest and stomach, and their area should be smaller.

To evaluate the protective effect of the ballistic vest, the results (morphology and biochemistry) obtained into animals subjected to both TNT and IPN explosions in the open and in the structure were compared.

For each detonation of the explosive two pairs of equal animals (one wearing the vest and one without it) were selected and placed within the same distance from the epicenter. 15 pairs were tested all in all at different distance, conditions and the type of explosive).

To study the obtained morphology changes in the animals (wearing the vests and without them) subjected to the blast effects, the comparison analysis of the ballistic vest properties was done using coefficients corresponding to the absolute values of the contusion injury degree discovered by autopsy (table 2).

Obtained summary results have been demonstrated some decrease in harmful blast effect when the animals were worn the ballistic vests, in comparison with the animals without them. The

protective effect of the vests can be described as screening and damping of the air mass impact on the most sensitive to blast waves organ – lungs.

Table 2

Summary of coefficient value of injury degree under different conditions

Condition/ Tested objects	Trotyl			LD		
	5 kg in the open	1 kg inside the structure		5 kg in the open	1 kg inside the structure	
		By the wall	In the passing wave		By the wall	In the passing wave
Animals clad in the vest	8	4	6	7	5	7
Animals without vests	10	7	7	9	7	10

Besides, the protective effect was recorded by biochemical methods (activity of lipid peroxide oxidation products and the lung, myocardium, liver enzymes - marker activity in the serum decreased).

Due to the testing results a ballistic vest equipped with steel or ceramic plates reduces degree of contusion injuries by 25% in average.

### **Harmful Fragment Effects on Biological Objects**

A criterion of damage effect in injury ballistics is the empirical fragment parameter dependence of the injury caused by it. But the damage effect of a bullet or a fragment is determined not only by their parameters, but also by the location of the injury. Thus, the “lay out” effect is probable when a vital organ (VO) is injured, heavy ballistic fractures or vast muscle wounds occur.

Determining the probability of injuries and their level, it is necessary to take into account the total area of VO. By the foreign literature VO contain central nervous system, heard and main vessels, about 15% of the body area. Russian authors interpret VO wider and also include neck, abdomen and vessels inaccessible for surgical operations. The average VO area (front projection) is 26% or 0.13m<sup>2</sup> out of the upright body.

A group of criteria including such parameters as kinetic energy, kinetic energy density, specific impulse are used for predicting damage effects caused by various fragments and bullets. The above mentioned parameters are connected with such injury hypothesis as the depth of fragment penetration into the tissues or the body cavities, long tubular limb fractures and various skin injuries.

Investigating fragment damage effects, injury ballistic studies a certain sample of a fragment, as it is done with bullets.

The literature analysis shows that there are no universal criteria of fragment injuries.

As a significant parameter for a criterion of fragment damage caused by artillery shells (the criterion was developed by Military Medicine Academy and military unit No 33491 in 1954) kinetic energy density was used. The authors found that 0.5- 0.3 g fragments of random shape and with kinetic energy density 100-120 J/cm<sup>2</sup> can cause penetrating injuries of the chest, abdomen and damage internal, cause cranial bone fractures, shin-bone fractures, penetrate into limb muscle to 6-8cm.

A.G. Krivodjeyko classified fragment effects into three levels: safe, moderate injuries, heavy injuries. As a fragment injury criterion he took a specific impulse dependence of the depth of a fragment penetration into the tissues or the body cavities (ball or cylinder shape fragments of more than 1.0g were considering). The specific impulse was the linear momentum /fragment cross section ratio.

L.B. Ozeretzkovski in his work on investigation the mechanism of ballistic injuries made significant contribution into development of fragment injury effect criteria. The obtained results showed that small weight fragments did not penetrate deep into the body, and this fact explains that mostly ‘blind’ wounds recorded in the testing with bio-objects.

Based on the investigation carried out, the kinetic energy is the main parameter determining a degree of long tubular limb injuries, breastbone injuries and cranial injuries. It was found that penetrating injuries of the chest caused by steel balls occur at  $E=22.9 \pm 3.7$  J, and those caused by steel fragments occur at  $E=60.6 \pm 12.4$  J (table 3,4).

The average minimum kinetic energy of 0.25 – 2.0 g fragments resulted in 7-30 days of disability is 45 J for ball fragments and 70 J for fragment of natural fragmentation.

Table 3

Criteria of Minimum and Disabling Damage Fragment Effects on Biological Objects

Criterion	Level of Criterion	
	Disabling	Minimum
Nature of Fractures	Comminuted and double side, perforating	One side perforating fractures of shin bone, and comminuted fractures of humerus bone
Depth of wound channel, cm	8...10	5

Kinetic energy levels of fragment injuries (J).

Injury type	Head	Abdomen cavity, trunk	Limbs
Under skin penetration	2	2	2
Soft tissue	30	18	18
Bone tissue	48	48	48

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