PERSONAL BALLISTIC PROTECTION REQUIREMENT FOR BULGARIAN SOLDIER

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Abstract: *Individual ballistic protection properties of the soldier are extremely important in modern war condition when possibility increases to work against enemy in close distance.*

Quality of maintenance determination of the protective properties brings to contribution for development and design optimization of elements of protection in bulletproof vest and battle helmet.

The protection items quality is required by NIJ and Stanag standards. But in NIJ standards are required 100 % no-penetrating. There has not information about level of protection, only information is that protection is in required frame of the NIJ standards.

For example STANAG 2920 determines conditions for test where can receive V50 limited ballistic velocity for standard fragments. But V50 does not give information about V05 and V95 points at curve of distribution of the probabilities of penetration. There has not information for a slope of a curve what allows comparing conditions of vest or helmet in acquisition time.

The ballistic limit V50 test does not give the information on distribution of probabilities as a function of a range of speeds and does not allow to find points of slope of curves probabilities V05 and V95 (or other close points), which give the complete information on behavior of curves penetration and no-penetration probabilities, Fig.1. If there has this information it is possible to look after for change of protective properties of a ballistic material through due course and to create base of the statistical data by limited number of shots.

It is necessity to have more information about protection level and how it changes in acquisition time of the ballistic protection items. This

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information and in addition the battle threats level allow to build requirements for effective ballistic protection of the soldier.

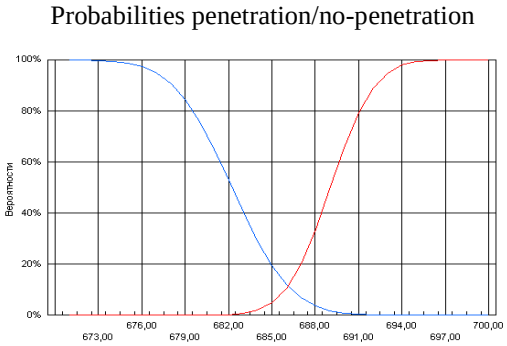

Fig.1. Distribution of the penetration probabilities in helmet test V50 determination.

Introduction

Ballistic protection is one of the most important equipment for Warriors, Special Forces and Security Personals because it enhances their survivability in hostile environments. Special material technology, human factors engineering, and quality control enable to provide comfortable, durable and NIJ & STANAG certified ballistic protection that is optimized for all combat situations.

Today, personal ballistic protective equipment is a sophisticated combination of advanced woven fibres, flexible laminates, and composite and ceramic hard plates in body armour, which are augmented by composite helmets and shields - each component thinner, lighter, more effective. In body armour, for instance, some models are scarcely visible under ordinary clothing [1].

To estimate level of protection, military use in practice V_{BL} ballistic limit test for assessing the fragmentation resistance of personal protection, particularly hard armour, helmet, and vest. The V_{BL} ballistic limit velocity for material is defined as that velocity, for which the probability of penetration of the chosen projectiles is exactly 0,5 [2]. The ballistic limit V_{BL} = *V50* test does not give the information on distribution of probabilities in function of the impact velocities and does not allow finding points of bend of probabilities curves points *V05* and *V95*, which give the complete information on behaviour of curves penetration and no-penetration probabilities. If there has this information it is possible to follow changing protective properties of the ballistic material through life cycle of military products.

1. Factors for Ballistic Protection Determination

First factor is determination of **battlefield threats**. There has to know as ballistic properties of threats as well as probability for resistance in different zones of human body. First known detailed analysis was made in 1962 when experts work at accessible information for injuries in Second World War and Korean War. After analyses there were determined relative defence places for human body parts for standing figure – for a head and a neck 12%, for a chest – 16%, for a stomach – 11%, for upper limbs – 22%, and for lower limbs – 39% [5]. In addition, reasons for battle injuries are from approximately 70% low velocity ammunition fragments and shrapnel which could be stopped using light armour. Applying of body armour in the Second World War late years shown 60-74% diminution of firearm injuries [5], what shows effect of the light body armour.

Second factor is **psychological stress** from body armour in body heat giving out diminish in time of warrior duties execution what distracts attention in battle situation.

Third factor is effective **construction of the body armour**. This does mean construction and its elements which must not obstruct soldier to move and fire in the battlefield what is directly connected with human anatomy and ergonomics.

US Army Forces estimated these three factors and in time of Korean War, the bulletproof vests have become real for soldiers. This vest had surface density 6 kg/m^2 and weight 4 kg and ensured resistance more and less against several short barrel bullets and velocities types, but was the first effective body armour at battlefield.

Next step in bulletproof vest design is a resistance against long barrel bullets from armour piercing shots of rifles and small calibre machine guns. In addition, a requirement has appeared for ergonomic – the warrior's bulletproof vest must be used several hours, but not only in time of short action like policemen.

First breach was in ceramics, in the area of hard personal ballistic protection. In the beginning of 60 years, first high-technology composite was developed, which could stop rifle/machine gun bullet due to combination of hard ceramics and aluminium oxides and fibres laminates. If there has a ceramics with equivalent properties and densities less than aluminium oxides, the weight is realized in body armour elements. Boron carbide is material which gives approximately 20% economy in the weight with equivalent properties. The commercial sector has been interested in using boron carbide armour for police and rangers operation in term of

high risk. But this body armour is too heavy and uncomfortable for warrior in time of dynamic battle situation when is difficult to forecast the battle risk and it is necessary for soldier to be in body armour relatively long time.

Second breach appeared in polymers area and DuPont was first with new arramid fibre. In the middle of 1978 the first anti-fragmentation vest 'Standard A' was made from Kevlar®29 for US Army.

Almost half of century has passed since them and for study on piercing process there is necessary to accept following definitions [2, 3].

Defeat affect does mean an every applied threat into equipped person with body armour, what could provoke injury or dead and influences could be [5]:

- Fragments with weight to 1,1 g - 60%;
- High-velocity bullets - 22%;
- Low-velocity bullets – 5%;
- After-blast effect and Burning and Stab-Weapon – 13%.

Ballistic threat does mean every 'ballistic element', bullet, projectile fragment, shrapnel, fragment simulator which has high-kinetic energy and flies on ballistic trajectory with velocities 200,…,1200 m/s.

Ballistic material is every material what could be used for personal armour design for defence against above showed defeat affects.

Ballistic impact is those impacts due to hits on the target by projectiles, fragments or other aerodynamically-affected threat mechanisms.

Ballistic resistance does mean a measure of the capability of a material or component to stop or reduce the impact velocity and mass of an impacting projectile or fragment.

Fragment simulator is a designed projectile for simulation the effects of munition fragmentation and striking into target.

Classification of the body armours could be made on the basis of indications:

- Type of the threats;
- Purpose of the threats;
- Structure of the threats;
- Requisite for agility.

It is important to note that army body armour are indented and designed more for projectile fragments resistance insurance against fragments with determinate weight and velocity, but not for bullets resistance as police bulletproof vests, where fragments resistance is secondary need.

The police bulletproof vests and helmets must ensure the requirements for 100% protection against standard threats, while the army vests meet the requirements only for 50% protection, what for the army vest allows to diminish their weight. Police use body armour in short-term actions and in limited ratio, but Army Forces body armour must be easy fit and effective resistance in prolonged time (to 12 and more hours) without considerable decrease of fighting efficiency of the soldiers.

In Table 1 is presented several mechanical properties of the fibres with ballistic application. Kevlar 29 properties are really impressive, its strength is 2,5 times more than other ballistic fibres and Elasticity modulus is enough to give shock reaction.

Table 1

Fibre	Straight, MN/tex	Elasticity Modulus mN/tex	Sound Velocity in Material, m/s	Relative Elongation %	Ballistic Limit, V_{BL}, m/s
Nylon	795	3540	3000	18	380
Kevlar 29	2031	35400	9400	4	500
Silk	440	4154	3000	19	426

Policemen and soldiers in correspondence with their duties to wear hard metal or nylon bulletproof vest with weight to 6 kg, have had new flexible effective material. But these two groups receive different ballistic threats, predominant the policemen have bullets, in opposite the soldiers have munition fragments. Therefore, threats estimation are too different, threats include large number pistol bullet and projectile/bomb fragments respectively.

Main threats for policemen are showed in table 2 [6, 7].

Table 2

Calibre	Weight of the Bullet, g	Muzzle Velocity, m/s	Muzzle Energy J
.38	10	243	295
.22	2,6	305	133
.45	15	259	503

.357	10	381	725
9x19 mm	8	332	440

Pistols bullet calibre .38 and .22 are more dangerous threats for West-European and US policemen. The first threat could be stopped by three layers Kevlar only with density 0,196 kg/m^2 and fibres 111 tex. But in this case, blunt trauma appears for live danger in a zone of lung and heart and liver. For that reason additional layers up to 9-10 numbers of Kevlar are necessary to soften up the hit to acceptable level for human constitution. For the second threat .22 calibre 10 layers of Kevlar are not enough due to sharp shape what is factor for vest piercing. In this case, the layers increase up to 20 numbers in dependence with requirements for blunt trauma level. Low Nylon prices impose these Nylon fibres type to market with equivalent protection.

Another important factor is humidity. For example against .22 calibre the wet vest loses up to 40% of its protection. To avoid this defect the Kevlar fibres are processed at fluorine-carbon treatment what lead to eliminate humidity defect.

2. Requirements to Soldier Ballistic Protection

In time of his mission, the soldier comes across with various ballistic attacks from kinetic elements. Modern armies use high-power personal fire systems and ammunition, which bullets and fragments as ballistic threats have enhanced dynamic effects due to high velocity and mechanical properties for ballistic threats corresponding with their hard cores, high material densities, improved ballistic forms. High limits for strength and elasticity for cores materials and increased power of explosives are determining factors for their applying in bullets and fragmentation ammunition design as instrument for ballistic threat.

It is advisable to use two types of battle helmets in depending on different tactical part of Army Forces:

- Battle helmet for the Army and the Navy
- Battle helmet for the Air Force.

And concerning to bulletproof vests there are three types:

- Standard fragmentation resistance vest for the Army and the Air Forces;
- Bulletproof vest for Special Forces;
- Fragmentation resistance vest for the Navy.

2.1. Requirements to Battle Helmets

The human head cannot assume dynamic hit as other parts of human body. Old type of steal helmet hanging brings a heavy risk for soldier in case of high velocity impact. Therefore equally with ballistic protection there must develop new hinging shock-absorber system in the helmet.

High-explosive ammunition fragments and short barrel bullets are today threats to human head. The helmet design with protection against long barrel bullets is not applicable although technical ability for this. Mane principles to build requirements to battle helmets are:

- Ballistic limits determination V_{BL} which is main property. The objective decision can be made for certificate on the base of V_{BL} and for extension of the term for exploitation;
- Ballistic limit V_{BL} is not less of the notify tactical requirement from Army/Navy/Air Forces Staff (for example $V_{BL} \geq 650$ m/s);
- Full short barrel bullet resistance against for mission region determinated threats (for example 9x18mm/9x19mm and 7,62x25mm);
- Three point hanging shock-absorber system;
- Weight must be conformable to requirements for additional equipment in battle helmet (for example NVD (night vision devices) and C3 accessories;

Fig.1. Ballistic limits determination V_{BL} in accordance with STANAG 2920 and FSP 17grain/1,1 g.

2.2. Requirements to bulletproof/fragments resistance vest

Modern trends analysis in field of the army forces ballistic protection vests show that principles are combination between bulletproof and fragments resistance vest but with some

differences. Standard fragmentation resistance vest for the Army and the Air Forces and for the Navy defends priority against ammunition fragments but bullets resistance is secondary. Bulletproof vest for Special Forces defends priority short barrel bullets and fragments resistance is secondary. In addition for Special Forces is necessary to have stab resistance due to possibility to have battle contact with an enemy. Determination for bullets test is 9x19 mm Para и 7,62x25 mm TT, if there have not additional requirements. For fragmentation test must be used STANAG 2920 and ballistic limit V_{BL} test.

Hard plates must protect against long barrel bullets in accordance with NIJ 0101.06 Standard and in addition against bullets produced by East-European countries - 7,62x39 mm AK47; 5,45x39 mm AP AK74; 7,62x39 mm AP AK47, 7,62x54 mm API Dragunov. Therefore using hard plates in the vest design are mandatory.

2.2.1. Standard Fragmentation Resistance Vest

2.2.1.1. Soft Ballistic Protection

Main principles for design:

- First rate factor is fragmentation resistance in accordance with STANAG 2920 and
  $V_{BL} \geq$ 650 m/s with FSP 1,1 g;
- Secondary factor is bullet resistance against 9x18mm/9x19mm. Vest closing in front is recommended and construction must includes neck-piece and groin protector;
- Stab resistance is function of fragmentation and bullet resistance, but it is not priority due to common weight of the vest;
- Density of the soft panels does not be more 5,7 kg/m^2. That way if the protected area covers all chest and stomach and groin then ballistic soft panel weighs approximately 3,6 kg.

2.2.1.2. Hard Ballistic Protection

Main principles for design:

- Main ballistic threats is long barrel bullets 7,62x51mm F1, 5,56x45mm F1A and 7,62x39 AK47 M43;
- Density of the hard panels does not be more 17 kg/m^2. Then ballistic hard panel 250x300 mm weighs approximately 1,3 kg.

2.2.1.3. Configuration and Ergonomic

- Vest closing in front is recommended. That way enhanced protected area is

provided;

- Construction must include neck-piece and groin protector. All soft and hard panels must be extracted from their cases;
- The common case of the vest must be compatible with battle equipment of the soldier;
- Hard panels have to be ergonomic bend at the human body not less with two axes;
- Weight of the fragmentation resistance vest must not be more 6,5 kg.

Fig.2. Standard fragmentation resistance vest.

2.2.2. Bulletproof Vest for Special Forces

2.2.2.1. Soft Ballistic Protection

Main principles for design:

- First rate factor is pistol bullet resistance against 9x18mm/9x19mm and 7,62x 25mm TT;
- Secondary factor is fragmentation resistance in accordance with STANAG 2920 and
  $V_{BL} \geq 600$ m/s with FSP 1,1 g;
- Third factor is stab resistance due to fact that ranger has direct contact with enemy;
- Density of the soft panels does not be more 10 kg/m^2. That way if the protected area covers all chest and stomach and groin then ballistic soft panel weighs approximately 4,5 kg;
- It is preferable side closing of the vest what gives more protection on sides and free movements for the hands in front direction. Neck-piece is mandatory but less surface than in standard vest and here groin protector is unnecessary.

2.2.2.2. Hard Ballistic Protection

Main principles for design:

- Main ballistic threat is long barrel bullets 7,62x51 AP P80, 7,62x54 APIR B32 with high piercing properties tipical of sniper rifles;
- Density of the hard panels does not be more 32 kg/m^2. Then ballistic hard panel 250x300 mm weighs approximately 2,5 kg.

2.2.2.3. Configuration and Ergonomic

- Vest closing in side is recommended. This ensure more movement for hands in front;
- Construction must include short surface neck-piece and has not groin protector. All soft panels and hard must be extracted from their cases;
- The common case of the vest must be compatible with battle equipment of the soldier;
- Hard panels have to be ergonomic bend at the human body not less with two axes;
- Weight of the vest for Special Forces must not be more 9,5 kg.

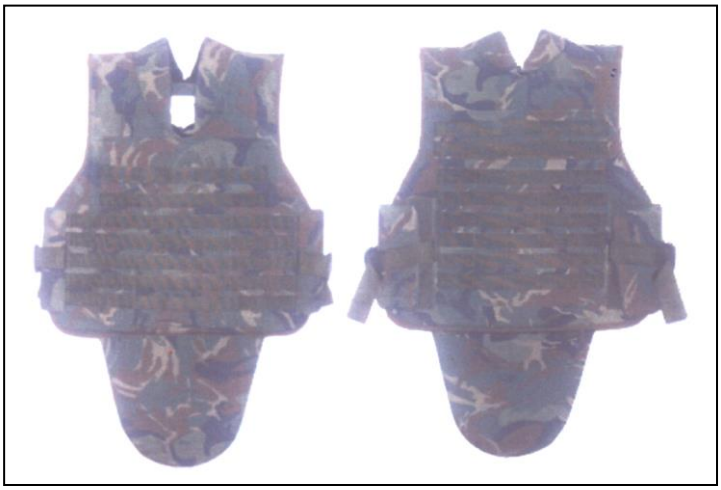

Fig.3. Special Forces Bulletproof Vest.

2.2.3. Fragmentation Resistance Vest for the Navy

In depend of battle tasks the Navy should use fragmentation resistance vest or more protected bulletproof vest for Special Forces which combine ballistic and floatable properties. But there have some differences. Requirement for compatible with other equipment drops out. In addition stab resistance is not so necessary, in depend on battle tasks. The vest case colour must be signal orange. Total weight must not exceed 7,5 kg. The vest must ensure position for soldier body in water 30 º -60º between soldier spine and water surface and distance

between water surface and soldier mouth must be more than 120 mm. Positive floating of the vest must be 275 N in accordance with STANAG 2997 и EN 399.

Fig.4. Model of Navy Bulletproof Vest.

3. VBL Curve Characteristics Determination

Using the Up and Down firing method in accordance with STANAG 2920, the first round shall be loaded with the amount of propellant calculated to give a projectile velocity equivalent to the estimated V_{BL} ballistic limit for armour. After numbers of shots V_{BL} is calculated as average of the velocities recorded for six fair impacts consisting of the three lowest velocities for complete penetration and the three highest velocities for occasional penetration, provided the frame is not larger 40 m/s. Many body armour manufacturers use a modified form of the military V_{BL} testing as a design tool to develop and assess new body armour products. This test identified the velocity at which specific projectile has 50-percent chance of penetrating the armour being testing.

V_{BL} ballistic limit testing is a useful and informative statistical tool for evaluating certain characteristics of armour during design phase of armour development as well a tool in evaluating armour's degradation over time. But the ballistic limit $V_{BL} = V50$ test should give an information on distribution of probabilities as a function of a range of speeds and does not allow to find points of bend of curves probabilities *V05* and *V95* (or other close points), which give the complete information on behavior of curves penetration and no-penetration probabilities. If there has information it would be possible to look after for change of protective properties of a ballistic material through his life cycle and to create base of the statistical data for behavior of protective properties of protection systems in time of life cycle – Fig.5.

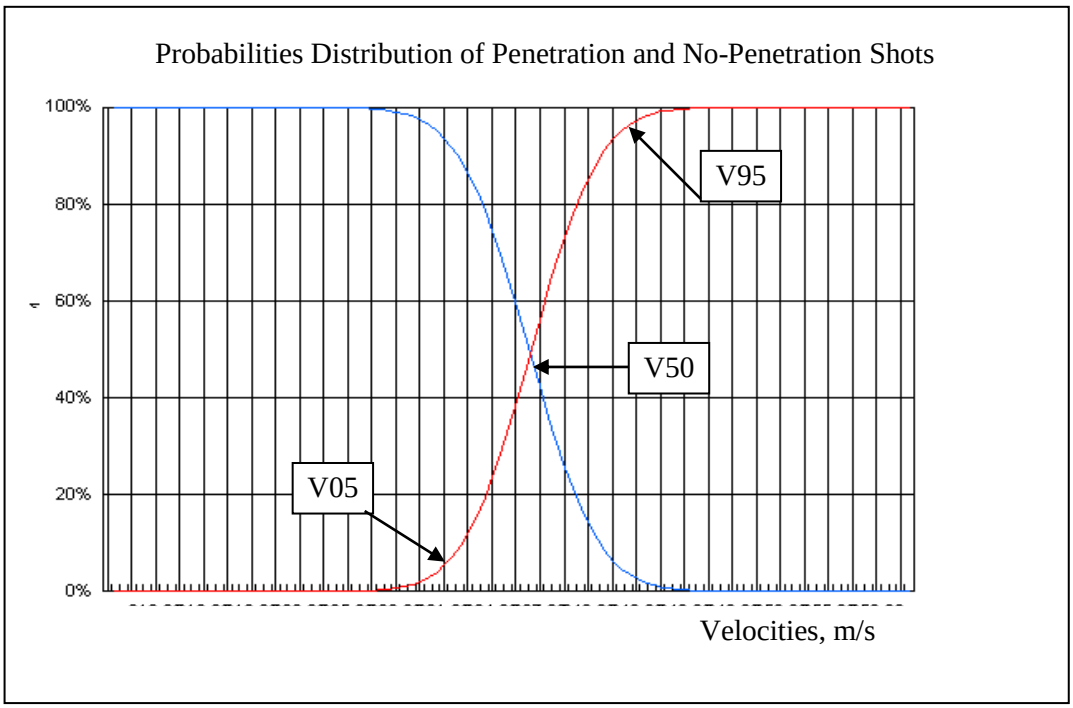

Fig.5. Behaviour Determination of Penetration Curve on the Base of V_{BL} Ballistic Limit Test.

4. Conclusion

Personal ballistic protection of the soldier must protect soldiers against more of battle field ballistic threats. But requirements for enhanced protection come across with strong limitation for low weight and flexible construction of the bulletproof/fragmentation protective vest. The design of protective vest is compromised process between tactical needs and technical possibilities.

Another side of this process is to follow changing of protective properties in time of its live cycle.

The mathematical model and procedure to estimate the basic properties of the body protective armour had created in form of the probability functions of the impact velocities especially *V05*, *V50* and *V95*.

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