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CRITERIA FOR EVALUATING THE EFFECTIVE USE OF ULTRA-STRONG TEXTILES IN PERSONAL ARMOR PROTECTION

Purpose. *The purpose of the article is to systematize knowledge in the production of personal armor protection and formulate special requirements to be met by finished products, evaluate knitted fabrics' efficiency for their manufacturing.*

Methodology. *The methods of analysis and synthesis were applied to show the current state of PPE production, requirements for performance indicators and benchmarks of quality.*

Results. *The criteria for assessing the quality of personal armor protection were analyzed. It was clarified that the personal body armor must meet stringent, complex and contradictory requirements arising from the terms of usage and degree of expected threats.*

Scientific novelty. *The requirements for personal armor protection for the manufacture of textiles that use ballistic purposes were set; classification of body armor for various types of features was made.*

Practical value. *The assessment of textile materials efficiency will help to establish domestic production of knitted fabrics ballistic purposes. The criteria of personal armor protection quality assessment will determine ways to address the issue of increasing the level of protection against damaging factors of different weapons.*

Keywords: *personal armor protection, ballistic knitted fabric, body armor, equipment damage, spark proof and bulletproof resistance.*

Introduction. Both in peacetime and wartime law enforcement agencies, security guard agencies, government officials, various military units, politicians, advocates, businessmen and people of other professions are often exposed to threat while carrying out their duties. They face threats from criminals and other violators of law which may use edged weapons and firearms. To ensure protection against damaging factors of different weapons personal ballistic-protective equipment (PPE) can be used.

Highly efficient PPE contributes not only to the preservation of human life and health, but also improves moral and psychological state of the military men, special units' personnel, law enforcement agencies and other government structure personnel giving them an opportunity to use their weapons effectively in order to perform their tasks.

Objectives. Firearm development trends result in the need for constant search of the ways to increase protection level by introducing new materials, design solutions and technologies in personal body armor products manufacturing. Practical experience in the use of military body armor in the course of settling existing local armed conflicts indicates that modern body armor is still far from being perfect [1]. The main reasons for soldiers' negative attitude towards body armor are their excessive weight that causes premature fatigue, decreases mobility and increases runtime of training and combat missions. Raising the level of military protection always contradicts other important characteristics such as maneuverability and ergonomics. The ratio of these indicators is also determined by solvency, which takes into account technical and economic characteristics of the materials used.

The development of ultra-strong textile materials with new structures for modern PPE production will facilitate design and ensure free movement in implementing the assigned tasks. Based upon the analysis of existing literature the conclusion was made that the comprehensive

evaluation issue of modern body armor functional properties and efficiency of usage of various textile materials for their manufacturing had not yet been studied carefully. To solve these problems it is necessary to systematize the knowledge of the PPE production and development of special requirements that the finished goods should satisfy.

Research results. Personal protective equipment (or personal armor protection) is used by law enforcement, military and some civil professions representatives with the aim to protect vital body areas from various injuries that offenders may cause by edged or firearm weapons, metal bars or stick attacks, throwing objects and mine shrapnel, grenades and shells. The normative document [2] defines personal armor protection as wearable products with periodic usage intended for a human body (head, neck, torso and limbs) against specific ballistic threats in preset operating conditions and also ensure exclusion or minimization of the impact of force applied to the body from weapons and are aimed at protecting it from other damages.

PPE with the use of ballistic textile requires special analysis in terms of efficiency of its properties. They include a body armor (BA) and its additional elements, helmets and other equipment (protective knee and elbow pads, pants, capes, cloaks, jackets, blankets and protective underwear) that have a high degree of strength and sustainability to mechanical and other influences. Additional removable body armor elements include neck and shoulder, groin, side lining to protect the torso, removable protective elements (armor plates). Modern body armor protects a human against penetrating effect of bullets, shrapnel or other elements of defeat due to its ballistic properties. The material used for its manufacturing must delay or minimize the speed element damage, absorb the maximum and disperse collision energy.

The development of effective personal body armor is challenging given the large number of tactical and technical requirements and factors that contradict each other and affect combat effectiveness. Each country is actively working to improve the structure of used materials and the design of individual elements of personal armor protection [3-7].

The most important characteristic of armor clothes is its protection class. The protection class must meet the current requirements of National Standardization System of Ukraine DSTU V 4103-2002, which establishes requirements for ballistic body armor [2]. The protection class, i.e. the list of weapons, from which it protects, is the most important armor clothes characteristic; it is a defensive structure stability indicator of specific body armor to weapons. Modern domestic market offers a wide range of body armor of both foreign and domestic production. According to their type the wearable bullet-proof vests differ. There are hidden, semi-hidden and open (external) wearing types. BA of a hidden type must possess minimum thickness and maximum comfort; must have an appropriate color that is not noticeable under the clothing, provide a good ventilation and impact absorption, allowing wearing it under the clothing for a long time like ordinary clothes or as an item of clothing. Therefore, hidden BA is usually produced only in 1 and 2 class of protection.

According to the type of application there can be military, assault, police and civil body armor. Also there exist body armor for dog training and special armor with high levels of protection for a long stay in the water.

Modern body armor consists of three main elements:

– textile outer cover with fastening and fit system,

– armor material placed inside the cover– hard (with armor plates) or soft ballistic package,

– cushioning pads.

According to the materials used the body armor construction can be rigid on the bases of hard structural elements (metal, ceramic, composite armor, etc.), soft (textile armor) and semi-rigid (combined) that means a combination of textiles with armor material plates. The PPE is often made as a combined type of armor. It consists of hard structure parts – metal plates and soft armor, which present a textile package. Soft armor protective structures consist of packets based on 15-30 layers of ballistic fabric made of heavy-duty and lightweight aramid (kevlar, twaron, nomex, heracron, etc.) or high-molecular polyethylene (dyneema, spectra, doyentrontex, izanas etc.) fibers.

In terms of protection the body armor is divided into:

– splinterproof – protection against knives, small-caliber firearms bullets, fragments and mechanical damage; designed for usage by civilians;

– bulletproof – protection against bullets of various types of firearms; designed for special combat missions by military capture groups and intelligence groups;

– differentiated, in which the protective structure has different ballistic resistance rates, i.e. design includes both splinterproof and bulletproof protective compositions with varying degrees of security chest and spinal sections designed for the use in combat;

On the basis of the analysis of the existing body armor range a classification of different types of attributes shown in **Figure 1** has been developed.

The application analysis of BA types indicates that the appropriate level of splinter and bullet protection mostly depends on the weapons used in assault. The PPE shows maximum efficiency in combat missions not associated with long active movements, incurring guard service, in the course of military equipment marches, intermittent assault shares; so, the usage of chest and spinal armor plates is justified only in sedentary activities that soldiers perform vertically. For long marches, combat operations in the mountains, exploration and other types of military activities requiring exertion limit constant wearing of bulletproof armor plates is considered as inappropriate [8].

Protective ballistic textile is used as the basic material for modern ballistic PPE manufacturing. Its properties are determined by its physical and mechanical characteristics. Designing products for protection of various human body parts under certain conditions requires a special approach. A key component of new textile materials design process for PPE is the development of scientifically based opinions on the basis of theoretical and experimental studies. Such products must possess high protective properties depending on the application and fully meet the complex requirements that are to be met. Depending on the type of troops or the nature of the actions the requirements set can vary downwards their number. But the major ones will be required. Physical and mechanical properties and weight of the protective armor elements for various weapons differ sometimes in dozens of times. The problem of appropriate use of the majority of armor proof materials in different conditions has not been solved so far.

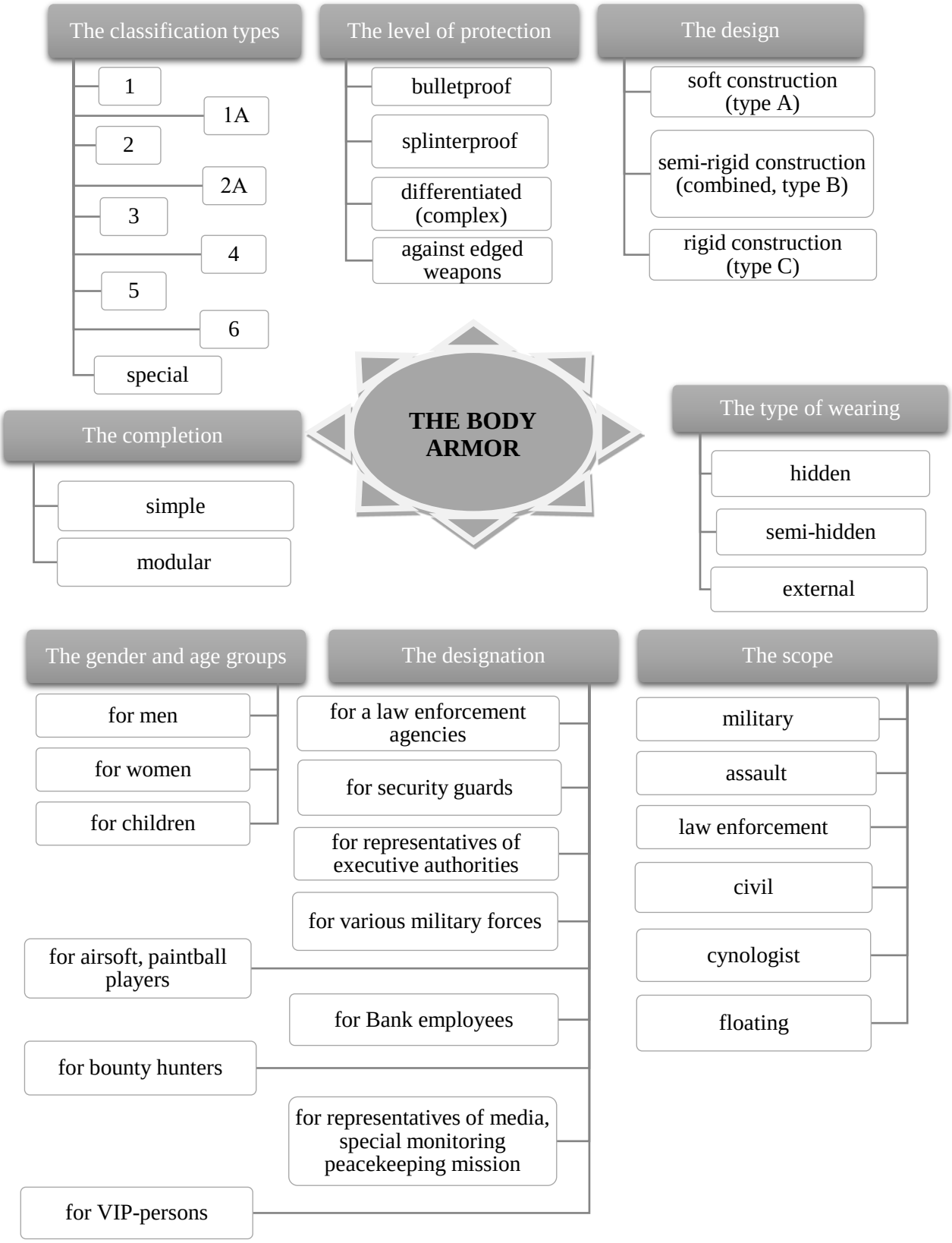

Fig.1.The body armor classification

In the process of creating body armor and its constituents various problems may arise. They are caused by the following contradictory requirements. In the course of analysis the set of requirements that apply to ballistic protection products according to specified conditions has been formed:

• bulletproof and high resistance to weapons penetration. Depending on the type body armor has to withstand certain amount of hits in accordance with the stated protection class. The definition of these characteristics is a complex scientific and technical problem the solution of which is currently carried out by field experiments. A significant drawback of this simplified approach is the criterion for assessing the quality of armor structure "penetration - non-penetration";

• high resistance to impact (i.e. reducing the BFS depth measurement that can be dangerous to the object of protection). BFS depth measurements are evaluated differently in various countries. Almost all foreign standards evaluate this option by the depth of the print on a special plasticizer left by the bullet after its penetrating into the bulletproof vest. The main problem is that different standards accept different values of this parameter. In the United States (standard NIJ 0101.06) [9] the dent is allowed to be of 44 mm in depth, in Germany and Britain - 22 mm. Statistics gathered by foreign experts shows that the upper obstacle injury depth of 44 mm probability of death is almost 10%. It is important to note that the DSTUV 4103-2002 also sets strict requirements for BFS depth deformation, which should be no more than 25mm. For wearing hidden protection classes body armor should possess 1, 1-A, 2 – 35mm. The depth of knives penetration (length release on the back surface of the body armor) should be no more than 5 mm.

• minimum weight to ensure sufficient mobility and maneuverability for the personnel to perform all sorts of tasks with an effective protection area. Body armor linear dimensions affect combat effectiveness, reducing mobility, complicating movement and inspection. To compensate such effects, personal body armor is designed to be close to the body; soft and hard armor elements are located rationally. The usage of tactical (handling) vests is also effective that gives an opportunity to distribute the load over a larger area and improve mobility;

• ergonomic high performance, comfort in use;

• maintaining resistance to weapons under given conditions using a particular product – under certain temperature, humidity, atmospheric precipitation and being immersed in water, or under short-term fire impact;

• preservation of functional properties after repeated ingestion of striking element in the same defense area;

• preservation of functional properties after repeated usage for a certain period and lack of armor elements deterioration without direct exposure to bullets and shrapnel;

• PPE design should provide easy and quick donning without assistance, fit snugly to the body, be securely fixed, not restrict freedom of movement and allow a person to conduct active actions;

• textile materials and seams that are used in manufacturing of PBA protective structures should be strong, smooth, environmentally friendly and allow mechanical removal of dirt and washing without performance and protection decline;

•flammable and toxic elements and coatings are forbidden in PPE manufacturing.

The trend for gradual increase of security indicators made the security and weight limit become the defining BA characteristic. All other parameters are considered secondary. Thus, the

customer makes a choice on the basis of the prior protection area and the product weight. Because of the lack of balance between security and mobility a set of unique requirements for the optimal body armor has not been yet formed.

For the manufacturing of body armor vests and other items of personal body protection heavy-duty textile materials are used, the structure of which is formed by means of ultra-strong threads. The performance of physical and mechanical properties of raw materials largely determines the main consumer properties of the finished products.

The Ministry of Defense of Ukraine has set the demands only for textile materials used for manufacturing of the outer covers of body armor, which must meet the requirements concerning their weight, moisture resistance, tear force, resistance to abrasion. They should not burn or maintain fire and impair their physical and mechanical properties under the impact of oils, gasoline and organic substances soluble in the process of dry cleaning or under the influence of detergents during washing. However, the requirements for textiles produced from ultra-strong threads that have ballistic properties have not been set yet.

It should be noted that all the manufacturers of body armor in Ukraine use imported cloth. There is practically no domestic production of ballistic textile materials with a high degree of durability. But the disadvantage that should be noted is the usage of woven structures. Under the influence of bullet the warp and weft threads, located in fabric structure in mutually perpendicular directions, are parted without lingering weapon debris. Therefore, due to its elasticity and structure features knitted fabric is the best textile material for the hidden type of body armor manufacturing, BA extra components to protect various parts of the body (neck, groin, shoulder and hip) and forming a substrate armor blocks protection against fragments and rebounds. In the process of dynamic interaction of a ballistic jersey with a bullet its loop structure due to elastic properties will reduce the bullet's energy bounce and its fragments more effectively. On the basis of it a study should be conducted aimed at the development of such a knitted structure. Such a trend is promising, because in Ukraine there are no companies that specialize in manufacturing of knitted fabrics for body armor and other knitted products that protect human body against various types of weapons and firearms [10].

Heavy-duty processing of raw materials for flat knitting and circular knitting equipment has been studied by us. Sufficient capacity indicators were determined for the knitting ability of ultra-high-molecular-weight polyethylene fiber linear density of 132 tex in the raw on the double bar warp knitting machine for a single and double weft knitting structure: plain, rib, based on the combined rib and plain and in combination with smooth polyamide filament technical 29 tex or with polyester 16,7x2 tex; also interlock and double-layer weft knitting structure with the press layers connected by basic yarns on a circular rib machine with interlock needles arrangement. Knitting capacity check has proved that the polyethylene thread can be processed smoothly by the knitting equipment with concentrated takedown traction by sinkers. This way it becomes possible to obtain the most dense knitted fabric structure. By varying the knitting parameters one can get the knitwear possessing different deformation characteristics, and therefore varying degrees of bulletproof resistance and other types of mechanical impact.

Thus, with the aim to develop textiles, including knitted fabrics for the manufacture of PPE the following theoretical aspects of the must be considered:

– the process of the dynamic impact of weapons (bullets, fragments of knives or weapon) and estimation of over obstacle effects upon the actions;

– the interaction between the protection back side and the human body and the evaluation of the degree of over obstacle impact intensity in terms of the human condition threshold criteria.

It should be noted that the mechanism of dynamic interaction between a bullet or a blade and the protection elements made of textile materials has not been studied yet, especially in view of possible biomedical effects caused by different over obstacle effects. In theory the complex creation and studying of relevant mathematical models that adequately describe the behavior of the objects mentioned above prevent us from solving the problem. These models are usually multidimensional, non-linear and they have ambiguity of characteristics that make them approximate and incomplete. In this regard, the role of experimental studies has become significant. The results of it can be used to clarify the development of mathematical models and valuation methodologies for over obstacle effects.

Many problems arise in the course of organizing and conducting experimental studies: exceptional intensity and transience of bullet impact processes and their interaction with PPE requires the use of rather a sophisticated measuring, specific recording tools and a special test stand. For medical and biological experiments it is necessary to make tests with biological objects, therefore there arise difficulties (they are connected, in particular, with the need to use living objects – biomannequins). It is clear that this complex and urgent problem can be solved only through the combination of theoretical and experimental studies with existing results of medical experiments conducted in similar conditions. We can assume that required intelligent and financial expenditures will be compensated by the saved lives and health of people and by the improvement of their professional qualities.

Conclusion. The analysis conducted has proved that the development and evaluation of the effective use of personal body armor should be based on an appropriate set of quantitative criteria to optimize parameters. The complexity of this task lies in the fact that currently there are no scientifically based methods of quantitative assessment of physical and mechanical characteristics indicators. The lack of specific assessment criteria prevents the formulation of technical requirements for materials used in manufacturing of body armor and its components.

The effective personal body armor development is challenging as it faces a large number of tactical and technical requirements and factors that contradict each other and affect combat effectiveness. Therefore, the choice of material for PPE must be determined by the complex performance.

The research issues analysis has proved the necessity to consider optimal balance of protective body armor properties in the design and development of PPE, wearing comfort and mobility of the military personnel, the ability to perform complex military and educational training tasks in different conditions to ensure their maximum efficiency.

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КРИТЕРІЇ ОЦІНКИ ЕФЕКТИВНОСТІ ВИКОРИСТАННЯ ТЕКСТИЛЬНИХ МАТЕРІАЛІВ ПІДВИЩЕНОЇ МІЦНОСТІ В ЗАСОБАХ ІНДИВІДУАЛЬНОГО БРОНЕЗАХИСТУ

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Мета.*Систематизація знань у сфері виробництва засобів індивідуального бронезахисту та формулювання спеціальних вимог, яким повинні відповідати готові вироби,оцінка ефективності використання трикотажних полотен для їх виготовлення.*

Методика. *Використано методи аналізу та синтезу існуючого стану виробництва засобів індивідуального захисту, вимог до показників експлуатаційних характеристик та критеріїв оцінки якості.*

Результати.*Проаналізовано критерії оцінки якості засобів індивідуального бронезахисту (ЗІБ). Встановлено, що ЗІБ повинні відповідати комплексу жорстких і суперечливих вимог, обумовлених умовами їх використання і ступенем очікуваної загрози.*

Наукова новизна.*Встановлено вимоги до засобів індивідуального бронезахисту, для виготовлення яких використовуються текстильні матеріали балістичного призначення; розроблено класифікацію бронежилетів за різними видами ознак.*

Практична значимість.*Оцінка ефективності використання текстильних матеріалів сприятиме налагодженню вітчизняного виробництва трикотажних полотен балістичного призначення. Виявлені критерії оцінки якості ЗІБ дозволять визначити шляхи вирішення питання підвищення рівня захисту від дії уражаючих факторів різних видів зброї.*

Ключові слова*: засоби індивідуального бронезахисту, трикотаж балістичного призначення, бронежилет, засоби ураження, протиосколкова та протикулева стійкість.*

КРИТЕРИИ ОЦЕНКИ ЭФФЕКТИВНОСТИ ИСПОЛЬЗОВАНИЯ ТЕКСТИЛЬНЫХ МАТЕРИАЛОВ ПОВЫШЕННОЙ ПРОЧНОСТИ В СРЕДСТВАХ ИНДИВИДУАЛЬНОЙ БРОНЕЗАЩИТЫ

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Цель.*Систематизация знаний в области производства средств индивидуальной бронезащиты и формулировки специальных требований, которым должны соответствовать готовые изделия, оценка эффективности использования трикотажных полотен для их изготовления.*

Методика.*Использованы методы анализа и синтеза существующего состояния производства средств индивидуальной защиты, требований к показателям эксплуатационных характеристик и критериев оценки качества.*

Результаты.*Проанализированы критерии оценки качества средств индивидуальной бронезащиты (СИБ). Установлено, что СИБ должны отвечать комплексу жестких и противоречивых требований, обусловленных условиями их использования и степенью ожидаемой угрозы.*

Научная новизна.*Установлены требования к средствам индивидуальной бронезащиты, для изготовления которых используются текстильные материалы баллистического назначения; разработана классификация бронежилетов по различным видам признаков.*

Практическая значимость.*Оценка эффективности использования текстильных материалов будет способствовать налаживанию отечественного производства трикотажных полотен баллистического назначения. Выявленные критерии оценки качества СИБ позволят определить пути решения вопроса повышения уровня защиты от воздействия поражающих факторов различных видов оружия.*

Ключевые слова: *средства индивидуальной бронезащиты, трикотаж баллистического назначения, бронежилет, средства поражения, противоосколочная и противопулевая стойкость.*