ned and also the integrity or quantity of perforations in the witness plate.

The impact is considered fair, if numerical values of bullet velocity and shooting range are equal to the values set in Federal standard GOST R 50744, the body armor protective structure is not perforated, and the achieved impact point is spaced not more than 10 mm from the supposed impact point.

On the basis of processing of the received data on perforation (non-perforation) velocities (speeds) of the witness screen by different test weapons, the following data were determined and created:

- probabilities of normal distribution (frequency curves) of impact on the aluminum witness plate
- parameter of protective properties of the aluminum witness plate vs splinter type (weight) diagram

On the basis of the obtained data the values of velocity for 50% non-perforation (V_{50}, m/s), energy intensity (E_{50}, J) and energy density (E_{den}, J/cm^2) were determined, rated on the basis of obtained value of 50% non-perforation (V_{50}, m/s).

The obtained data is represented in Table 1. From the obtained data it follows:

- the energy intensity of the aluminum witness plate in the investigated range of velocities and weights of the selected fragments does not practically depend on the type (weight) of the fragment and at the average is equal to$E_{den\ 50}$ (20.5±2) J/sm^2;
- the obtained value of the aluminum witness plate energy density sufficiently correlates with biomedical tests data on injurious effect of fragments formed when bullets ricochet from the steel armor panel of body armor (safe criteria – 10-11 J/cm^2, fatal – 100 J/cm^2 and more) (Projects of S.M. Kirov Military medical academy and N.N. Priorov Central institute for scientific research of traumatology and orthopedics)

In accordance with experimental findings evaluation of ARS has been proposed by three-type qualitative assessment of witness plates.

Anti-ricochet structure is classified as Type 1 if there are no perforations recorded in witness plates after all impacts on test items from the types of weapons declared in technical documentation.

Anti-ricochet structure is classified as Type 2 if there is no more than one perforation in each witness plate.

Anti-ricochet structure is classified as Type 3 if there is more than one perforation in each witness plate.

During the investigation it was found out, that for armor steel protective panels the following amount of material in body armor ARS basically solves the problem of localization of secondary fragments: 6 layers of art. 56319 for Protection Class 2, 16 layers for Protection Class 3 and 18 layers for Protection Class 5, mainly for secondary fragments localization task.

Risk Analysis in Designing of Body Armour

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Introduction

The risk analysis and an ocean of potential threats arising from the process of designing, manufacture as well the experience resulting from post-manufacture stage of ballistic body armours' life cycle are helpful tools for providing the functionality of the products, and the adequate, acceptable security level to their users.

The risk management has been approved and implemented i.a. as basic requirement for the medical products according to the provisions of European Directive 93/42/EWG [1] and defined in the standard PN-EN ISO 14971:2007 [2] and PN-EN ISO 22442-1:2008 [3]. The tool is versatile so much, that there are possibilities of applying it directly to the designing, manufacture and marketing.

General rules concerning applying the risk analysis

At the stage of designing the modern ballistic body armour the selection of most suitable and optimum technical, technological and design solutions for pro-

Table 1. Definitions of concepts related to the risk analysis [2]

Concept	Definition
Harm	• physical injury, health impairment of individuals or damage to a property or environment
Threat	• potential source of harm
Threatening Situation	• a circumstance, under which some individuals, property or environment are exposed to one or more threats
Expected Usage	• usage, for which a product, process or service is dedicated according to the specifications, instructions and information provided by the manufacturer
Residual Risk	• a risk that remains after applying the means of risk controlling
Risk	• combination of probability of harm occurrence and its severity
Risk Analysis	• systematic applying the available information for identification of threats and for estimation of risk
Risk Assessment	• full process including the risk analysis and assessment of risk acceptability
Risk Controlling	• process, within which the decisions are taken and means of risk reduction to certain levels or to keep it at a certain level are implemented
Estimation of Risk	• process being applied in order to assign a magnitude to the probability of harm occurrence as well as to the severity of the harm
Assessment of Risk Acceptability	• process of comparing the estimated risk with given criteria of risk in order to find the risk acceptability
Risk Management	• systematic applying the management policy, procedures and practices to the tasks of risk analysis, assessment of risk acceptability, risk controlling and monitoring
Severity	• measure of possible consequences of threat
Security	• lack of inacceptable risk

ducts is presumed, so the solutions were before all compliant to the security rules while taking into account state of the art of knowledge and technology. The goal is to eliminate or partially reduce the risk to an acceptable level, applying the adequate protective factors to the risk, which isn't fully eradicable as well as full information to the users on the residual risks resulting from the adopted security means [2].

Using the body armour is always connected to some risk level, which varies depending on the product, its wearer, usage time and other factors, mainly external ones.

According to the provisions in [2] the definition of risk includes two elements:

- the probability of occurrence of a harm,
- consequences of the harm, i.e. how severe the harm could be.

The acceptability of risk is depending on the above elements and the awareness of the risk occurrence both at the manufacturers and the user. The assessment of the risk level should take into account the expected application, functional properties and the risks related with the protective product, as well as the risks and benefits related to the procedure or circumstances of usage.

Definitions and process of risk management for the ballistic protection products

The concept of risk is a junction of two phenomena: probability of harm occurrence an the consequences of the harm i.e., its severity. When estimating the risk for the protective products, the following should be considered:

- the initiating occurrence or circumstances,
- the sequence of events, which could lead to a threatening situation,
- probability of occurrence of such a situation,
- probability of the situation leads to a harm,
- kind of harm, which could arise [2].

According to [2] it is indispensable to define the concepts supporting the analysis of threats arising from design, manufacture and usage of the protective products.

The process of risk management for ballistic protective products is presented on Fig. 1.

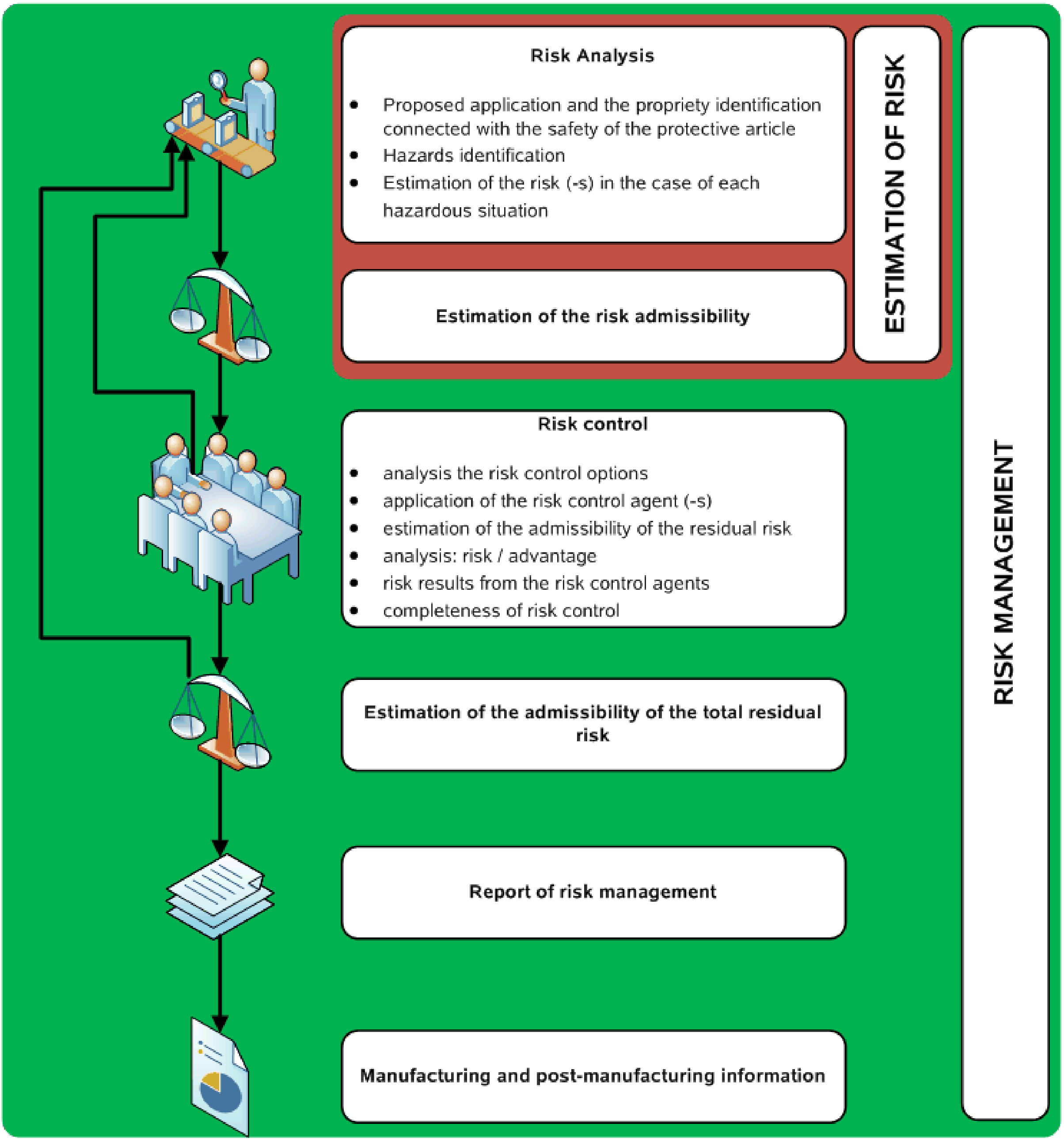

Figure 1. Proposed process of risk management for ballistic protective products [2]

The activities related to the risk management for protective products should be planned with special carefulness. A plan of risk management should include:

- the scope of planned activities related to risk management, identifying and describing a protective product and its life cycle stage (i.e. designing, manufacture, post-production phases, etc.), where each element of plan applies,
- assigning the responsibility and authorizations,
- requirements regarding review of activities related to risk management,
- criteria of risk acceptability, including also the criteria of the risks' acceptability, where the probability of harm occurrence isn't possible to estimate,
- the verifying activities necessary in order to reduce the risk to the acceptable level,
- the activities related to collecting and reviewing the adequate information concerning the design, manufacture and post-manufacturing [2].

The risk management documentation prepared in the above manner will allow for providing the traceability of each detected threat and shall ensure implementation as well as verification of the means affecting the reduction of risk level to the acceptable value [2]. The documentation is helpful at assessment of acceptability of each occurring residual risk. A remark should be made, that there is no such situation, to reduce a risk to 0, i.e. eliminate existing risk. Every time, despite prevention activities and/or correcting ones, some risks exist at a residual level. Question is, whether the level is equally acceptable for both the manufacturer, and for the users of the protective product.

An important element in a process of risk reduction (risk management) is foreseeing all of the factors appearing at the expected application and full identification of the protective product's properties related to the security guaranteed by the product. Any rationally predictable improper use of the protective product should be assumed with connection to potential threats resulting from such an use. One should also weigh, whether the protective product can be in use by an unprofessional (untrained) user as well as whether the protective products may be used in situations other, than the manufacturer intended and in situations other than expected at the stage of designing the product [2]. The manufacturer should „look into future", perceiving the threats caused by potential applying their product, effect of external conditions on the operational properties. He should look ahead, on an „event tree" basis (expectable damage as a result of sequence or combination of incidents), occurrences, that may appear, in case of product's damage as well as in it's impracticability states ie. damage, long-term exposition to sunlight or getting the ballistic insert wet. In case of threats, when estimation of damage probability is impossible, a list of potential consequences arising from given threat or threats accumulation should be made.

The information immensely important at estimation of risk may be aquired from published Standards or other standardizing documents (ie. NIJ [4] standardizing documents), scientific and technical information (including technical and technological documentation), the operating data concerning equivalent protective products in use, published reports concerning unwanted events and/or incidents (i.e. related to bullet- and fragment-proof vests made of Zylon® [6] or Dragon Skin [7] bullet- and fragment-proof vest), tests of usage among typical users and organizations dealing with verification of usage safety and ballistic performance of protective products (ie. [5]), usage data, results of laboratory tests, opinions from experts, data published in peer-review publications etc. It is important to realize, that the risk may only be assessed and managed, (meaning introduction of preventive measures and/or corrective in order to decrease level of risk to an acceptable one), if the threatening situation is identified. This shall enable reasonable predicting the event sequences that convert a threat into an incident or unwanted happening. The process of estimating the probability of threat conversion into an incident or unwanted happening includes a situation and event sequence from trigger reason to the damage occurrence. The mentioned above damage probability is directly and inseparably linked with human exposition to an unwanted effect of protective product. Thus, the level or scope of threat should be considered, i.e. assessing the aspects related to:

- threat situation occurrence without impracticability,
- threat situation occurrence with impracticability,
- threat situation occurrence only with multiple impracticability and
- probability (quantitative and qualitative) of threatening situation to lead to a damage [2].

As a practical aspect the following approaches to probability estimation are being applied, which are also applicable for ballistic protective products [2]:

- applying relevant historical data,
- probability forecasting with analytical or simulation techniques,
- applying experimental data,
- reliability estimation,
- production data,
- post-production information,
- applying the experts' opinion.

One should be also aware, that the probability of damage occurrence as a consequence of threatening situation depends on:

- what lifecycle stage is the protective product at (i.e. is it a recently-developed product, or is it rather a product already present on the market for many years),
- estimated quantity of products on the market.

A decision whether the reduction of risk is required, should be taken for each identified threatening situation, certainly having the mentioned criteria applied. The minimum requirement is to apply the screening test of risk acceptability of threat related to the protective product. In case of necessity to reduce the risk level, the factor (or factors) should be identified, which applied properly contribute to decreasing risk to an acceptable level both for manufacturer and the user. It may be accomplished by:

- introducing the rule of full safety at the research & development stage as well as the implementation works, for each product, by eliminating particular threats, decreasing probability of damage occurrence and/or reducing the severity of damage,
- assuring adequate, acceptable level of safety to the protective product itself and during the process of its manufacture (i.e. suitable selection of quality check techniques, placing the warnings

into the product marking, limiting the application or application conditions, giving the information on improper use, on threats, which may occur, or other information, that may support risk reduction, including the information about methods of reducing the damage, providing training for manufacturer's employees in order to improve their activities or their possibilities of errors detection at the stage of manufacture and control processes),
- adequate, widest possible range of information dedicated for user, including verification of training scope on using given ballistic protective product.

In order to assess the operative efficiency of applied element, introduction of mentioned risk reducing factors should be verified, under conditions which simulate usage or under conditions of regular using the ballistic protective product.

Reducing the risk to an acceptable level always relates to leaving a residual risk, the permissibility of which should be each time assayed as well as the possibility and reasonableness of applying the risk reducing factors. For the residual risks, level of which has been considered acceptable, the manufacturer should decide what residual risks to disclose and what information is necessary to include, i.e. in the product's user manual [2]. On the other hand, when the residual risk is not considered acceptable and there's no way to decrease risk level by applying additional factors, the manufacturer should censoriously review the data (usage, expertises, market feedback etc.) and publications (preferably peer-review periodicals) in order to determine whether benefits of expected application outweigh residual risk.

If such an analysis yields no conclusions proving domination usage and protection benefits over existing residual risk, then such a risk must remain inacceptable. Otherwise, i.e. in cases of risks, overweighed by benefits, a decision is necessary, which information are indispensable for safety and usefulness of protective product, to disclose the residual risk [2]. For protective products it is recommended to determine acceptable risk level reasonably and censoriously.

Applying the risk level decreasing factors brings two-fold threats:
- probability of introducing new threats or threatening situations and
- changes of risk levels of threats that have been previously identified, described and proving previously (i.e. before introduction of the factors) risk at an acceptable level.

In such a situation, the effect of the factor on the levels of all identified risks related to safety and usefulness of ballistic protection product should be weighted. It is especially important for complex protective products with numerous risks.

To recapitulate, the final stage of risk management process should yield the conclusions of accepting the total residual risk and introducing for practical applications the procedures aiming to gain the manufacture and post-manufacture information, which may be helpful at new threats identifying, or reducing the residual risk. For this reason a system of collecting and reviewing information on the product or equivalent products present on the market should be implemented and maintained. The information should be assessed for possible link to safety and usefulness, especially:
- if any unrecognized before threats or threatening situations occur, or
- if estimated risk resulting from threatening situation is not acceptable anymore [2].

Table 2 shows sample criteria of threats identifications and their description for the ballistic protection products.

Table 2. Threats identifications criteria and their description for the ballistic protection products [2].

What it anticipated use and how the protective product should be used ?	Factors, which are recommended to be weighted, include a) functions of the protective product (i.a. protection of torso, head or other body parts), b) the way of protection applied, c) application recommendations, d) any special intervention in case of product incapacity necessary?
Is the protective product intended for direct contact with the user ?	Factors to be weighted include kind of presumed contact, i.e. area of contact and possibility of emission of potentially toxic substances during usage, considering most extreme usage conditions

Is the protective product intended for regular cleaning and disinfection by the user ?	Factors, which are recommended to be weighted, include kinds of cleaning or disinfecting agents, which are to be applied, as well as any limitations of cleaning cycles' number. The product's design may also impact the effectiveness of regular cleaning and disinfection. Moreover, the effect of cleaning and disinfecting agents on safety and functionality of product is recommended to be weighted.
Do the protective product's properties alter during storing and using ?	Factors, which are recommended to be weighted, include: • temperature, • humidity, • atmospheric air composition, • pressure, • sunlight and its spectrum.
Is the protective product intended for usage with a link to other products or other techniques ?	Factors, which are recommended to be weighted, include identification of any other products or other techniques, which might be concerned, and potential problems related to such mutual interactions.
Is there any unwanted substance emission from the protective product ?	Substance related factors, which are recommended to be weighted, include emission of substances being used in process of manufacture, cleaning or testing, which have unwanted physiological effect, if they remain in the product. The impact of materials of which the protective product has been made of on the natural environment should be weighted [8].
Is the protective product sensitive to impact of environment ?	Factors, which are recommended to be weighted, include environment of using, transportation and storage. They include light, temperature, humidity, vibrations, flooding, variable climatic conditions, exposing to sunlight and variations of its spectrum.
Are any necessary consumables or equipment linked with the protective product ?	Factors, which are recommended to be weighted, include specifications regarding consumables or equipment and any limitations of choice, layed upon users.
Does the protective product feature limited period of usability or storage ?	Factors, which are recommended to be weighted, include marking or indicators and disposal of the products, when the usability period expires. The usability period should be weighted as well as the storage period, which does not deteriorate presumed usability properties (including the protective ones).
Are there any results of delayed or long-term usage of the protective product ?	Factors, which are recommended to be weighted, include ergonomic and cumulative results. Examples could include mechanical fatigue, loose straps and fastenings, effects of vibrations, labels which get attrited or lost, long-term degradation of material as a result of environmental factors, bad maintenance of product, bad way of storing them, etc.
What mechanical forces will be the protective product subject to ?	Factors, which are recommended to be weighted, include for example the force necessary to keep a protective vest integral (of the Quick Release type) and the force necessary to release it, force necessary to pull a wounded user with safety belts, etc.
What determines the lifetime of the protective product ?	Factors, which are recommended to be weighted, include those, which affect degradation of materials directly responsible for functionality and safety of protective product. Factors, which are recommended to be weighted, include environment of use, transportation and storage. They are light, temperature, humidity, vibrations, flooding, dynamic climatic conditions, exposure to sunlight as well as its spectrum variations,
Is a safe recycling of the protective product necessary ?	Factors, which are recommended to be weighted, include waste products, arising during recycling of used or damaged protective product. For example, does it contain toxic or dangerous materials or whether the material is suitable for recycling?

Does the transport, storing, using or maintenance of the protective product require any special training or special skills ?	Factors, which are recommended to be weighted, include novelty of protective product as well as probable skills and training of personnel responsible for transportation, storage, using the product and its maintenance.
How the information will be delivered in order to allow for safe usage of the protective product ?	Factors, which are recommended to be weighted, include: a) if the information shall be delivered directly to the end-user by the manufacturer, or a third party shall be committed, such as distributors, whether a training will be a result of that and whether performing such a training is necessary, b) whether it might be required, on a base of expected usage period of the product, to re-verify the safety and functionality of protective product.
Will it be necessary to establish or introduce new manufacturing processes ?	Factors, which are recommended to be weighted, include new technology or new manufacturing scale necessary to introduce for given protective product.
Is the protective product being used In the environment, or under conditions, where distraction may result with a threat towards health or life of user or others ?	Factors, which are recommended to be weighted, include: a) effect of the protective product's ergonomics on frequency of threat occurrence, b) consequences of usage fault, c) is the distraction a common occurrence or not, d) are the user's perception or focusing exposed to rare interference resulting from design of the protective product.
Does the product include attachable parts or additional equipment ?	Factors, which are recommended to be weighted, include possibility of bad fastening, similarity to other solutions applied into other products strength of fastening, feedback regarding join integrity and too strong or too weak joining, linking properties, etc.
Is the product to be used by individuals of special needs ?	Factors, which are recommended to be weighted, include the user, his mental and physical capabilities, skills and training, ergonomic matters, usage environment, users' abilities to affect the use of the protective product. Special attention is recommended to the fact, that the protective product may be in use among individuals of various skills level and cultural origin.
How the product could be improperly used, on purpose or unintentionally ?	Factors, which are recommended to be weighted, are improper use of joints, which obstruct safety elements, neglecting the maintenance recommended by the manufacturer.
Is the product planned to be mobile or portable ?	Factors, which are recommended to be weighted, are necessary handles, grips, ties, mechanical stability, physical integrity during transportation and storage, as well as the durability. Attention should be paid to intuitive and easy set-up after transporting or storing the protective product.
Does the protective product's usage depend on its basic applicative properties ?	Factors, which are recommended to be weighted, are adequacy of ergonomic solutions, assumed minimum protective area, ballistic class of the product, etc. [9-10]

Findings

The risk analysis as well as the risk management process proposed in the paper is based on the verified procedure described in international standards and applied for assessment of risk on the medical products area. Implementation of such a kind of process shall be helpful at providing the safety of using the protective products, including ballistic ones and ensuring their long-term functionality.

A benefit of risk management process entails directly economical results of manufacturers, who have implemented such a procedure within their factories. It is linked to a fact, that full analysis of threats for a given kind of protective product gives also the data related to manufacturing process optimisation, marketing data regarding the product and equivalent ones, thus enables improving the product as well, as easy identification of competition's weak points.

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On Non-Stationary Energy Absorption when Interacting High-Speed Striker with Textile Armor Materials

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Last years, questions of energy absorption when interacting strikers with various ballistic materials are of all greater interest. This interest is based on the attempt to find a scientific approach to the problem of designing optimum armor materials and protection systems on their basis.

Assume a ballistic efficiency as a parameter for evaluating the ability of material (a sample) to absorb kinetic energy of a hitting element falling at effective contact area S_0.

In our experiments, the ballistic efficiency was determined from the expression (1),

$$\beta_t = \frac{\Delta E}{m} \text{ (J/kg)} \quad (1)$$

where ΔE is energy absorbed by a barrier, $\Delta E = E_1 - E_2$ and E_2 are the striker kinetic energy values before and after the barrier respectively, m is material weight on the contact site (sample weight).

Taking into account changing kinetic energy of the striker when piercing each layer, it must not be used too many layers to characterize materials under study. At the same time, energy absorption is effected by not only the single layer properties but and the interaction of layers with each other, for example, the frictional interaction which always takes place in the actual armor protection system.

In this connection, we have selected for our experiments a packet of 4 layers of fabrics with surface density from 130 to 240 g/m2 and measuring 20 cm x 20 cm in a plane. Figure 1 presents energy absorption of 4 different types of textile armor materials as a function of striker speed over the range of 250 m/s to 750 m/s.

It is seen that over the studied range of fragment speeds, we deal, in reality, with the energy absorption spec-