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A Preliminary Study of Photon Radiation Attenuation from Ballistic Protection Materials

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Abstract. Modern ballistic protection equipment is lightweight, flexible, and withstand multiple types of threats. Depending on their purpose, they are assembled from various materials, with ceramic plates and composites based on high-performance polymer fibers finding wide application in recent years. Multilayer fabrics with different textures woven from synthesized special mechanically high-resistant polymer fibers successfully withstand the high-speed and high-energy impact of the striking element. Given the risk of exposure to radiation during military conflicts or industrial accidents, it is necessary to know the anti-radiation parameters of protection means. The report attempts to establish the degree of protection against photon radiation in the range of 40 KeV to 120 KeV for samples of ballistic panels with ballistic protection levels III+, III++, and IV. The degree of attenuation of photon radiation with these energies was measured by irradiating the examined ballistic panels. A dose-dependence has been obtained with level of ballistic protection for the specific material as a function of the energy of photon irradiation.

Keywords: radiation safety, attenuation coefficient, hard armor plate.

I. INTRODUCTION

In the modern conditions of the evolution of human society in the development of military conflicts and industrial accidents (accidental or intentional) in infrastructure facilities using intensive production technologies with unconventional energy sources, there is a critical factor of occurrence of radiation that is more powerful than the allowable natural radiation pool. Part of this radiation is ionizing radiation, which passes through matter and ionizes it, adversely affecting human life.

Technological advances in obtaining new more efficient materials used in ballistic protection such as ultra-high molecular weight polyethylene (UHMWPE), carbon nanotubes, liquid armor, graphene, composites, etc. are also leading to better photon radiation protection capabilities!?

On the other hand, there are experimental trials of standard means of individual ballistic protection through which the possibility of radiological examination of a patient wearing protective body armor has been established [1]. In cases of combat injury, this reduces the time required for preliminary diagnosis, as the ballistic protective equipment need not be removed and the appropriate medical procedure can be carried out on time.

Polymer composites are generally not suitable for attenuation of photon radiation due to the low content of high-order elements from the Mendeleev table. In recent years, attempts have been made to incorporate classical high atomic number elements (PbO) into polymer matrices, thereby increasing the shielding capability. Moreover, there are studies in which the protective lead oxide has been replaced by low-toxicity lead-free shielding compounds [2].

Regardless of the degree of exposure, it is unacceptable to underestimate the invisible and insensitive effects of photon radiation on human organs. Therefore, it is necessary to know to what extent the generally accepted (traditional) clothing and means of individual ballistic protection of servicemen, depending on the structural composition and geometrical parameters protect and absorb radiation. The purpose of this paper is to present experimental data on the degree of radiation attenuation in irradiation of a certain type of hard body armor with ballistic protection levels according to a generally accepted NATO standard [6].

II. MATERIALS AND METHODS

2.1. Hard Body Armor

Currently, the most widely used materials in the manufacture of ballistic protection devices in the hard

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armor segment are based on polymers and ceramics, and in the combat helmets segment on polymers of the aramid and kevlar type [3], [4].

Hard Body Armor MARS Armor® was used for the study [11]. They are designed to protect the human body mainly from bullets and fragments and consist of Ballistic Inserts and Plate Carriers.

The Ballistic Inserts represent Plates to protect from high-velocity ammunition, including rifle and machine gun fire (also by using a silencer [5]). Plate Carriers are designed to provide maximum coverage and protection, with good mobility and wearing comfort of the Ballistic Inserts types.

Six types of Ballistic Inserts with different levels of protection were investigated in the active laboratory experiment. The general device of Ballistic Inserts or Ballistic Panel consists of a Plate and a Substrate (Backing). A hybrid type of Ballistic Insert it is composed of two parts ceramic and high molecular weight polyethylene.

1) Ballistic Insert, hybrid type, Protection level III+, Standart NIJ 0101.04.

The Plate has a composition of ceramic SiC with dimensions - 250x300 mm and thickness – 6 mm.

The Substrate has a composition of compressed high molecular weight polyethylene Dyneema HB50 with thickness – 11 mm.

2) Ballistic Insert, hybrid type, Protection level III++, Standart NIJ 0101.04.

The Plate has a composition of ceramic SiC with dimensions - 250x300 mm and thickness – 6 mm.

The Substrate has a composition of compressed high molecular weight polyethylene Dyneema HB80 with thickness – 11 mm.

3) Ballistic Insert, hybrid type, Protection level IV, Standart NIJ 0101.04.

The Plate has a composition of ceramic SiC with dimensions - 250x300 mm and thickness – 10 mm.

The Substrate has a composition of compressed high molecular weight polyethylene Dyneema HB80 with thickness – 10 mm.

4) Ballistic plate made of ceramic Al_2O_3 with dimensions - 245x285 mm and thickness – 10 mm.

5) Substrate made of compressed high molecular weight polyethylene FMS H62 with thickness – 15.6 mm.

6) Successfully tested Ballistic Insert in a seven-shot firing with an 7.62x39mm AP cartridge. Ballistic Insert is a hybrid type, Protection level III+, Standart NIJ 0101.04. The Plate has a composition of ceramic SiC with dimensions - 250x300 mm and thickness – 6 mm. The Substrate has a composition of compressed high molecular weight polyethylene Dyneema HB80 with thickness – 11 mm.

Fig.1 Ballistic Inserts with different levels of protection.

2.2. Experiment setup

For the experiment, PHILIPS Diagnost 1 and Siemens Polymat 70 diagnostic X-ray units were used. Both X-ray units allow obtaining and precisely controlling the X-ray radiation parameters in the desired range as well as adjusting the geometrical parameters of the experiment. The X-ray units have the necessary certificates for normal operation.

To measure the actual values of the quantities characterizing the X-ray radiation, a solid state detector-dosimeter Radcal AGMS-DM+, Solid State kV/Dose Multisensor using Accu-Gold+ Digitizer and Accu-Gold Software was used [9]. The Accu-Gold+ system used allows for measurement of the maximum energy of the generated X-ray pulse in the form of maximum pulse kilovolts, average kilovolts, absorbed dose, dose rate, pulse duration, half attenuation layer, pulse shape as well as total filtration.

The Accu-Gold+ system used has undergone calibration and certification with a certificate issued on 08.2023 by MEDEIX LAB SofiMae France [10].

The geometrical configuration of the experiment is as follows: the Ballistic Plate is placed on top of a horizontally positioned table with the center coinciding with the center of the X-ray beam. The distance between the work table and the focal point of the radiation generator is set to 1 m. The field of the generated beam is selected to completely cover the object. The beam is generated vertically downwards. The detector is placed along the beam axis once on or below the plate. The measurements on and under the plate are taken with the same set of X-ray parameters [7].

III. RESULTS AND DISCUSSION

During the measurements, the radiation intensity was kept constant by keeping the generator current and pulse duration constant at 100 mA and 100 ms. The pulse energy is controlled by setting the accelerating voltage in the X-ray generator. A higher accelerating voltage at the same current and time gives a higher pulse energy.

After the X-ray pulse is generated and until it reaches the point of measurement, the pulse undergoes attenuation due to absorption partially in the exit window of the X-ray tube and other structural materials in the beam path. This type of absorption and scattering is called self-filtration of the X-ray generator. Filtration modifies the energy spectrum of the outgoing radiation primarily filtering out low energies.

The intensity of the radiation also decreases inversely proportional to the distance from the source focus to the measurement point.

The absorbed dose in a material per unit of time depends on the energy of the incident radiation, its intensity, and the type and structure of the material. In general, it can be said that for the same energy and intensity of the incident radiation, denser bodies absorb more, and, in addition, the material with a higher effective atomic number absorbs more.

The calculation of the effective atomic number and the mass attenuation coefficients of the material remain beyond the objectives of this preliminary study.

The corrected for the time measured absorbed dose along the central line of the beam with the detector placed in front of the armor plate (Din) and behind the armor plate (Dout), for a ballistic plate with protection level IV, are presented in Fig 2.

The absorbed dose rate at the entrance of the ballistic plate increases but not linearly because it also depends on the filtration which is also a function of energy. The dose rate at the exit of the armor plate also increases with increasing radiation energy but more slowly due to the absorption and scattering of radiation in the material.

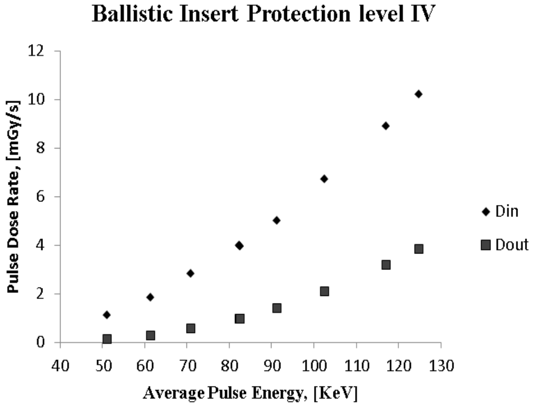

Fig.2. Measured time normalized dose on and below the ballistic slab with protection level IV.

Fig.3 shows the increase in absorbed dose in the armor plate material as a function of incident radiation energy.

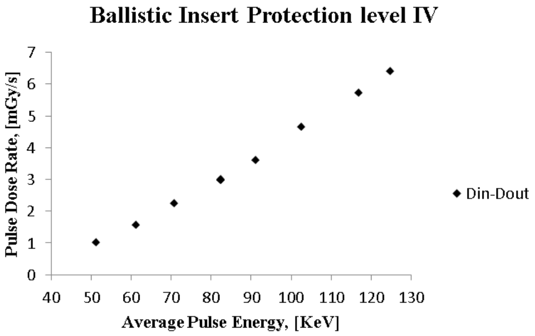

Fig.3. Calculated time-normalized absorbed dose in a ballistic plate with protection level IV.

In Fig. 4 we have shown the calculated attenuation values of the radiation passing through the armor plate material as a function of the incident radiation energy, other things being equal. It can be seen that at low energies we have more protection.

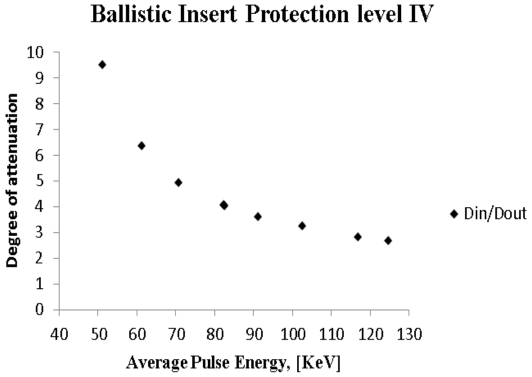

Fig.4. The calculated degree of attenuation of radiation energy passed through a ballistic plate with protection level IV.

Fig. 5 shows the comparison of the attenuation rate of passed radiation from ballistic plates with different degrees of ballistic protection. The attenuation rates for two different energies are indicated on the graph.

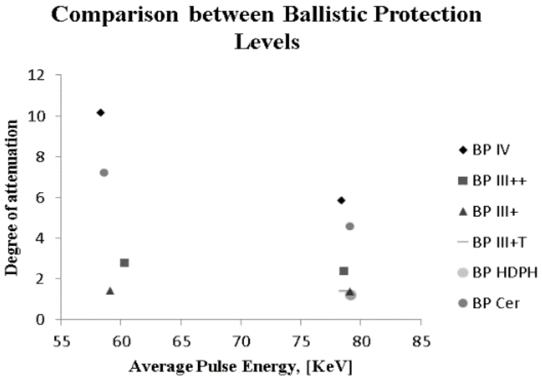

Fig.5. Comparison between attenuation values for ballistic plates with different levels of protection.

It is interesting to note the coincidence of the values of four test plates at 80 keV. Armour plate 6 retains its attenuation rate value despite the post-ballistic test structural damage.

Fig.6 shows an X-ray image of test plate 6, it can be seen that the structural damage of the plate material is localized in an area close to the point of impact and the overall homogeneity of the plate is preserved.

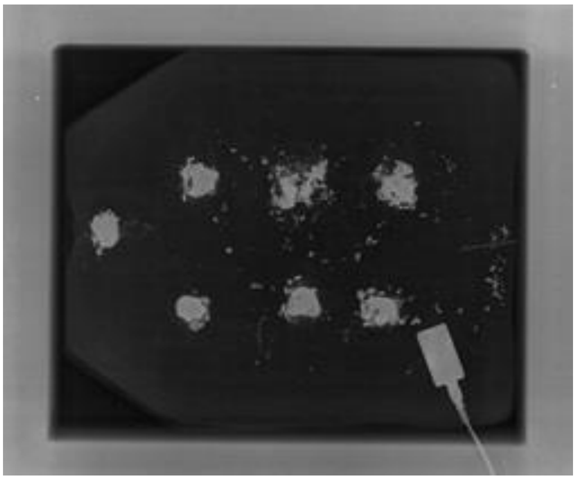

Fig.6. shows an X-ray image of test plate 6.

Fig. 7 shows the dependence of the attenuation as a function of the incident radiation intensity for a pulse interval of 100 ms and an energy of 80 keV. The radiation intensity is represented by the magnitude of the pulse charge which is the product of the magnitude of the current and the pulse time. It can be seen that the variation is less than 0.02 and practically the degree of attenuation does not depend on the intensity in these intensity ranges.

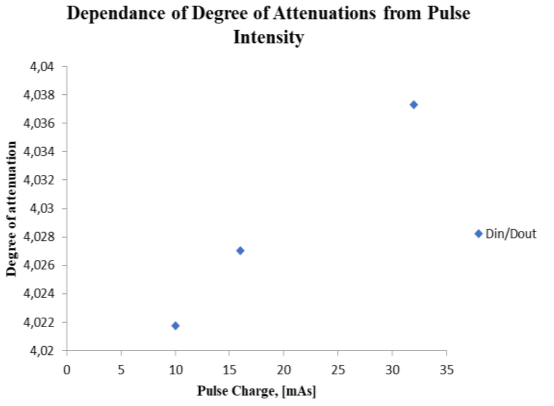

Fig.7. Degree of attenuation as a function of the incident radiation intensity for a pulse interval of 100 ms and an energy of 80 keV.

Conclusions

To the best of the authors' knowledge, results on photon radiation attenuation in this energy range from ballistic panels are presented for the first time. Thus, the obtained original results will allow us to model the degree of protection in various hypothetical situations with various complex spatial configurations [8], as well as to assess the harmful effects of photon radiation on servicemen. Having these estimates, it will be possible to modify the action plans to maximally protect personnel operating in environments with increased radiation hazards.

The data obtained in the study will help to design a more thorough study of various ballistic materials.

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