Features of the use of protective equipment in the conditions of the influence of corpuscular radiation

Poplavets Serhii¹, Hyshko Henadii², Yavtuschenko Yolodymyr³, Lukianov Serhii⁴, Drol Oleksandr⁵, Chepurnyi Viacheslav⁶, Kolmohorov Oleksii⁷

¹ Philosophy Doctor, Professor of Department; Ivan Kozhedub Kharkiv National Air Force University (KNAFU); Ukraine
² PhD in Military Sciences, Associate Professor, Associate Professor of Department Ivan Kozhedub Kharkiv National Air Force University (KNAFU); Ukraine
³ Senior Lecturer of Department; Ivan Kozhedub Kharkiv National Air Force University (KNAFU); Ukraine
⁴ Senior Lecturer of Department; Ivan Kozhedub Kharkiv National Air Force University (KNAFU); Ukraine
⁵ Senior Lecturer of Department; Ivan Kozhedub Kharkiv National Air Force University (KNAFU); Ukraine
⁶ Senior Lecturer of Department; Military Legal Institute of Yaroslav the Wise National Law University; Ukraine
⁷ Lecturer of Department; Ivan Kozhedub Kharkiv National Air Force University (KNAFU); Ukraine

Abstract.
The analysis of the available means of individual protection of the leading countries of the world, the concept of creating a complex of combat equipment (KBE) of the servicemen of the Armed Forces of Ukraine and the existing state of equipment of the servicemen made it...
It is possible to conclude that they do not fully meet the requirements of modern armed struggle and are not considered to be able to solve tasks qualitatively protection. Proposals have been made for the protection of personnel in conditions of radioactive contamination and exposure to ionizing radiation through the use of modern elements of military equipment. Proposals are being formed that can be reflected in methodological guidelines and algorithms for actions under conditions of exposure to ionizing radiation and programs for creating a complex of military equipment for servicemen of the Armed Forces of Ukraine. Based on the conditions of radioactive contamination, it is proposed to protect the organs of vision with the help of protective ballistic glasses-masks, which, due to their design and the properties of the materials from which they are made, prevent the effect of radioactive substances on the mucous membrane of the eyes and the skin around them, which greatly facilitates their removal during remediation. The above-mentioned proposals can be reflected in the instructions and algorithms of actions in the conditions of impact on the personnel of ionizing radiation and programs for the creation of a complex of combat equipment for servicemen of the Armed Forces of Ukraine.

**Keywords:**
- ionizing radiation
- personal protective equipment
- equipment
- radiation cataract
- lens of the eye
Formulation of the problem. Recently, a significant threat to Ukraine in particular and the world as a whole has been acquired by international and state terrorism, which turns the civilian population into an object of forceful influence in order to destabilize the situation, intimidate people, deprive them of their ability to offer organized resistance [1, 2]. In Ukraine, the situation is complicated by the fact that as a result of Russia's treacherous invasion of Ukraine, which violates the rules of warfare and commits war crimes en masse ,, the possibility of chemical, biological, radiation, nuclear (CBRN) terrorist incidents increases significantly.

CBRN threats are changing, and although their use in conflict is prohibited, this does not stop the production or use of these weapons. The willingness to use CBRN assets in combat, previously considered unacceptable by any leader for fear of international condemnation, is a very worrying trend. As the events of recent years have shown, no criticism can stop the leaders of quasi-states from such actions [3].

Ukraine belongs to the countries with a high level of nuclear energy development. Currently, there are four nuclear power plants (NPP) operating on the territory of Ukraine, which use 15 nuclear power reactors (AER), another 4 NPPs (one of which was destroyed) are in a stopped state at the Chernobyl NPP. [4–6].

At the present stage, personal protective equipment, which is provided to the personnel of the Armed Forces of Ukraine, according to the nomenclature of radiation, chemical, biological (RCB) protection weapons, does not protect the organs of vision from ionizing radiation, namely from (alpha and beta) particles that occur in conditions of radioactive contamination (contamination), as well as the influence of factors that may arise as a result of destruction (accidents) at radiation-hazardous facilities (RNOs) and places of conservation and use of sources of ionizing radiation.

Of concern is the fact that the management team does not have a proper understanding of the need to protect personnel from exposure to ionizing radiation, namely: the protection of the organs of vision in order to prevent the occurrence of
radiation cataracts.

**Analysis of recent research and publications.** In the modern special literature, which is intended for military specialists, the fundamental concepts of ionizing radiation, namely corpuscular alpha and beta radiation, are revealed at an insufficient level, and not enough attention is paid to their effect on the organs of vision. This aspect is important for assessing the degree of radiation damage to a person performing a combat mission in conditions of radioactive contamination.

The concepts of creating a complex of combat equipment (KBE) of a serviceman of the Armed Forces of Ukraine [7], an analysis of the existing means of personal protection of the leading countries of the world [8] and the current state of equipment of servicemen of the Armed Forces of Ukraine allowed us to conclude that they do not fully meet the requirements of modern armed struggle and do not allow to qualitatively solve the task of protecting a serviceman [9].

A significant drawback is that the existing documents regulating the use of personal protective equipment according to the nomenclature of RCB protection weapons do not define the procedure and rules for their use in combination with other means, in particular ballistic protection.

The scale of observation of people affected by ionizing radiation is reflected in the literature [10], which describes in detail the most important radiation incidents in the world. These include incidents at radioisotope installations and radiation sources, industrial nuclear reactors, nuclear submarines, and during nuclear tests. The most significant in their consequences are man-made accidents at civilian nuclear facilities: Three Mile Island nuclear power plants in the USA (28.03.1979), Chernobyl nuclear power plant in the USSR (26.04.1986), Fukushima nuclear power plant in Japan (11.03.2011), as well as the results of tests and use of nuclear weapons in the city of Los Alamos in the USA (16.07.1945) and in the cities of Hiroshima and Nagasaki in Japan (6 and 9.08.1945), which led to the uncontrolled release of radionuclides into the environment.

The consequences of man-made accidents at nuclear power plants, the generation of scenarios of their destruction with
the determination of the scope of measures and the necessary forces and means to eliminate the consequences of radioactive contamination are considered in works [5, 6] and [11-15]. The experience accumulated to date allows us to draw conclusions about the nature of the lesions of the human body by ionizing radiation [16]. An important property of radioactivity is ionizing radiation. Ionizing radiation - any radiation, the interaction of which with the medium leads to the formation of electric charges of various signs [17].

The purpose of the article is the analysis of possible options for the integrated use of elements of military personnel's equipment in conditions of radioactive contamination and the development of proposals regarding the content of training military personnel for actions in these conditions.

Presenting main material. To protect against alpha and beta radiation, it is enough to use glass of ordinary glasses; to protect against beta radiation, a layer of plexiglass with a thickness of 2–2.5 cm is used; lead glass with tungsten phosphate is suitable for protection against gamma rays, glass with cadmium borsilicate or fluoride compounds is suitable for protection against gamma rays [18].

During the elimination of the consequences of the accident at the Chernobyl NPP, in order to protect the spinal cord, 3 mm thick plates were cut from lead and lead melts were made. To protect the back of the head, lead screens were attached to headdresses. To protect the skin of the face and eyes from beta radiation, the brushes were made of organic glass polymethyl methacrylate with a thickness of 5 mm [7].

As can be seen from the photo (Fig. 1), due attention was paid to the protection of the eyes during the liquidation of the Chernobyl accident. Analysis of the results of scientific research shows that the lens of the eye is the most radiosensitive tissue of the body. When comparing the radiosensitivity of different eye tissues, detectable changes in the lens are noted in the dose range of 0.2 – 0.5 Gy, while other types of ocular pathology in other tissues develop in acute or fractional (multiple irradiation with an interval of several hours to several days) irradiation in the range 5 – 20 gr [8].
The average mileage of electrons in a substance is determined according to the continuous deceleration model according to the formula [9]:

\[
R(E_0) = \int_0^{E_0} \frac{dE}{(dE/dx)},
\]

(1)

where \( dE/dx \) – is the total energy loss of electrons.

It should be noted that the average mileage in environments with a large atomic number \((Z)\) does not fully reflect the physics of electron transfer processes.

For beta particles, the absorption curve has a shape close to the exponential one and asymptotically approaches the abscissa axis, crossing it at some thickness \( R_{\text{max}} \), called the maximum mileage of beta particles with the limiting energy \( E_\beta \).

For substances with a thickness less than the maximum mileage, the attenuation of the flux density of beta particles approximately corresponds to the exponential law:

\[
\varphi = \varphi_0 \exp(-\mu_m d) = \varphi_0 \cdot \exp\left(-\frac{0.693d}{\Delta_{1/2}}\right),
\]

(2)

where \( \varphi_0 \) – is the flux density of beta particles at the detection point without protection;

\( \mu_m \) – mass electron absorption coefficient, \( \text{cm}^2/\text{g} \);

\( d \) – absorber thickness, \( \text{g/cm}^2 \);

\( \Delta_{1/2} \) – a layer of half attenuation \( \text{g/cm}^2 \), usually determined experimentally.

The dependence of \( \mu_m \), \( \text{cm}^2/\text{g} \) on the maximum energy of beta particles \( E_\beta \text{ MeV} \), can be approximated by the formula:

\[
\mu_m \approx 15.5E_\beta^{-1.41} \approx 17E_\beta^{-1.43} \approx 22E_\beta^{-1.33},
\]

(3)

In this case, the thickness of the protective layer is:

\[
d = \frac{\Delta_{1/2}}{0.693} \cdot \ln \frac{\varphi_0}{\varphi} = \frac{1}{\varphi} \cdot \ln \frac{\varphi_0}{\varphi},
\]

(4)
There are several formulas for calculating the length of the run:

1. The maximum mileage of monoenergy electrons or beta particles can be taken equal to the 30% increased extrapolated mileage of monoenergy electrons or electrons with maximum energy in the spectrum of beta particles, respectively. This value makes it possible to obtain an upper estimate of the maximum mileage.

2. Extrapolated mileage \( R_{\text{ex}} \), g/cm\(^2\) of monoenergy electrons in the energy range from 0.3 keV to 30 MeV for materials with atomic numbers from 5.3 (effective atomic number for polyethylene) to 82 at normal fall can be determined by the formula:

\[
R_{\text{ex}} = a_1 \left[ \frac{1}{a_2} \ln(1 + a_2a_0) - \frac{a_3a_0}{(1 + a_4a_5a_0)} \right],
\]

(5)

Where \( E_0 = \frac{E_0}{m_0c^2} \) (\( E_0 \) - electron energy, MeV; \( m_0c^2 \) - electron fielding energy; \( m_0c^2 = 0.511 \) MeV);

\[
a_0 = \frac{E_0}{m_0c^2},
\]

\[
a_1 = \frac{0.2335M}{Z^{1.209}},
\]

\[
a_2 = 1.78 \cdot 10^{-4}Z;
\]

\[
a_3 = 0.9891 - 3.01 \cdot 10^{-4}Z;
\]

\[
a_4 = 1.468 - 1.180 \cdot 10^{-2}Z;
\]

\[
\frac{1.232}{Z^{0.109}} \quad (M \text{ - atomic mass}, \ Z \text{ - atomic number}).
\]

The maximum error of the approximating ratio (5) will be:

- for \( E_0 > 1\) MeV 4.5%; for \( E_0 < 1\) MeV, %.

The above mathematical apparatus makes it possible to determine the thickness of the protective screen layer, taking into account the energy of the electron and the properties of the substance from which the screen will be made.

Protective ballistic goggles are made of a single size and consist of the following elements:

- frame 1 (a solid element that holds the lens and serves
as the basis for fastening the locking system and the main belt);  
- replaceable polycarbonate lens 2 with a thickness of 2.4 mm to 3.2 mm, which provides high-quality eye protection;  
- head belt 3 (elastic belt, provides fit of the product to the face and fixation of the OMZB on the head or helmet) on which the anti-glare cover is placed (to prevent unmasking glare from the lens when placing the OMZB on top of the helmet and for protection in this position from sand, dust and other small particles, fragments).

Taking into account the thickness of variable polycarbonate lenses [16], the results of studies that are given in the literature [16, 17], the testimony of the doctor of technical sciences, Major General M.D. Tarakanov, who led the operation to remove highly radioactive elements from particularly dangerous zones of the Chernobyl nuclear power plant [18], it is possible to formulate proposals to ensure the protection of personnel under the influence of ionizing (corpuscular) radiation through the integrated use of existing elements of military equipment, namely: protective ballistic protective mask goggles.

The current guidelines and instructions do not reflect the issues of protecting the organs of vision in order to prevent the occurrence of radiation cataract of the lens of the eye as one of the constituent parts of radiation sickness. Solving this problem becomes possible due to their addition and unconditional use by personnel with the mandatory use of protective ballistic glasses-masks in a complex with personal protective equipment.

Recently published observations [8, 19] of people who are chronically irradiated indicate the existence of a long-term risk of developing cataracts and the need for eye protection even at low doses of radiation.

Based on the above, in conditions of radioactive contamination (pollution), it is recommended to protect the organs of vision with protective ballistic glasses-masks, which, thanks to their design and the properties of the materials from which they are made, prevent:  
- the effect of radioactive substances on the mucous membrane of the eyes and the skin around them, which greatly
facilitates their removal during remediation;
- the appearance of the main pathology of the lens of the eye (cloudiness), which is called a cataract at a late stage of its development.

**CONCLUSIONS.** Thus, the paper analyzes possible options for the complex use of elements of equipment of military personnel in conditions of radioactive contamination (pollution) and makes a proposal regarding the content of training military personnel for actions in the specified conditions, taking into account the existing state of personnel support. The process of using protective equipment under conditions of exposure to corpuscular radiation on the human body has been studied.

Formulated proposals to ensure the protection of personnel in conditions of exposure to ionizing (corpuscular) radiation through the comprehensive use of existing elements of the equipment of military personnel, namely: protective ballistic glasses-masks, which will allow to prevent the ingress of radioactive substances on the mucous membrane of the eyes and the skin around them, significantly will facilitate their removal during sanitation.

The above-mentioned proposals can be reflected in the instructions and algorithms of actions in the conditions of impact on the personnel of ionizing radiation and programs for the creation of a complex of combat equipment for servicemen of the Armed Forces of Ukraine.

**References:**


MILITARY AFFAIRS
AND NATIONAL SECURITY

Vancouver, Canada
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