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RADIATION PHENOMENA: SOME NATURAL SOURCES, MECHANISMS OF EFFECTS, WAYS OF BIOLOGICAL ORGANISMS PROTECTION AND REHABILITATION

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Radiation is an important and dangerous factor in contemporary reality in some regions of industrial countries, after technological accidents at nuclear objects, chemical enterprises, etc. This is also the reality of some contemporary military activities and armed conflicts. Radiation damages of organisms can arise also due to the natural reasons — aviation or space flights at high altitudes or even long stay on mountain heights. Natural reasons of such effects have been studied insufficiently for today.

Purpose. To outline briefly some results of studies of the characteristics of ionizing radiation at different heights above the Earth. To describe briefly the influence of radiation factors on biological organisms and main mechanisms of these effects. To describe effects that cause pathological changes in organisms of people exposed to the low doses of radiation for a long time and methods of post-radiation rehabilitation of affected people in highlands conditions.

Methods. Space satellite exploring of the Earth atmosphere at different altitudes above sea level with measurements of different characteristics of solar and galactic radiation (mainly X-ray, gamma radiation, as well as other types of ionizing radiation in some other ranges). Comparative analysis of the results of long-term observation of patients in hospital conditions using many standard laboratory methods of their states examinations. The conducted scientific research consisted of a complex of methodological techniques and approaches: clinical and physiological studies of respiratory and cardiovascular systems, hematological and immunological states, and functional state of higher nervous activity, mental and neurotic state; administration of antihypoxants, histochemical, biophysical and other methods were used to evaluate oxybiotic processes. Mathematical processing of the results, as well as methods of mathematical modeling were applied.

Results. The results of the measurements of ionizing radiation levels during the satellite exploring of the Earth atmosphere at different altitudes were analyzed and presented in schemes. The mechanisms of damaging radiation effects in organisms at nano level were described: water radiolysis, "oxygen effect" as radio sensitizer, formation of various types of free radicals and peroxides with future consequences for organic compounds, cells, tissues, organs, and organisms. The results of medical treatment and rehabilitation at the EMBS of the persons irradiated by the low doses of radiation were presented, observed and discussed. Many of represented results were obtained thanks to the collective work of the great commands of our predecessors in science who searched for the possibilities of medical treatment and rehabilitation of patients who obtained low doses of radiation during long time. The contemporary results of possibilities of some developed pathological states pharmacological corrections were discussed; practical recommendations were done.

Conclusions. Some of results of fulfilled works, which can be valuable in the treatment and rehabilitation of people of various contingents exposed to low doses of radiation of various natures for a long time, were presented. The outlined recommendations can be offered to persons of various radiation risk contingents for the purposes of their rehabilitation, in practice of health care, etc.

Key words: radiation damage to organisms, high altitudes, adaptation, radioprotectors, correction.

Increased level of radiation is an important and dangerous factor of contemporary reality in some regions of industrial countries, after technological accidents at nuclear objects, as well as reality of some contemporary military activity and armed conflicts. Radiation damages of organisms can arise also due to the natural reasons — aviation or space flights at high altitudes or long stay in mountain conditions. Natural reasons of these effects have been studied insufficiently for today. But it is known that the high level of radiation in mountain conditions is formed due to two main reasons: 1 — high level of space radiation due to a smaller (compared to sea level) thickness of the residual layer of the atmosphere and 2 — the higher radiation of granite rocks in comparison with sedimentary rocks. People are also exposed to small doses of radiation during flights at high altitudes, primarily pilots, but the effect of this factor on their organisms has not yet been studied in detail. It should be noted that common features characterize many mechanisms of the influence of ionizing radiation on biological organisms. Accordingly, some individual methods for correcting radiation damage, studied on one of the models, can be applied (after the appropriate studies) on another model.

Our studies of these phenomena were based on the results of the work of the groups of our predecessors in science, who worked at Elbrus Medical and Biological Station (EMBS) under the leadership of its Director Prof. Pavel Beloshitsky for many years, and under whose supervision Dr. Klyuchko Olena performed numerous scientific works. Results of numerous contemporary investigations in these directions we have accumulated in present observation [1–65]. Among them there are our personal publications linked with these items [1–3, 64, 65]. Studies of the influence of radiation factors under the high-altitude meteorological conditions, adverse environmental conditions (for example, as a result of Chernobyl tragedy) and the possibility of subsequent rehabilitation of the people exposed to these factors were the subjects of research at the EMBS for a number of years. Organization EMBS was subordinated to the National Academy of Sciences of Ukraine during long years, and it was located in Caucasus Mountains on the territory of Kabardino-Balkarian Republic (now — territory of Russia). This station was located in the highlands of the Caucasus on the slopes of Elbrus, the highest mountain in Europe — 5,641 m above sea level (a.s.l.). EMBS was the site of many years of research by Ukrainian scientists, as well as scientists of other multinational teams. They studied and solved topical problems in biology and medicine using the latest methods at every stage. Research works were started here by Academician M. M. Sirotinin in 1929 and continued by his students [1, 64, 65]. A number of obtained here results (often unique) in various fields of knowledge have already been observed in our previous publications. There were represented our results, obtained in various directions of investigations at EMBS and later, in process of works with the results previously obtained at EMBS [66–75]. Important results of the study of radiation effects on living organisms were obtained and accumulated at EMBS long before 1986. Also there were obtained numerous results and suggested the ways of rehabilitation of irradiated persons in highlands conditions. So, with all this potential (intellectual, laboratory, hospital conditions, others), already in the first days after the Chernobyl accident, EMBS Director at these times, Doctor of Medical Sciences Pavel Beloshitsky and the staff of the station were suggested to start post-radiation rehabilitation of affected people in the conditions of the Caucasian mountains as well as the search of new ways for their treatment. This program was successfully implemented at EMBS, as a result of which significant number of the people obtained here their treatment and were successfully recovered ("chernobyltsy" — Chernobyl residents as well as "liquidators" of the consequences of the Chernobyl accident — people who fought with the consequences of that accident) [64, 65].

Works on the rehabilitation of "chernobyltsy" and "liquidators" were started at EMBS on May 1986 [64, 65]. This happened after the approval of the information sheet on the use of the methods of treatment and rehabilitation of irradiated persons in mountain climate conditions developed at EMBS in combination with taking antioxidants, vitamins and other medical substances; document is by Academic Councils of O.O. Bogomoletz Institute of Physiology of the National Academy of Sciences of Ukraine and the Institute of Oncology and Radiology of the Ministry of Health of Ukraine (May, 1986). Below there are some of results of these works, which can be valuable in the treatment and rehabilitation of people of various contingents exposed to low doses of radiation of various nature for a long time.

To outline briefly some results of the radiation researches in space physics and geophysics; influence of these factors on

biological organisms and main mechanisms of these effects. To describe influences that cause pathological changes in organisms of people exposed to the low doses of radiation for a long time and methods of post-radiation rehabilitation of affected people in highlands conditions, including pharmacological corrections of some damages. We would like to apply further such methods in health care practice, for students' education, and to continue these researches.

Radiation effects at different altitude levels above the Earth surface up to the ionosphere: brief analysis. In some our preliminary works we had observed the influence of ionizing radiation at different altitudes above the Earth surface on various substances and objects in the atmosphere [1]. The necessity of such works was caused by the high radiation doses, obtained by the pilots and passengers during the flight, radiation influences on the surfaces of the aircrafts such as airplanes, satellites, etc. Continuing this theme in present work, we would like to observe the specificity of some factors that cause such effects. According to contemporary imaginations, total radiation above the Earth can be subdivided mainly onto two main components – solar radiation and galactic radiation, both have different origin and characterized by different physical characteristics (sometimes other components are distinguished too). Contacting with the atmosphere, they cause such phenomena, as ionosphere. The ionosphere could be called "plasma covering membrane of the Earth" [2–9, 19], and its properties had been studied deeply and reflected in numerous publications [2–64]. The manuals specify that the ionosphere covers the region of near-Earth space in the height range from 50 km, where the presence of free electrons already noticeably affects the propagation of radio waves, up to a conditional 1000 km, where the ionosphere continuously transitions into the magnetosphere. The ionosphere includes regions D (50–90 km), E (90–140 km), F1 (140–200 km), and F2 (above 200 km). This division is not only traditional, but also reflects the difference in physical processes that define the state of plasma at different altitudes. Fig. 1 demonstrates the standard profile of the ionosphere — the dependence of concentrations of free electrons on different heights. A logarithmic scale is applied to the horizontal axis, which visually smooths the graph; in fact, the plasma concentration at the altitude of, f.e., 300 km is 5–10 times higher than at 100 km. Thus, the profile of the ionosphere is stretched in vertical direction. The main mass of the plasma is enclosed in layers at altitudes of 200–600 km. Unlike the neutral atmosphere, the ionospheric layer does not adhere to the Earth's surface, but, as we can see, floats above it.

The ionosphere is formed as a result of atmospheric absorption of solar radiation at altitudes of 100–200 km. In the range of wavelengths less than 1000 (extreme ultraviolet and X-ray), the energy of photons exceeds the thresholds of dissociation and ionization of atmospheric gases, which initiates chains of photochemical reactions in the atmosphere, and this radically changes the properties of the atmosphere.

The ionosphere is not a static object, but a stationary process of circulation of neutral and charged particles. Arising under the action of solar ionizing radiation, charged particles partially recombine with each other, returning to the mother's neutral atmosphere, and partially flow along the lines of force of the Earth's magnetic field upwards into the magnetosphere. At night, the plasma stored in the magnetosphere descends to the heights of its birth and recombines. So, if to speak about such effects on living organisms at different altitudes, we have to subdivide two main factors of influences: 1) the radiation by itself (solar, galactic, or other types) (Figs. 1, 2); and 2) influences of charged atmospheric particles (Fig. 3). These effects were already studied and observed, the results were presented on Figs.1, 2, 3 [26] and Fig. 4.

The spectrum of solar radiation includes a powerful and very stable optical part (visible part of the spectrum, the "solar constant"), as well as weak and variable short-wave and long-wave components (solar activity). The

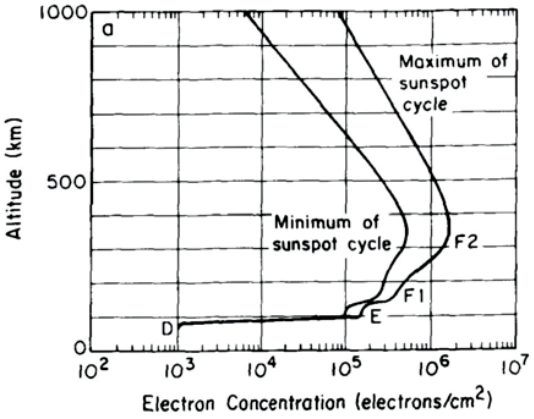

Fig. 1. **Dependence of ionospheric plasma concentration (horizontal axis) on height (vertical axis) in conditions of low and high solar activity [1, 2, 19, 26]**

upper atmosphere is a chemically active environment under the aggressive influence of solar radiation. The upper atmosphere is a "photochemical boiler". Plasma is born, drifts up and down and recombines. In such a way the ionosphere is formed. The spectrum of solar radiation is represented on Fig. 2. Radiation in the ranges of this spectrum causes its effects on the biological organisms at different altitudes in the Earth atmosphere. These various effects associated with high-energy, radiative effects on substances in the atmosphere and at the surface of the Earth's, as well as on living organisms at different heights above the Earth's surface. According to the known regularities of the Nature, the part of the cosmic and solar radiation that enters the atmosphere dissipates, other part is absorbed — most strongly in the upper layers of the atmosphere — the ionosphere, and part of the component is reflected from the upper layers of the ionosphere, as from a mirror. In other words, due to all the above effects, the Earth's atmosphere protects biological beings at the bottom of this "atmospheric ocean" (the Earth surface) from the harmful effects of solar ionizing radiation. However, the intensity of both cosmic and solar radiation fluxes to the Earth is very high. Therefore, a certain part of the components of this ionizing radiation flux still "breaks through" the atmospheric shell and reaches the Earth's surface. Studying dangerous influence of observed kinds of radiation on biological organisms we have to take into account all these phenomena.

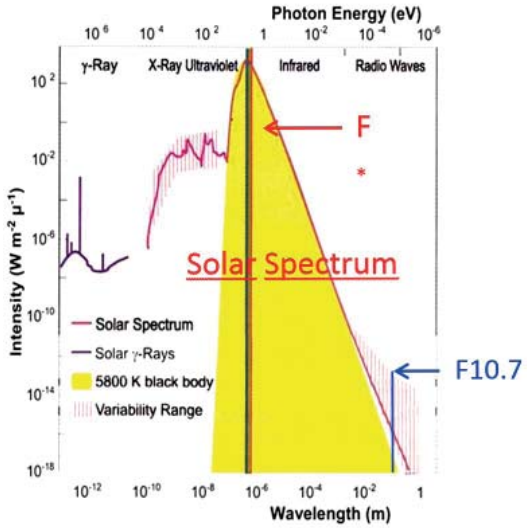

Fig. 2. **Solar spectrum — spectrum of solar radiation that penetrates the Earth atmosphere from the upper layers of the ionosphere down to the surface of the Earth (explanations see in text) [1, 2, 19, 26]**

We had mentioned above about the influence of solar and galactic radiation on particles in atmosphere. When particles in the upper atmosphere are exposed to solar radiation, energy is transferred to them, which transfers the simplest molecules and atoms of elements in the gases of the atmosphere into an excited state, which leads to their transformation. It causes the formation of such forms as ions, free radicals, various other charged particles with high energies that are able to damage biological organisms. Space is not empty! At an altitude of 600 km, the concentration of particles is ~106 cm^{-3}, and far in interplanetary space is ~10 cm^{-3}. But for understanding the properties of the space environment, it is not so much the concentration that matters, but the length (distance) of the free path of the particles. The closer to the Earth's surface, the shorter the free distances (paths) between the particles of the atmosphere. And vice versa — the higher above the Earth's surface, the greater the free path between these particles. This dependence is shown in Fig. 3.

The direction of the arrows coincides with the direction of the ionizing radiation flux vectors — i.e. to the surface of the Earth. When considering the physical and physio-chemical effects, it is indicated whether they increase or decrease in this direction (explanations see in text).

Studying various natural phenomena that cause numerous effects associated with high-energy, radiative effects on substances in the atmosphere and at the surface of the Earth

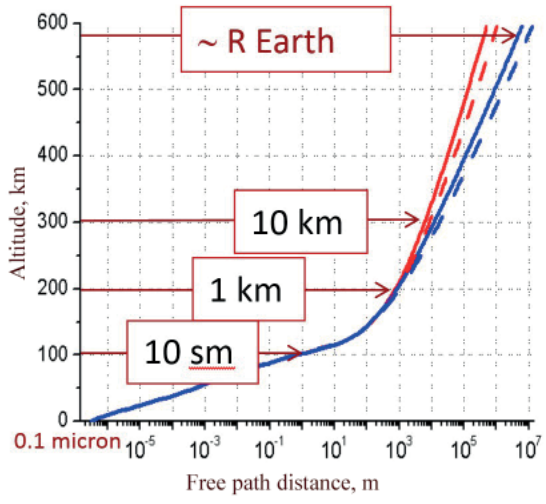

Fig. 3. **Various densities of matter particles (gases, microscopic dust particles other) at different altitudes above the Earth surface (explanations see in text) [1, 2, 19, 26]**

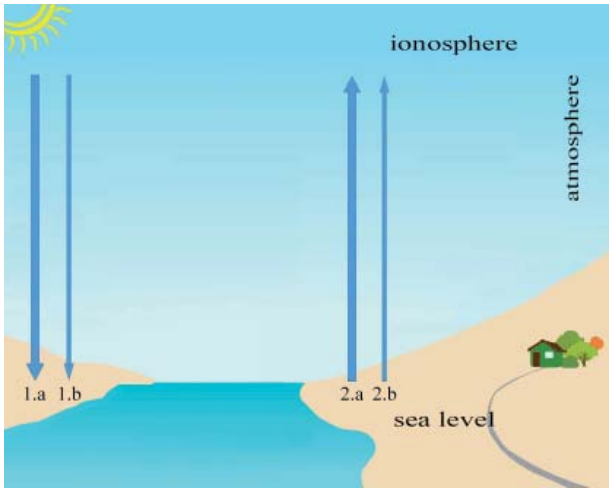

Fig. 4. **Various natural phenomena that cause numerous effects associated with high-energy, radiative effects on substances in the atmosphere and at the surface of the Earth**

as well as biological objects, we distinguished four groups of effects; they are listed below (see also Fig. 4). These effects, their changes in time and interrelations are on the Fig. 4; they all are given below.

1.a. Increasing of effects along the vertical "ionosphere — Earth surface"

1) The densities of matter particles at different altitudes above the Earth surface increase (gases, microscopic dust particles others – up to biomolecules and solid matters). 2) Number of neutral particles in atmosphere increases. 3) Protective properties of the atmosphere increase.

1.b. Decreasing of effects along the vertical "ionosphere — Earth surface"

1) Radiation in the narrower ranges of spectrum is registered close to the Earth surface. 2) High-energy, high intensity radiation is registered in ionosphere; it decreases in direction to the Earth surface. 3) Various effects associated with high-energy, radiative effects on substances decrease. 4) The closer to the Earth's surface, the shorter the free distances (paths) between atmospheric particles. 5) Radiation doses, obtained by persons during the flight. 6) Radiation influences on the surfaces of the aircrafts. 7) Number of charged particles and free radicals in atmosphere decreases. 8) Aggressive influence of solar radiation decreases.

2.a. Increasing of effects along the vertical "Earth surface – ionosphere"

1) Radiation in the widest ranges of spectrum is registered in ionosphere. 2) High-energy, high intensity radiation is registered in the ionosphere; it increases in direction to the ionosphere. 3) Various effects associated with high-energy, radiative effects on substances increase. 4) The further from the Earth's surface, the longer the free distances (paths) between atmospheric particles. 5) Radiation doses, obtained by persons during the flight. 6) Radiation influences on the surfaces of the aircrafts. 7) Number of charged particles and free radicals in atmosphere increases. 8) Aggressive influence of solar radiation increases.

2.b. Decreasing of effects along the vertical "Earth surface – ionosphere"

1) The densities of matter particles at different altitudes above the Earth surface decrease (from biomolecules and solid matters — to gases, microscopic dust particles others). 2) Number of neutral particles in atmosphere decreases. 3) Protective properties of the atmosphere decrease.

So, in this chapter, we considered various natural phenomena that cause various effects associated with high-energy, radiative effects on substances in the atmosphere and at the surface of the Earth's, as well as on living organisms at different heights above the Earth's surface. In the chapter below the mechanisms of the radiation influence on atoms and molecules in living organisms will be explained in details.

Mechanisms radiation influences on organisms. Organisms irradiation in conditions of high-altitude flights and high altitudes. In this chapter, we will consider how those components of ionizing radiation that enter the lower layers of the atmosphere affect water molecules, biological macromolecules, living organisms in these layers and on the surface of the Earth. The materials of this chapter are based on long-term studies of teams of Ukrainian scientists at the EMBS of the National Academy of Sciences of Ukraine, some of which were included in the book [65]. So, these studies were carried out at altitudes comparable to the height of Mount Elbrus (5642 m a.s.l., Caucasus Mountains).

The problem of biological effects of ionizing radiation is, actually, the problem of the excess of radiant energy transfer to a living system, biological substrate and the subsequent destiny of this energy in cell, or in organism. Ionizing radiation is high energy radiation; its carriers — ionizing particles and quanta (photons) carry such significant energy that during primary or secondary (neutron fluxes) interaction with atoms (molecules) of

substances they cause ionization (they pull out individual electrons from an electrically neutral atom or turn its nucleus into an ionizing particle).

For the destiny of irradiated cell, organism, the fact that the primary and secondary products of interaction of high-energy radiation with a living system have a powerful chemical and biological activity, start, initiate a whole chain of successive chemical (biochemical) reactions. It is these chemical reactions transformations, reaching vital cellular structures (DNA, nuclear chromatin, systems of biological membranes, mitochondria) cause their more or less deep, up to irreversible damage, lead to the death of some of the most radiosensitive cells or the entire organism [65].

It is especially important that the radiation death of organism, including such perfect one as human organism, occurs at doses of ionizing radiation that do not cause noticeable increase of living system temperature. This so-called "radiobiological paradox" is known for a long time. It means that it is not the amount of absorbed energy that is decisive for the destiny of the irradiated organism, but the number and chemical (biochemical) activity of those active products that are formed after the effect of primary ionization, as well as electronic excitation of atoms in living system [65].

What are these active products?

The knocked-out electrons can move freely between atoms for some time until they join neutral particles (atoms, molecules), forming negatively charged ions. Consequently, an electronic vacancy, a "hole" in the place of ejected electron, turns the corresponding atom (molecule) into a (+)-ion. Along with (+)- and (-)-ions, excited atoms also can be formed. In such atoms the electron is not knocked out of the atom, but only moved to a higher electronic level. Such atom also has reserve of additional energy and therefore it is capable to be involved into more diverse chemical reactions than an unexcited atom.

Since The tissues of the human body consist on 65–70% of water, the primary radiation-chemical reactions develop primarily in the aqueous phases. In this case, the ejected electrons in the aquatic medium acquire additional stability, each being surrounded by a kind of envelope of water molecules (hydrated electron, e'_{hydr}). Ions H_2O^+ and H_2O^-, as well as excited H_2O^* molecules decompose easily with the formation of H· protons and molecules of hydrogen H_2, free radicals O_{2-}·, HO_2, ·OH and –OH·. In this case, the initial amount of reducing (e^-_{hydr}, H·, H_2) and oxidizing (O_2·, ·OH, H_2O_2) products is the same [65].

However, further, already at the second stage of transformations of products of water radiolysis, living tissues, oxygen starts to play its role. Being a necessary component of living tissues, it is present in the extracellular and intracellular environment, in all liquid media of organism, oxygen directly reacts with primary products of irradiation. Following reactions are going [65]:

$$e^-_{hydr} + O_2 \rightarrow HO^{\cdot}_{2-} \quad (1)$$

$$H\cdot + O_2 \rightarrow HO^{\cdot}_2 \quad (2)$$

As a result, all elementary products after interaction with O_2 acquire oxidative characteristics. Indeed, the radiation injury, radiation sickness is the result of the attacks of vital cellular structures by active oxidative products of radiation. Among them there are following free oxidizing radicals: superoxide O_{2-}·, hydroperoxide HO_2·, hydroxyl ·OH, as well as the so-called singlet oxygen $^1O_2$, hydrogen peroxide H_2O_2. When oxygen and oxidizing water radicals interact with organic radicals (R·), hydroperoxide radicals and hydroperoxides can be formed easily [65]:

$$R^{\cdot} + O_2 \rightarrow ROO^{\cdot} \rightarrow ROOH \quad (3)$$

$$R^{\cdot} + HO^{\cdot}_2 \rightarrow ROOH \quad (4)$$

After the interaction with molecular oxygen, all active irradiation products not only become strong oxidizing agents, but also acquire a longer life time. So, after this they obtain a longer time of life and, consequently, a greater radius of action on biologically important cellular structures. Therefore, the presence of oxygen enhances significantly the damaging effect of ionizing radiation — 3 times more by maximum! In other words, the oxygen which presents in the tissues at the time of irradiation behaves as radiosensitizer, as a substance that increases the sensitivity of organic comcalled "oxygen effect" characterizes the most important role of oxygen in the biological effect of radiation [64, 65].

Radiation disorganization of oxidative and energy metabolism makes an additional contribution to radiation damage of organism.

Finally, the process of post-radiation restoring of biological structures, return of irradiated organism to a more or less normal life needs energy supply, biosynthetic processes and, consequently, the participation of oxygen, the activation of oxidative

phosphorylation. So, oxygen is an active and necessary participant in the process of reparation of structures affected by irradiation and, consequently, acts in an opposite way to the primary oxygen effect.

Therefore, approaching theoretically, by increasing and decreasing O_2 content in body cells, one can try to correct the effects of ionizing radiation within certain limits. Based on these considerations, EMBS scientists proposed an effective way of post-radiation recovery of cells, tissues, and organisms on 1986 [64, 65]. It became possible to develop these methods as a result of long-term works at EMBS. It had happened due to the fact that for a number of years, a lot of attention at EMBS was paid to the study of O_2 role in organism and the effect of its lack (hypoxia). Consequently, a large amount of results, various materials were developed [1, 64, 65]. It was shown that the dosed effect of hypoxic hypoxia, primarily the factors of high mountains (among which mountain hypoxia played the leading role) stimulated the vital forces of irradiated organism, increased its non-specific resistance, accelerated the medical and social rehabilitation of people from the radiation risk contingent [1, 64, 65]. The use of developed approaches helped to restore the health of significant number of affected Chernobyl residents who underwent treatment and rehabilitation at the EMBS.

The influence of adaptation to the factors of mountain conditions on the state of irradiated organism. The analysis of accumulated experimental data makes it possible to give a comparative estimation of the effectiveness of existing means of increasing of organism's resistance to extreme factors [1, 64, 65], including radiation factors. Based on the researches at EMBS, the use of active adaptation to the high-altitude climate for this purpose is recognized as the most promising [64, 65]. Accordingly, among the various methods of training and adaptation to high altitudes, the most effective regimen for increasing the organism's resistance is recognized as the stepwise high altitude adaptation. In animal experiments, it was shown that primary adaptation to high-altitude hypoxia (adaptation to high-altitude conditions) significantly increases animals' resistance to cold, ionizing radiation, blood loss, and lateral accelerations; to cyanides and factors that cause myocardial necrosis, hypertension, etc. In addition, numerous results of empirical observations are known, which indicate that patients with anemia, respiratory allergies and other diseases can be recovered quite quickly in mountain conditions.

The transient processes occur that disrupt the activity of antiradical and antioxidant protection with the changes in the external environment, complex action of various adverse factors, action of large doses of high-frequency radiation waves, ultraviolet and ionizing radiation. In this case, a side effect of excess O_2 is revealed, this is so-called oxygen effect [65]. At the same time, the presence of ions of variable valence (including calcium of the endoplasmic reticulum, iron, which is a part of the heme released during the breakdown of methemoglobin), activates peroxide and radical processes. Therefore, the facts of the increase of the number of organic lesions and encephalopathies in liquidators of the Chernobyl accident can be explained by the activation of peroxide processes and closely related phenomena of intercellular interactions in blood capillaries, membrane permeability disorders, and development of circulatory and tissue hypoxia [64, 65].

Many researchers recommend using the climate of mountain heights for the rehabilitation of such pathological conditions as anemia of various etiologies: hemolytic, post-hemorrhagic, post-radiation, hypoplastic, as well as caused by the action of chemical substances. Recommendations were based on positive morpho-functional and biochemical dynamics of blood indicators: increase in hemoglobin content, disappearance of metabolic acidosis, normalization of glucocorticoid supply of organism and content of ovarian steroids. The success of the treatment of iron-deficiency anemias in mountains should be accompanied by obvious intake of iron-containing medical preparations in combination with vitamin and antioxidant therapy both before arriving in the mountains and during the stay in mountains [64, 65].

Obtained data form theoretical basis for the researches of possibilities of using the mountain climate for the purpose of irradiated patients' medical treatment, for the development of appropriate indicators, contraindications and recommendations. Several hundred people were examined on the basis of EMBS — sick and healthy residents of Kyiv, Slavutych, Borodyanka in the 1990s of the XX century. A comprehensive estimations of the state of health of examined persons were carried out primarily in Kyiv, and later in the mountains at EMBS: on the 2^{nd}-3^{rd} day after arrival in Terskol (2100 m), and on the 22^{nd}-23^{rd} day after active gradual acclimatization.

Complex method of rehabilitation included climate treatment in mountain conditions for 24 days, a dosed movement regime, ascents on a cable car to altitudes of 2750–3700 m a.s.l., dietary, phyto-, narzanotherapy, thermobarotherapy, etc. [64, 65].

The conducted scientific research consisted of a complex of methodological techniques and approaches: clinical and physiological studies of respiratory and cardiovascular systems, hematological and immunological states, and functional state of higher nervous activity, mental and neurotic state; histochemical, biophysical and other methods were used to evaluate oxybiotic processes. Some data are represented in the Tables 1, 2 [1, 64, 65].

During the studies of the processes of transport and utilization of oxygen at the systemic and tissue levels in irradiated persons during rehabilitation in the conditions of mountain heights the following results were

Table 1

Indicators of the efficiency of respiratory system, obtained in Terskol (2100 m a.s.l.) during patients examination on the second (1) and twenty-second (2) days of adaptation [64, 65]

Name	Minute volume of respiration (MVR), $l.min^{-1}$		Alveolar ventilation (AV), $l.min^{-1}$	Respiratory volume (RV), ml	Respiratory rate (RR)	Ventilation rate (VR)	Oxygen effect of respiratory cycle (OERC), ml/r.c.
1-st	1	7.0	4.4	500	0.77	40	13.0
	2	6.5	3.5	440	1.00	46	16.0
2-d	1	5.9	4.6	530	0.89	32	16.0
	2	5.3	2.9	670	0.82	47	14.0
3-d	1	6.6	4.4	410	0.84	35	12.0
	2	6.7	5.3	560	0.79	39	14.0
4-th	1	5.3	2.5	300	0.82	55	5.4
	2	6.2	3.8	410	0.73	43	9.4
5-th	1	5.0	3.7	360	0.77	40	9.1
	2	4.6	3.4	420	0.79	44	9.1
6-th	1	5.2	3.5	330	0.83	44	9.5
	2	5.1	3.6	430	0.73	38	11.0
7-th	1	3.6	2.2	210	0.78	41	5.2
	2	3.5	3.1	350	0.85	32	11.0
8-th	1	7.3	3.9	610	0.92	44	14.0
	2	6.7	4.7	670	0.90	41	16.0
9-th	1	4.9	2.9	450	0.75	30	15.0
	2	5.0	3.1	420	0.76	35	12.0
10-th	1	462	3.0	720	0.97	40	9.4
	2	4.8	3.3	440	0.80	45	9.8
11-th	1	5.8	4.4	440	0.84	35	13.0
	2	6.0	5.0	500	0.75	32	16.0
12-th	1	3.7	2.1	270	0.95	43	6.2
	2	4.2	2.6	260	0.90	44	6.3
13-th	2	7.6	4.9	630	0.90	43	15.0
M	1	5.3	3.4	425	0.85	39.9	10.6
	2	5.5	3.8	477	0.82	40.1	12.3
m	1	0.3	0.3	42	0.02	1.9	1.08
	2	0.3	0.2	34	0.02	1.4	0.86

Comments. The leftmost column shows the order number of the individual examined patients (names are not given in accordance with medical ethics).

registered. After twenty days of adaptation, the respiratory and hemodynamic systems of the examined people began to work more economically, the O_2 content in the arterial blood increased in almost all the observed persons. Such an increase allowed organism to provide the necessary rate of O_2 delivery by arterial blood at a lower minute volume of blood. An increase in O_2 content in mixed venous blood was also registered.

Anti-radiation effect of medical preparations that are capable to increase the level of physiological antioxidant system. As it was mentioned above, under the conditions of exposure to low-intensity radiation for significant periods of time, a state of oxidative stress occurs in organism. A long-term state of oxidative stress leads to a gradual "burnout" of endogenous antioxidants (AO), to a decrease in the efficiency of the AO enzyme systems. As a result, the insufficient power and efficiency of the physiological antioxidant system (FAOS), its depletion under the action of low-intensity irradiation, is the limiting factor determining the organism's stability.

In these conditions, the most effective against the consequences of organism irradiation is the use of those medical preparations that can increase the power of the PAOS, namely antioxidants, adaptogenes, immunomodulators. The authors have already published descriptions of some experiments of the study of effects of some substances capable of such functions performing [1]. Reducing the intensity of lipid peroxidation (LPO) and replenishing endogenous antioxidant (AO)-resources, having low toxicity, AO were able to counteract effectively the negative effects of long-term low-intensity irradiation. Since LPO activation is a necessary molecular link of the mechanism of stress, including one of non-radiational nature, the use of AO is able to counteract the undesirable effects of environmental and psychoemotional stress. On the other hand, adaptogens and anti-stressor medical preparations are effective even with long-term exposure. Finally, immunomodulators, under the condition of very careful and dosed use, are capable of mitigating the effects of post-radiation immunodeficiency, which is inherent to contingents of radiation risk from the Chernobyl zone [63–65].

All medical preparations that can be assigned to the specified group are actually different from both radioprotectors and means of treatment of radiation injuries. First, they were introduced, mainly, against the background of exposure continuation, but not before and not after its finishing. Secondly, they are united by a general focus on overcoming (mitigating) of early post-radiation processes, such as LPO activation, stress response. Therefore, EMBS scientists proposed to allocate them to a special third group of anti-radiation substances — means of early pathogenetic therapy of radiation damage [63–65].

The substances and preparations for some pathological states pharmacological corrections we had suggested already on the base of the works, done by Dr O. Gonchar and her colleagues [114–123]. For pharmacological correction of disorders caused by radiation, following substances and preparations as fullerene C60, yackton, sufan, splenozide, others can be used; they primarily were studied as antioxidants and suggested for hypoxia disorders corrections [1, 85, 116–118].

The effectiveness of mountain climate therapy. The state of oxygen deficiency is pathogenetically related closely to the main clinical syndromes characteristic of irradiated people ("liquidators", residents of the Chernobyl zone, others). These clinical manifestations include iron-deficiency anemia, encephalopathies, vegetative-vascular dystonias, as well as secondary immunodeficiencies, which are accompanied by an increase in the frequency of acute inflammatory diseases (primarily respiratory), exacerbations of chronic diseases, and an increase in their duration and frequency of complications. Therefore, the correction of hypoxic conditions in various categories of radiation-affected persons, their treatment with the use of healing factors, including mountain ones, are relevant and promising. One of the effective means of increasing the organism's defenses is adaptation to hypoxybaria. The results of the effectiveness of mountain climate therapy are shown in the Table 3.

Some key results, which can be used for treatment, rehabilitation of the people of various contingents exposed to low doses of radiation (EMBS experience). Here are some conclusions made on the basis of works on the rehabilitation of the people that were exposed to the consequences of the Chernobyl accident "chernobyltsy". We note that they can be valuable for carrying out work on the treatment and rehabilitation of people from other contingents of radiation risk. These recommendations previously were published in Ukrainian [64].

Table 2

Estimated indicators of hemodynamic system and hypoxic state obtained in Terskol (2100 m a.s.l.) during patients examination on the third (1) and twentieth (2) days of adaptation [64, 65]

Patient	Day of adaptation	Minute blood volume (MBV), $l.min^{-1}$	hemodynamic equivalent (HE)	oxygen effect of the cardiac cycle (OECC). ml/beat	blood oxygen capacity (BOC).	oxygen content		saturation of mixed venous blood with oxygen. ($S\bar{v}O_2$)
						in arterial blood (CaO_2)	in mixed venous blood ($C\bar{v}O_2$)	
1-st	3-d	3.5	20.0	2.6	19	16.25	11.10	58.4
	20-th	3.3	23.0	2.2	20	18.84	14.59	72.9
2-d	3-d	4.1	23.0	2.4	18	15.21	10.82	60.1
	20-th	2.6	23.0	1.9	21	14.70	10.46	49.9
3-d	3-d	4.3	23.0	3.1	21	18.06	13.64	71.8
	20-th	3.1	18.0	3.1	19	13.33	7.84	71.2
4-th	3-d	4.3	44.0	3.2	19	16.82	14.56	44.2
	20-th	4.2	29.0	2.2	19	15.96	12.39	65.2
5-th	3-d	3.5	28.0	2.4	19	14.15	11.20	65.2
	20-th	3.8	37.0	1.5	19	17.48	13.57	78.2
6-th	3-d	4.4	32.0	2.0	18	15.84	12.66	70.3
	20-th	4.4	32.0	2.0	19	16.15	12.97	68.3
7-th	3-d	3.0	34.0	1.5	14	11.90	8.97	49.8
	20-th	2.7	24.0	2.0	16	13.60	9.53	59.5
8-th	3-d	4.7	28.0	2.4	18	15.48	11.86	65.9
	20-th	3.8	23.0	2.4	18	16.20	11.99	47.4
9-th	3-d	4.8	29.0	2.4	14	13.13	9.80	70.0
	20-th	3.4	24.0	2.1	16	13.60	9.19	57.4
10-th	3-d	4.2	23.0	3.0	15	12.00	9.62	64.1
	20-th	4.3	40.0	1.5	18	14.49	11.93	66.3
11-th	3-d	3.6	22.0	2.6	16	14.16	9.44	59.0
	20-th	4.6	24.0	2.8	19	16.91	12.78	67.3
12-th	3-d	3.9	46.0	1.4	16	13.84	11.63	72.7
	20-th	3.6	38.0	1.6	18	14.40	11.76	65.3
13-th	20-th	2.8	21.0	1.9	19	17.77	11.34	59.7
M	3-d	4.03	29.3	2.4	17.3	14.73	11.27	62.3
	20-th	3.58	27.3	2.1	18.5	15.65	11.56	63.7
m	3-d	0.15	2.4	0.2	0.64	0.54	0.50	2.5
	20-th	0.18	1.9	0.1	0.38	0.49	0.52	2.4

Comments. The leftmost column shows the order number of the individual examined patients (names are not given in accordance with medical ethics).

Table 3

Symptoms of diseases of liquidators of the Chernobyl accident according to the data of Ministry of Health of Ukraine (I), authors' data (EMBS) (II), and (III) demonstration of effectiveness of mountain climate-therapy [64, 65]

Symptoms	Frequency of symptoms, %			
	I	II	III-a	III-b
Headaches	82	100	52	48
Vertigo	91	72	48	20
Nausea	98	80	48	32
Vomiting	–	28	–	–
Pain in the eyeballs	–	48	95	20
Noise in head	36	36	16	20
Disequilibrium	81	76	52	24
Increased sweating	62	76	48	24
Astringency in throat	82	72	64	8
Sleep disturbance	64	40	32	8
Short-term loss of consciousness	37	32	28	4
Pain in area of heart	–	80	44	32
Vegetative crises	–	76	48	21
Trunk seizures	–	24	24	–
Asthenic syndrome	58	20	20	–
Decrease in working capacity	53	–	–	–
General weakness	96	–	–	–
Hoarseness of voice	64	–	–	–
Hearing loss	42	–	–	–
Motion sickness in transport	52	–	–	–
Pains in joints	–	55	8	12
Increased fatigue	–	88	72	16
Seizures of "cramp" type	–	28	20	8
Asthenic syndrome	–	20	12	8

Comments. Symptoms: a — disappeared completely, b — disappeared partially, "–" — the data were not presented.

1. The symptoms of diseases of the liquidators were determined (Table 3). Also the structure of radiation-induced morbidity of children from the 4th zone was determined: gastrointestinal diseases 78.6%, respiratory diseases 58.9%, thyroid gland 57.1%, vegetative-vascular dystonia 19%.

2. Approximately ten the most informative criteria for evaluation of "mountain-therapy" were defined. These are the criteria of the organism's oxygen balance, the efficiency of processes of oxygen transport and utilization, the degree of progressive action of hypoxia, adaptability and level of adaptation, physical and mental capacity, etc.

3. It was revealed that in the genesis of the "Chernobyl syndrome" of irradiated people, the polyfunctional disorders in the systems of transport and utilization of oxygen, which leads to the development of hypoxic conditions, are of primary importance. These states of organisms were revealed through the clinical pictures of vegetative-vascular dystonias, anemias, respiratory allergies, dyscirculatory encephalopathies, etc.

4. It was revealed that in persons chronically irradiated with small doses of radiation, the organism's reserve capacities were reduced. There are: indicators of oxygen consumption, efficiency of oxygen transport systems, and activity of respiratory enzymes responsible for urgent adaptation.

5. It was established that in the process of adaptation to the mountain climate in the specified contingent of peoples numerous characteristics were changed. There were:

psycho-emotional state and regulation of vegetative functions were improved, the parameters of respiration, hemodynamics, and the immune status of the blood were normalized, the mode and electrical activity of the heart were stabilized, degenerative changes on the part of blood cells were reduced, regeneration processes were activated, oxygen content in arterial blood was increased, lysosomal activity of white blood cells was increased, DNA synthesis was increased, activity of respiratory enzymes responsible for urgent adaptation was increased, aerobic and anaerobic tissue enzymes were activated, oxygen transport systems were economized, indicators of the level of functional mobility, dynamism of nervous processes were improved. So, in patients with anemia, "mountain-treatment" caused an improvement in the general condition and well-being, increase in the adaptation reserve, transition to a new level of regulation, improvement in the quality indicators of erythrocytes, platelets; increase in the number of erythrocytes, leukocytes, rod-nuclear neutrophils, and plasma lymphocytes; decrease in values of "ventilatory" and hemodynamic equivalents; improvement of indicators of the dynamics of nervous system, attention, ability to direct reproduce the test material, and etc.

6. For the first time, a comprehensive method of rehabilitation of "Chernobyl" residents was developed and used with high efficiency in the conditions of stepwise mountain adaptation, which includes sanatorium-resort treatment at an altitude of 550 m a.s.l. with subsequent rehabilitation at an altitude of 2100 m a.s.l. with short-term ascent to an altitude of up to 4200 m a.s.l., thermobarotherapy, phytotherapy and diet therapy, balneotherapy, etc.

7. In the peripheral blood of persons who lived and worked in the zones of radiation contamination, with a normal content of leukocytes, pronounced neutrophilopenia and lymphocytosis were registered, and with large number (up to 50%) of altered neutrophils (nuclear fragmentation), plasmatized lymphocytes with fringed cytoplasm; a decrease in the activity (in neutrophils) of NADPH was determined; in the lymphocytogram, with a normal value of large granulomatous lymphocytes, significant decrease in the level of small lymphocytes, which were the main effectors in realization of immune response, were registered.

8. As a result of experimental studies, it was shown that in irradiated animals were registered: activation of peroxidic and catabolic processes, glycolysis and proteolytic enzymes; antioxidant reserve, ATP synthesis, number of erythrocytes, blood serum relaxation time, erythrocyte resistance, total oxygen consumption decreased; and were increased: the level of spontaneous chemoluminescence, glucose consumption by erythrocytes, deficiency of buffer bases, malonaldehyde content, lactic acid concentration. Also in in irradiated animals were registered that pH shifts towards acidification; the content of serotonin and histamine increases, which increases the narrowing of arterioles, smooth muscles and bronchi; the membranes of erythrocytes were changed, which is expressed in the increase of their star-shaped forms; destructive processes occur in the capillary walls and glial phagocytes cluster around them; pericapillary couplings and the basal layer expand due to the detection of hydration centers in the basal membrane, as well as due to an increase in the number of its petals and the number of pericytes, which leads to sharp deterioration in the permeability of the blood-brain barrier; mitochondria were destroyed, the number of lysosomes were increased, respiration and phosphorylation were uncoupled. All this leaded to the emergence of a hypoxic state of the combined type (circulatory hypoxia, deoxidation), hypoergy, decrease in the organism's resistance, premature aging. All these effects can explain the development of the clinical picture described above, and they were registered by EMBS researchers in people that were exposed to the consequences of the Chernobyl accident "chernobyltsy".

9. The developed mathematical and software tools can be successfully used to estimate the functional state of oxygen transport systems in radiation pathology, in particular, to calculate indicators of the speed and intensity of oxygen utilization, voltage cascades and the speed of oxygen transport along the entire path (from lungs to tissues), cost-effectiveness systems of external breathing, hemodynamics, etc.

10. A high degree of correlation was determined between the parameters of organism's oxygen condition, adaptability, work capacity, general non-specific resistance, and the morphofunctional state of blood cells.

Thus, in present article the last results of investigation of various characteristics of ionizing radiation in atmosphere at different altitudes above sea level were given. The results of the measurements of ionizing

radiation levels during the satellite exploring of the Earth atmosphere at different altitudes were analyzed and presented in schemes on Figs. 1–4 [1–62, 76–85]. The mechanisms of damaging radiation effects in organisms at nano- level were described; among them there are water radiolysis, "oxygen effect" as radiosensitizer, formation of various types of free radicals, peroxides, hydroperoxides with future consequences for organic compounds, cells, tissues, organs, and organisms. The results of medical treatment and rehabilitation at the EMBS of the persons irradiated by the low doses of radiation were presented, observed and discussed. With great respect we reminded some of the results of research and practical treatment and rehabilitation of victims of the accident at the Chernobyl nuclear power plant in 1986. This huge and humane work was done by the great commands of our predecessors in science at EMBS. The results they had obtained formed a scientific and practical background, based on which we can today develop new methods of research and rehabilitation of irradiated people, solve numerous emerging contemporary tasks. We described and discussed some obtained at EMBS results of medical treatment and rehabilitation of patients who obtained low doses of radiation during long time. On the base of these studies practical recommendations for such patients' medical treatment and rehabilitation were done.

The substances and preparations for some pathological states pharmacological corrections we had suggested already on the base of the works with antioxidants [83–113], including ones done by our colleague Dr O. Gonchar and her colleagues [114–123]. For pharmacological correction of disorders caused by radiation, following substances and preparations as fullerene C_{60}, yackton, sufan, splenozide, others can be used; they primarily were studied as antioxidants and suggested for hypoxia disorders corrections [1, 85, 116–118, 124–127]. Obtained results were important, too, for continuation of the works in biotechnology [124].

So, in present article some results of the works, which can be valuable in the treatment and rehabilitation of people of various contingents exposed to low doses of radiation of various natures for a long time, were observed. Final recommendations can be offered to persons of various radiation risk contingents for the purposes of their medical treatment and rehabilitation. Developed methods can be used also in the practice of health care and health recovery after the influence of ionizing radiation.

We would like to emphasize that it is necessary to implement as widely and actively as possible into the practice of health care the most effective methods of rehabilitation and treatment of persons from radiation risk contingents developed at EMBS in the conditions of adaptation to the natural conditions of the mountains (Carpathians, other mountains), as well as in the conditions of hypoxia simulation (methods of hypoxytherapy – hypobaric, normobaric, hypercapnic, interval, pulsed, periodic hypoxia, as well as hypoxia created in the conditions of barochamber, hypoxicator, hypoxic mixtures, and etc.) [64, 65].

At the same time, the research group headed by Prof. Beloshitsky P. V. had demonstrated that the methods of normobaric or hypobaric interval hypoxia were promising for the replacing of the stepwise mountain adaptation. It was demonstrated that the most effective was rehabilitation complex, which, together with "mountain-therapy", combined diet and phytotherapy, special physical and breathing exercises, thermobarotherapy, intake of bromine-iodine and silicon water, sulfate and dolomite natural waters like "Narzan", "Naftusia", etc. [64, 65].

Indeed, a trip to the Caucasus for the purpose of treatment in the mountain conditions is currently unrealistic for the population of Ukraine now. Therefore, alternative ways of treatment and rehabilitation were also studied and recommended by the authors. For Ukrainian radiation risk contingents, treatment in the conditions of the Carpathians is available and effective, where the authors have also accumulated experience in adaptation and rehabilitation [64, 65] in combination with other methods.

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this direction was done at EMBS – Elbrus medical and biological station of the National Academy of Sciences of Ukraine. Commands of Ukrainian scientists and doctors led by Prof. Beloshitsky P.V. from the first days after the accident fulfilled these tasks for many years (Baraboy V.A., Krasyuk A.N., Korkach V.I., Torbin V.F, and many others). Many sick people were saved thanks to the works at EMBS. Starting from these results, we — contemporary scientists of Ukraine — can continue to develop new methods for saving and rehabilitation of irradiated people, solve numerous emerging contemporary tasks.

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ФЕНОМЕН РАДІАЦІЇ: ДЕЯКІ ПРИРОДНІ ДЖЕРЕЛА, МЕХАНІЗМИ ЕФЕКТІВ, СПОСОБИ ЗАХИСТУ БІОЛОГІЧНИХ ОРГАНІЗМІВ ТА ЇХ РЕАБІЛІТАЦІЯ

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Радіація є важливим і небезпечним фактором в сучасній дійсності в деяких регіонах індустріальних країн, наслідком техногенних аварій на ядерних об'єктах, хімічних підприємствах тощо. Це також реальний наслідок деяких сучасних військових дій і збройних конфліктів. Радіаційні ураження організмів можуть виникати і внаслідок дії природних причин — авіаційних чи космічних польотів на великій висоті або навіть тривалого перебування на гірських висотах. Природні причини таких ефектів на сьогодні вивчені ще недостатньо.

Мета. Коротко викласти деякі результати досліджень характеристик іонізуючого випромінювання на різних висотах над Землею. Описати коротко вплив факторів радіації на біологічні організми та основні механізми цих впливів. Описати ефекти, що викликають патологічні зміни в організмі людей, які зазнали тривалого впливу низьких доз радіації, та методи реабілітації постраждалих від променевої радіації в умовах високогір'я.

Методи. Космічні супутникові дослідження атмосфери Землі на різних висотах над рівнем моря з вимірюванням різних характеристик сонячного і галактичного випромінювання (переважно рентгенівського, гамма-випромінювання, а також інших видів іонізуючого випромінювання в деяких інших діапазонах). Порівняльний аналіз результатів довготривалих спостережень за пацієнтами в стаціонарних умовах із застосуванням багатьох стандартних лабораторних методів обстеження їх стану. Проведені наукові дослідження складалися з комплексу методичних прийомів і підходів: клініко-фізіологічні дослідження дихальної та серцево-судинної систем, гематологічного та імунологічного стану, функціонального стану вищої нервової діяльності, психічного та невротичного стану; введення антигіпоксантів, гістохімічні, біофізичні та інші методи оцінювали оксибіотичні процеси. Застосовували математичну обробку результатів, а також методи математичного моделювання.

Результати. Результати вимірювань рівнів іонізуючого випромінювання під час супутникового дослідження атмосфери Землі на різних висотах проаналізовано та представлено у схемах. Описано механізми шкідливої дії радіації на організми на нанорівні: радіоліз води, «ефект кисню» як радіосенсибілізатора, утворення різних типів вільних радикалів і пероксидів з подальшими наслідками для органічних сполук, клітин, тканин, органів і організмів. Представлено, розглянуто та обговорено результати лікування та реабілітації на ЕМБС осіб, опромінених малими дозами радіації. Багато з представлених результатів були отримані завдяки колективній роботі великих команд наших попередників у науці, які досліджували можливості лікування та реабілітації пацієнтів, які протягом тривалого часу отримували малі дози опромінення; розроблено практичні рекомендації.

Висновки. Представлено деякі результати виконаних робіт, які можуть бути цінними при лікуванні та реабілітації людей різних контингентів, які протягом тривалого часу зазнали впливу малих доз радіації різної природи. Окреслені рекомендації можуть бути запропоновані особам різних контингентів радіаційного ризику з метою їх реабілітації, у практиці охорони здоров'я тощо.

Ключові слова: радіаційне ураження організмів; висота; адаптація; радіопротектори; корекція.