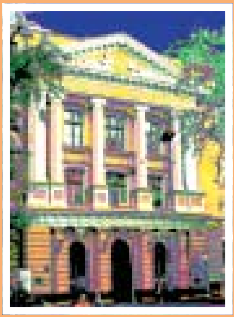

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FUNDAMENTALS OF RADIATION MEDICINE

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Medical Student's Library

Initiated in 1999 to mark the Centenary of the Odessa State Medical University (1900 — 2000)

Edited and Published by V. M. Zaporozhan, the State Prize-Winner of Ukraine, Academician of the Academy of Medical Sciences of Ukraine

The Odessa State Medical University

Dear Reader,

When in 1999 the lecturers and researchers of the Odessa State Medical University started issuing a series of books united by the collection entitled "Medical Student's Library" they had several aims before them.

Firstly, they wanted to add new books to the Ukrainian library of medical literature that would be written in Ukrainian, the native language of the country. These books should contain both classical information on medicine and the latest information on the state of the art, as well as reflect extensive experience of our best professionals. Secondly, our lecturers and specialists wanted to write such books which reflected the newest subjects and courses that have recently been introduced into the curricula, and in general there have been no textbooks on these subjects and courses at that time.

These two aims have successfully been coped with. Some dozens of textbooks and workbooks published in these years have become a good contribution of their authors and publishers to the development and making of the Ukrainian national educational literature.

The next step that we decided to undertake was to issue a unique series of books in foreign languages. The foreign students taking their medical education in the Ukraine, our University included, are expecting such books to be published. Other countries are also waiting for them as the Odessa State Medical University is a Fellow Member of the International and European Association of Universities. Our Medical University is over a hundred years old and has long since become a center of various original medical schools and trends. These are headed by well-know medical professionals whose competence is acknowledged not only in this country, but abroad as well.

Valery ZAPOROZHAN,
Editor-in-Chief of the Series "Medical Student's Library"
the State Prize-Winner of Ukraine,
Academician of the Academy of Medical Sciences of Ukraine

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A. P. Lazar
R. P. Matyushko

FUNDAMENTALS OF RADIATION MEDICINE

Recommended by the Central Methodical Committee for Higher Medical Education of the Health Ministry of Ukraine as a manual for English-speaking students of higher medical educational establishments of the III–IV levels of accreditation

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The Odessa State Medical University
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The manual gives a brief sketch of the history of radiation medicine and the contribution of Ukrainian scientists to its development as wellas general data on radiation. The basic forms of contact of a person with sources of radiation and aspects of biological action of ionizing radiation are considered.

The manual is intended for students, interns of higher medical schools.

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У навчальному посібнику викладено короткий нарис історії радіаційної медицини та внеску українських вчених у її розвиток, загальні відомості про радіацію. Розглянуто основні форми контакту людини з джерелами радіації, аспекти біологічного впливу іонізуючого випромінювання.

Для студентів, інтернів медичних вузів.

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INTRODUCTION

Radiation medicine is a science, which studies the features of influence of ionizing radiation on a person's organism, the principles of treatment of radiation effections and the prevention of possible consequences of population irradiation.

The existence of various types of ionizing radiation causes a necessity, first of all, for the knowledge of their characteristic, features of interaction with a substratum, and molecular mechanisms of action.

Radiation damage is examined at the level of cells, cellular populations, tissues, separate organs, critical systems and the organism as a whole. Thus, a special attention is given to the clinical course of acute and chronic radiation sickness.

The variety of radiation injury manifestations in case of the radionuclides incorporation is represented in the organic connection with the information on ways of entering, features of distribution of the most important radionuclides in an organism and kinetics of their elimination. Typical forms of developing defeats are stated from positions of the absorbed dose of radiation.

Principles of indication parameters selection and prognosis of radiation injuries are formed as well as the ways of their correction. Methodological bases and examples of the use of biochemical, hematological and immune-bacterial parameters of radiation injury are given.

The prevention of harmful action of ionizing radiation is carried out by the intervention in to the processes occurring in an organism at the moment of irradiation.

In order to solve the medical-social tasks on protection of a developing organism from the influence of ionizing radiation, it is completely necessary to know the features of an organism's reaction at all stages of individual development, the laws of inheritance of defects, the account of possible radionuclides entering through the placenta and with the mother's milk.

Special attention is given to the problem of remote consequences in both the practical relation (prophylactic medical examination of the irradiated contingents, actions to decrease the risk of occurrence of remote consequences), and the theoretical one (mechanisms of occurrence, modifying factors).

The Chernobyl tragedy attracted scientists to the decision of the above mentioned and other tasks specific for the Chernobyl failure (long residing on polluted with radionuclides territories, simultaneous influence of a complex of adverse factors). The results of scientific researches in the given direction enriched radiation medicine.

Radiation medicine is a complex scientific discipline having close connections with a number of theoretical and applied areas of knowledge, such as genetics, biophysics, cytology, nuclear physics, biochemistry, physiology, biology, and radiobiology.

An insufficient level of knowledge in the field of radiation medicine, conditioned, in particular, by the complexity of this "collective" discipline, can lead to an inadequate reaction of people, including doctors, both in emergency and in the influence of ionizing radiation for diagnostic and medical purposes.

The results of the authors' own researches and the basic data of well-known scientists, collectives of authors, materials of scientific conferences, analysis of data and conclusions of scientific committee reports of the United Nations on questions of nuclear radiation action are the basis of the manual.

The preparation of modern doctors and the post-degree training of doctors who received their medical diplomas 10–15 and more years ago irrespective of the specialty demand the mastering of the information stated in the given manual.

Chapter 1
A BRIEF SKETCH OF THE HISTORY OF RADIATION MEDICINE AND THE CONTRIBUTION OF UKRAINIAN SCIENTISTS TO ITS DEVELOPMENT

Radiation medicine appeared first of all due to the discovery of X-rays, to the natural radioactivity of uranium as well as to the radioactive properties of polonium and radium.

For a long time it was considered that X-rays were discovered by W. K. Roentgen (1895). However, it has recently become known that it was a Ukrainian scientist Ivan Puluy (1881) who discovered X-rays.

It is necessary to give tribute to the achievements of several outstanding scientists of the XIX century: H. D. Rumkorf (1803–1877) became well-known due to the invention of electromagnetic devices (induction coil). V. Hittorf (1824–1914), the professor of physics and chemistry in the Munster University, studied cathode rays and created a more perfect vacuum tube than previous models. William Crooks (1832–1919) designed a lot of vacuum tubes intended for the researches of "radiation substance". He was so well-known that during his life, the term "Crooks' tube" was used concerning any type of a vacuum tube. And, finally, F. Leonard (1862–1947) received the Nobel Prize in physics in 1905 for his works in the field of cathode radiation. In 1892 he created a tube where radiation was directed to a window made of thin aluminum, which for the first time allowed to study the cathode rays outside of a tube.

X-rays became not only a subject of intense study all over the world, but also found their practical application quickly. Besides this, they served as an impulse to detecting a new phenomenon — natural radioactivity. Henri Becquerel, a recognized authority in the field of luminescence, along with many others, was interested in the nature of all-penetrating X-rays. Investigating induced by sunlight a luminescence of various minerals, Becquerel found that it occurs even during the illumination of uranium salts. It Appears that if such salt is put on a photoplate wrapped in black paper, exposed to the sun, during development the plate will light only at the uranium salt's place. Becquerel decided to repeat this observation. However, the day appeared cloudy and the experiment was postponed, and the scientist left the plate in a dark box in the table. In 2 days, on March 1, 1896, the sun again came out, and it was possible to repeat the experiment. The scientist, impelled by intuition, decided to develop the plate, not exposing it to sunrays, and, surprisingly, on the plate there were exact outlines of a cross (the uranium salts were laying in the form of a cross). And it has been established, that, irregardless of the sunlight, uranium lets out invisible to the eye "uranium rays".

The study of the phenomenon of natural radioactivity by Marie Sklodovska Curie and Pierre Curie marked the opening of several radioactive elements, the main ones were polonium and radium. In 1903 the Nobel Prize in physics was awarded to Pierre and Marie Curie and H. Becquerel. In 1911, Marie Curie was awarded with a second Nobel Prize for works in chemistry — since then no scientist has been favored with such an honor. In all M. Curie was awarded with 10 premiums and 16 medals. She was elected to be a member of 106 various scientific organizations, academies and scientific institutes.

In 1935, 32 years after her parents, the Nobel Prize was awarded to their daughter Irene — for the discovery of artificial radioactivity (together with her husband Frederic Joliot-Curie).

The action of ionizing radiation on a living organism interested the world science from the moment of its discovery, from the first steps of radioactive radiation application. It is not a coincidence, because from the very beginning researchers have faced its negative effects. So, in 1895 Roentgen's assistant H. Grubbe received a radiation burn on the hand while working with X-rays.

The message on the harmful action of X-rays, shown in the form of dermatitis and loss of hair, belongs to Marcuse (1896). It was soon found out that such damage to the skin differs by acute morbidity and slow healing and can end with the death of skin tissue and the formation of cancer.

The dramatic consequences of changes, leading to the development of cancer as a result of X-rays, are described by Hall-Edwards in his articles (1904, 1906), which have an autobiographical character. Hall-Edwards began clinical researches some weeks after the press published about the Roentgen's discovery. In 1896, he conducted a number of X-rayings, each time subjecting his hands to the influence of X-rays within several hours. 2–3 weeks after he endured the irradiation, Hall-Edwards noticed that the skin around the nail bed was red and painful. So, the disease began, objectively described in all its tragedy in the first article, published in 1904. Within the next 2 years, there was no moment during which he did not feel pain; as a result he completely lost work capacity, both physically and mentally. 50–60 warts appeared on both hands, many of which merged. In 1908 his forearm was amputated; he died in 1926. "As far as I know, from the whole group of older workers engaging in radiology, he is the only one who avoided death from malignant disease" (Barling, 1926).

The first cases of cancer diagnosis in radiologists are described by Frieben (1902) and Sick (1903), and then by Lloyd (1903).

K. M. Dally was the first victim of X-rays in America, an assistant to T. A. Edison in designing the X-ray device. 7 years after the first irradiation, which took place in 1896, cancer developed on his hand on the place of the X-ray ulcer. Amputation was not done in time and he died of metastasis (Brown, 1936).

One of the first clinical radiologists was E. Fleischman-Aschheim. In 1897, she underwent X-rays for the first time, and in 1905 died of squamous cancer of the fingers (Brown, 1936). Kassabian was another early victim in America. He wrote 16 works on the influence of X-rays and a radiology textbook, which second edition was published in the author's death year (1910). Porter and White (1907) described the first 11 doubtless cases of X-ray cancer in people ending with death. The sequence of phenomena for the first of these patients is rather characteristic. Though he completely stopped working with X-rays one year before, ulcers emerged on his fingers and after the appearance in 1902 of the first signs of cancerous regeneration, similar changes occurred in eight various sites of the body.

When Rowntree read his lecture on the abilities of X-rays to cause cancer in 1909, it was already well-known that planocellular cancer occurs after dermatitis, developing as a result of repeated irradiations in low doses of X-rays, (Rowntree, 1908).

54 cases of X-ray cancer are recorded in the monograph of Hesse (1911), from which 26 in America and 13 in Germany and England. Among these 54 patients there were 26 doctors and 24 X-ray technicians.

On July 3, 1901, H. Becquerel carried in the pocket of his waistcoat an ampoule of radium for 6 h and received a burn. 10 days later after the appearance of erythema — an ulcer that does not heal for a long time — the scientist informed Marie Curie about it: “I am in love with radium, but I am also angry at it”.

Gilman was astonished by the effects of X-rays and sent a patient with inoperable breast cancer to Grubbe for irradiation. Good results were obtained because Grubbe himself continued the practice of roentgen therapy (after receiving a medical education). Later he became a victim to radiation cancer.

Nobody assumed that X-rays could influence the internal organs. Therefore, the skin was the object of research for a long time.

Albers-Schoenberg detected degenerative changes in the epithelium and azoospermatism in guinea pigs and rabbits (1903). Halberstaedter observed atrophy of the ovaries in irradiated animals (1905). Shortly after this, Osgood and Brown detected azoospermatism, that was the cause of sterility in young workers at an X-ray tube plant who had worked there more than 3 years.

Under the influence of E. London’s works, which revealed the lethal action of radium radiation on mice, H. Heineke employed X-rays for this purpose (1903). He succeeded in causing animals to die; he was the first to describe radiation anaemia and leucopenia; spleen atrophy. He described in details the changes in the cells of the marrow and lymph nodes in histological examinations.

In his numerous experiments, E. London demonstrated the action of radium radiation on many systems of an organism, particularly on heamopoiesis and sexual glands.

E. London’s monograph “Radium in Biology and Medicine” was published in German in 1911.

The works of a descriptive nature established two cardinal facts: the inhibition of cell division caused by ionizing radiation (Koerniche, 1905) and the difference in the response of various cells to irradiation (J. Bergonie, L. Tribondeau).

Spermatogoniae were found to be the most sensitive, while spermatozoids were the most resistant; their irradiation caused no morphological changes. On this basis, these experiments, in 1906, were generalized to form a law (rule), which entered the history as the law of Bergonie and Tribondeau: the biological action of X-rays the greater, the higher the reproductive activity of the cell, the longer the period of its mitosis, and the less the degree of differentiation of the cell with respect to its morphology and function. This rule has not lost its significance to date.

It is necessary to relate to a remarkable phenomenon of chromosome damage during irradiation of dividing cells (1904) discovered by Pertes, as well as the oppression under the influence of ionizing radiations of protective forces of an organism — immunity (1908) described by A. Benjamin and A. Smoke.

Thus, already in the earliest period of initial observations, the most important feature of ionizing radiations was noted, namely: the selectivity of their action, determined by the properties of those cells on which radiation operates. For this reason, despite the absolutely identical conditions of irradiation of the same cell, tissue, organ, some cells are greatly injured and die, while others exhibit no damages. For example, when the spleen or testes are irradiated, all (or the total majority) of the lymphoid elements disappear with complete intactness of the fibrous elements and Sertoli's cells. Very early the role played by damage to the nucleus in the radiosensitivity of a cell was established (1903). This conclusion was made by J. Boon.

The studying of the action of ionizing radiation on embryogenesis began in the first decade of XX century. The early observations were of a descriptive nature. There was no theory explaining the mechanism of action of ionizing radiation on living objects.

The second stage of development of radiation medicine is associated with the setting up of quantitative principles, relating the effect with the radiation dose. This stage is characterized by large-scale experiments on various populations of cells and animals with the quantitative reflection of the results on "dose-response" curves.

F. Dessauer proposed the first theory explaining the radiobiological effect of radiation (1922). These views were developed in the form of the "hit principle" and "target theory" in the works of N. Timofeev-Ressovsky, K. Zimmer, D. Lea and other researchers.

An epoch-making event was the detection of the action of ionizing radiation on the genetic apparatus of a cell attended by the hereditary transfer newly acquired features. These observations were first made by G. Nadson and G. Filippov in experiences on yeast (1925). This major discovery, unfortunately, was not acknowledged at that time as it should have been, and only after the works of H. Muller, who established the mutation effect of ionizing radiation in experiments on the drosophila, genetic studies made great strides through out the world.

Wolbach (1909) and Ordway (1915), working under the guidance of the cancer commission of the Harvard University, studied in detail the harmful action of radioactive substances to people, daily having to put up with these substances. The primary changes consisted of, mainly, the flattening of the palmary folds, thickening and peeling of the superficial layers of the skin, atrophy and ulceration. These objective changes appear small compared to the occurrence of such subjective symptoms as paresthesia, anesthesia, increased tactile sensitivity, rhythmical pulsations and pains. Wolbach believed that the occurrence of malignant properties is connected not to a single trauma, but a long progressing injury of the underlying connecting tissue.

From the beginning of the 50s of the XX century, the world began to show a serious concern on the influence of ionizing irradiation to a person and the environment. It was not only because of the fresh horror memories of the bombardments of Hiroshima and Nagasaki, but also as a result of tests with nuclear weapons done in the atmosphere, sent by three countries, radioactive material began to be distributed all over the globe. At that time very little was known about the action of radioactive deposits on a person and the environment, only numerous hypotheses were expressed about how irradiation would affect a person's health from this widely distributed source of radiation.

To solve this question, the General Assembly of the United Nations in December, 1995 founded the United Scientific Committee on the Effect of Atomic Radiation, UNSCEAR.

A significant amount of works during the XX century were devoted to the experimental studying of the laws of ionizing radiation influence on a living organism, metabolism and the biological action of radionuclides, the search for radioprotective substances, as well as the agents, accelerating the removal of radionuclides. The basic quantitative criteria of transfer onto a person of the results obtained in an experiment with external irradiation and the action of radionuclides are established in works of Yu. I. Moskalyov and others (1976).

The experimental research on the reaction features of a growing organism to the action of ionizing radiation (L. A. Shparo, 1960) has shown that the most vulnerable age to the influence of ionizing radiation is the youngest.

The basic general laws of ionizing radiation influence on the natural and artificial immunity (V. A. Troitsky, M. A. Tumanyan, 1958), as well as the intensity of the acquired antiviral immunity (O. P. Peterson and co-authors, 1961) are established.

During the same period, a number of collections and monographies are presented, candidate and doctor's degree are defended, devoted to the studies of the kinetics of metabolic and biological actions of the most dangerous and important in the practical relation radioactive isotopes: ^{131}J, ^{3}H, ^{137}Cs, ^{90}Sr, ^{237}Np, ^{239}Pu, ^{241}Am (Yu. I. Moskalyov, L. A. Buldakov, etc.)

The emersion of new sources and kinds of irradiations required the knowledge of the features of the biological action of brake radiation with big energy, fast particles, differing in properties (neutrons, protons, electrons, etc.). N. G. Darenska, L. B. Koznova, I. G. Akoyev, G. F. Nevska (1968) gave significant contribution to the decision of the given problem.

In connection with the constantly growing application of transuranium radionuclides (for manufacturing thermoelectric generators for feeding energy to space, ground and sea settings, life-support systems and cardial activity stimulators) many scientists have devoted their activity to studying the metabolism and biological action of transuranium elements (Ju. I. Moskalyov, L. A. Buldakov, E. R. Lyubchansky, A. M. Lyaginska, etc.).

The three-volume manual under the edition of A. Hollander was published in English in 1954–1956. It dealt with genetic effects of ionizing radiations on mammals and the question of genetic danger of radiation for a person (W. L. Russell), the influence of radiation on prenatal development of mammals (L. B. Russell) were examined, pathological physiology of damage by rays (H. M. Patt and J. M. Bruce), the action of ionizing radiation on the blood and haemopoietic organs (L. Jacobson), the waviness of the regeneration processes (V. Blot and M. Blot). However, only a few works are devoted to the regenerative and compensatory processes during radiation injuries (E. A. Zherbin, K. P. Hanson, L. P. Simbirtseva, and others, 1986).

The questions of the pathogenesis of radiation disease were successfully developed by P. D. Gorizontov and co-authors (1960).

A continuously increasing amount of artificial radionuclides was introduced in the second half of the XX century, as a result of the creation of the nuclear industry, atomic engineering, medical and household radiating equipment. The Earth polluting with these substances as a result of nuclear weapon tests and large nuclear installation failures led to the occurrence of regions with an increased level of radiation. A large number of people were compelled to live in conditions of maximum permissible doses, produced for professionals, and doses exceeding that level.

Numerous scientific works were devoted to the role of these influences in the destiny of irradiated adults, embryos, descendants of parents irradiated before conception, i. e. the destiny of the human population. Epidemiological and experimental materials about the remote consequences of ionizing radiation influence on the development of benign and malignant tumors, as well as a wide spectrum of non-tumor diseases of various organs, cirrhosis of the liver and others are generalized in the monographies of Yu. I. Moskalev.

The necessity of protection against X-ray radiation was clearly realized only in 1915 when the British radiological society published "Recommendations on the protection of persons working with X-rays".

The question about the maximal "transferable (tolerable) dose" was examined by the British committee of protection against X-rays and radium (1921), but the permissible dose of radiation had not been set yet because of the absence at that time of the standard method of measurement of radiation.

The greatest in the world radioecological catastrophe, having no analogues on medical, radiobiological and dosimetric aspects happened on April 26, 1986, 140 km from Kiev. It differs from other cases of mass people irradiation (Japan, USA, Brazil, Russia) by the amount of victims, structure and complexity of irradiation sources in a combination with the complex of adverse factors of traditional origin which accompanied the accident. In the same year, the Center of Radiation Medicine (first as the All-Union, and then as the Center of Radiation Medicine of the Academy of Medical Sciences of Ukraine) was organized. The priorities of the scientific researches were the following:

1. The research of irradiation influence on the health condition of the liquidators with verification and retrospective estimation of doses.
2. The research of the influence of a complex of factors of the Chernobyl accident on the health condition of children.
3. Long-term clinical-epidemiological researches of irradiation of the thyroid gland and haemopoietic system.
4. Researches in the field of preventive psychosomatic distress for the population injured as a result of long-term stress.

We can be proud that Ukrainian scientists have contributed to development of radiation medicine in the XX century. So, a laboratory for studying the phenomenon of radioactivity in the scientific and practical approach was created in March of 1910, in Odessa under the guidance of E. S. Burkser. An emanator was constructed in the laboratory. The emanator helped in preparation of radioactive water for medical and scientific purposes as long as in February, 1912. Employees of the laboratory studied the radioactivity of the atmosphere, rocks, minerals and mineral sources in the area of lakes of Tavria province, Mirgorod sources, Odessa estuaries and other resort areas. The received data has not lost its value up to date.

The Kharkov Scientific Research Institute of Medical Radiology was opened more than 80 years ago (in 1920). One of its tasks is scientific researches on the problems of biological action of ionizing radiations.

Scientific problems of radiation medicine in Ukraine are studied regularly; the Republican scientific conferences are devoted to the mechanisms of biological action of ionizing radiations (Lvov, 1969), to action of low doses ionizing radiation (Sevastopol, 1984), etc.

Since 1993 “The Ukrainian radiological magazine”, which brings an essential contribution to the development of radiation medicine, has been published.

Chapter 2
PHYSICS AND DOSIMETRY OF IONIZING RADIATIONS

2.1. THE NATURE OF IONIZING RADIATIONS

What is ionizing radiation and what is its nature?

Ionizing radiations — radiations (electromagnetic, corpuscular) that interact with substances directly or indirectly causing the ionization and excitation of its atoms and molecules. The atom of any chemical element is composed of two basic parts: positive-charged nucleus and rotating around it in various orbits, negatively charged electrons. The nucleus of an atom has a complex structure; it consists of positively charged particles having identical mass — protons and electrically neutral neutrons. A different variety of the same element, having a different nuclear mass (because of the various quantities of neutrons), but having an identical charge of atomic nuclei and identical chemical properties, received the name isotopes, or nuclide.

According to their physical properties all nuclides are divided into two groups: steady (stable) and unstable, decomposing (radioactive). The major property of decomposed radionuclides is intranuclear transformations, resulting in a spontaneous emission of particles and rays, ionizing the surrounding environment.

Ionizing radiation can have different origins:

1. Brake radiation — electromagnetic radiation, which originates with the dispersion (braking) of fast-charged particles into Coulomb field of atomic nuclei or electrons. It is essential for the light particles — electrons and positrons. The spectrum of brake radiation is continuous; the maximal energy is equal to the initial energy of the charged particles. For example: brake X-ray radiation in the X-ray

tube, brake acceleration of gamma-radiation of fast electrons when they hit their target, etc.

2. X-ray radiation — electromagnetic radiation with a wave length of 10^{-5}–10^{-2} nm, which is radiated with the braking of the fast electrons in a substance (continuous spectrum) and with the transfer of electrons from the external electronic shell to the internal one (linear spectrum). Sources — X-ray tube, some isotopes, accelerators and accumulators of electrons (synchrotron radiation).

2. Gamma-radiation — short-wave electromagnetic radiation with a wave length of < 0.1 nm, which originates with the decomposition of the radioactive nucleus, transfer of the nucleus from an excited state to the fundamental state, with the interaction of fast-charged particles with a substance, annihilation electron-positron pairs, etc.

Other types of ionizing radiation are presented by fast-moving particles of a substance. Some of them carry an electric charge, others do not.

Neutrons — the only non-charged particles, formed by any radioactive transformation, are an important variety of ionizing radiation, because they, as a rule, are connected with the processes occurring in nuclear bombs and nuclear reactors. The mass of a neutron is equal to the mass of a proton, but differing from the latter in that the neutron particles do not possess an electric charge. Since they are electro-neutral, they can deeply penetrate into any substance, including living tissues. These are the fundamental particles from which the nucleus of an atom is constructed. Neutrons can be received artificially in physical scientific laboratories in powerful particle accelerators.

Electrons — light negatively charged particles, which very often are emitted during radioactive disintegration of a substance and then they are called β-rays. These particles can be received in laboratory conditions. Beta-radiation — corpuscular electronic or positron ionizing radiation with a continuous power spectrum, which originates with the transformation of nucleus or unstable particles (for example, neutrons).

Protons — positively charged particles which are found in the nucleus of all atoms. Their mass is approximately equal to the mass of a neutron and is almost 2000 times as much than the mass of an electron. Protons usually are not emitted by the radioactive isotopes known on the Earth, however they are found in free space which can present a danger to cosmonauts.

Alpha-particles — the nucleus of helium atoms or in other words helium atoms, deprived of orbital electrons and consisting of two protons and two neutrons linked together, having a positive charge, rather heavy. Alpha-radiation — corpuscular ionizing radiation, which consists of alpha-particles and is radiated during radioactive disintegration or nuclear reactions, transformations.

Heavy ions — the nucleus of any atoms, deprived of orbital electrons and moving with high speed. Ions of almost all known elements are present in space.

2.2. PHYSICAL PROPERTIES OF IONIZING RADIATIONS

The physical properties of ionizing radiations are shown in table 1.

Table 1. **Physical properties of ionizing radiations**

Physical properties	Type of radiation			
	Alpha	Beta	Gamma	Neutrons
Energy of radiation, MeV	1–10	0.1–2.0	0.1–20	0.05–10
Velocity of distribution in a vacuum, km/s	20,000	270–280 thousand	300,000	$1 \cdot 10^{-3}$–$1 \cdot 10^{6}$
Length of the run in air	up to 20 cm	up to 15 m	hundreds of meters	hundreds of meters
Length of the run in tissue	up to 50 mcm	up to 1 cm	tens of cm	centimeters
Ionizing ability*	10–20 thousand pair/mm	5–10 pair/mm	1 pair/cm	tens, hundreds of thousands pair/mm

Note. *The ionizing ability (density of ionization) — amount of ion pairs, which are formed in the unit of run way in air.

2.3. THE INTERACTION OF IONIZING RADIATIONS WITH A SUBSTANCE

3 basic processes occur during the interaction of X-ray gamma radiation: the photoelectric effect (photoeffect), the Compton effect (Compton dispersion), the formation of electro-positron pairs.

1. The photoelectric effect (photoeffect) consists of the gamma quantums transferring their energy to the electrons and then disappearing.

2. The Compton-effect consists of the gamma quantums transferring a part of their energy to the electrons. After the energy collision the gamma quantum decreases and changes the direction of its motion.

3. The effect of electro-positron pair formation includes the transformation of gamma-quantums into a pair of particles — electron and positron. A positron exists in a substance for a small interval of time. As soon as a positron practically completely loses its speed, it is united with the closest electron, and instead of a pair of particles, it forms two gamma-quantums each with energy of 0.51 MeV, scattering in opposite directions. Such a process is referred to as annihilation.

All charged particles, passing through a substance, gradually lose their energy. Because almost all of the volume of the atom is occupied by electrons, the charged particles interact, basically, with the electrons of atoms and molecules. Flying by near the atoms electron shells, the charged particle tears off the electrons of atoms and molecules and forms ions. The primary negative ions are electrons, torn from atoms and molecules, and positive ions — atoms or molecules, deprived of one or several electrons. Such a process of formation of ions from neutral atoms or molecules is referred to as ionization. If the charged particle flies by with a fast speed at a significant distance from the electrons of atoms and molecules, it provides the electron with the energy insufficient to tear away from an atom or molecule. Thus, the electron goes to a more remote shell. This process is called excitation.

Neutrons, being uncharged particles, interact, practically, only with the nucleus of atoms of the environment during a direct impact with them.

Fast neutrons can experience elastic and non-elastic collisions with the nuclei. During an elastic collision the neutron gives a part of the energy to the nucleus, which due to the kinetic energy of a neutron gains energy and flies from the electron shell of the atom with a fast speed. Such fast nucleus is referred to as nuclei of recoil. During a non-elastic collision of a neutron, a part of its energy goes to nuclear excitation and part goes in connecting it with kinetic energy. Thus, the excited nucleus emits energy of excitation as one or several gamma quantums.

Slow neutrons during interaction with the nucleus of atoms of the environment experience only elastic collisions and captures, which is accompanied either by the emission of gamma quantums, or the emission of protons and alpha particles.

2.4. DOSIMETRY OF IONIZING RADIATIONS

Dosimetry is a section of applied nuclear physics in which the properties of ionizing radiations are considered, the physical sizes which characterize a field of radiation or the interaction of radiation with a substance, as well as the principles and methods of definition of these sizes.

The basic concept of dosimetry is the concept of a dose. The dose of ionizing radiation is understood to be the energy transferred by radiation to the elementary volume or mass of the irradiated substance. The following kinds of doses are distinguished: exposure, absorbed, equivalent, and effective.

The exposure dose (X) of X-ray or gamma-radiation is defined by the quantity of radiation, which is determined in air and evaluated by the ability to ionize. A unit of exposure dose in the SI system is such a dose, which forms in 1 kg of dry air ions, carrying a charge of 1 C of each sign (C/kg). Roentgen (R) — the non-system unit of exposure dose.

$$1 \text{ C/kg} = 3876 \text{ R}$$

Absorbed dose (D) — the mean energy d_E transferred by radiation to a substance in an elementary volume divided by the mass d_m of the substance in this volume:

$$D = d_E/d_m$$

The unit of measure in the SI system — Gray (Gy): 1 Gy = 1 J/kg. The off-system unit of absorbed dose — rad ("radiation absorbed dose").

$$1 \text{ rad} = 0.01 \text{ Gy}$$

Dose equivalent in an organ or tissue T (H_T) — the size which is designated as the absorbed dose D_T derivative in a separate organ or tissue T on the radiating weighing factor W_r (Table 2). The unit of dose equivalent in the SI system — Sievert (Sv). The non-system unit of measurements of dose equivalent — the biological equivalent rad (1 rem) — this is the absorbed dose of any kind of radiation which causes the same biological effect as a dose in 1 rad of X-ray or gamma radiations in a living organism.

$$1 \text{ Sv} = 100 \text{ rem}$$

Effective dose (E) — the sum of the products of equivalent doses H_T in some organs and tissues on the corresponding tissue weighing factors W_T (Table 3).

$$E = E_{H_T} \cdot W_T$$

Table 2. **The values of radiating weighing factors**

Type of radiation	Wr
Photons, all energy	1
Electrons and muons, all energy	1
Protons with energy > 2 MeV	5
Neutrons:	
with energy < 10 KeV	5
with energy 10–100 KeV	10
with energy from 100 KeV to 2 MeV	20
with energy 2–20 MeV	10
with energy > 20 MeV	5
Alpha radiation, heavy nuclei of recoil	20

Table 3. **The values of tissue weighing factors (H_T) for different tissue and organs**

Tissue or organ	W_T
Gonads	0.20
Bone marrow	0.12
Large intestine	0.12
Lungs	0.12
Stomach	0.12
Urinary bladder	0.05
Mammary gland	0.05
Liver	0.05
Esophagus	0.05
Thyroid gland	0.05
Skin	0.01
Skin surface	0.01
Other organs	0.05

The use of the effective dose concept is accepted when the values of dose equivalents, which are in the field value below the threshold of the determined effects occurrence.

Radiation weighing factor — the coefficient which takes into account the relative biological effectiveness (RBE) of different kinds of ionizing radiation. It is used exclusively during the calculation of effective and equivalent doses.

So, the effective dose is the quantitative characteristic of irradiation of an organism as a whole. Therefore, with the definition of the diagnostic irradiation dose, which a patient received during a year, it is possible to add one effective dose to another from various kinds of radionuclide researches, and add them to the effective doses of X-ray procedures.

The following methods of definition of radioactivity and ionizing radiations doses are distinguished: ionization, scintillation, radioluminescent, photographic, chemical, neutron-activation, biological, calorimetric, calculating. The basis of any method of registration is the quantitative estimation of processes which occur in the irradiated substance.

1. *Ionization method* is based on the measurement of ionization of an active volume of detector (ionization chambers) by measuring electric current or gas discharges, which occur in the detector under the influence of ionizing radiation.

2. *Scintillation method* of registration is based on the registration of flashes of light which arise in a scintillator, under the influence of ionizing radiations.

3. *Radioluminescent method* (photoluminescent and thermoluminescent) of measuring ionizing radiations is based on the absorption and accumulation of energy of ionizing radiations by special luminescent detectors with further transformation into luminescent, which intensity is proportional to the ionizing radiation dose, which is able to be registered with thermo stimulation (heating) or photoluminescence (irradiation with ultra-violet rays) by a special recording device.

4. *Photographic method* is based on the ability of radiations to cause photolysis of the haloid silver bromide (AgBr). With the development of exposed films, silver is reduced to metal and causes it to darken, intensity of which is proportional to the absorbed energy of radiation.

5. *Chemical (colorimetric) method* is based on the measurement of output of irreversible radiation-chemical reactions, occurring un-

der the influence of ionizing radiations in a liquid or solid system, which changes the color under the influence of radiation-chemical reactions.

6. *Neutron-activation method* is connected with the measurement of induced radio-activity. It is used for measuring weak streams of neutrons or the big streams of neutrons (short-lived actions).

7. *Biological methods* of dosimetry are based on the evaluation of reactions, which occur in some tissues during radiation of a certain dose, for example, the occurrence of erythematous doses, the quantities of chromosomal aberrations, the level of lethality of experimental animals, the degree of leukopenia, etc.

8. *Calorimetric method* is based on the determination of heat quantity, which is allocated in the detector during the absorption of energy of ionizing radiation and is proportional to energy.

9. *Calculation method* is used in clinical practice and scientific researches.

Many devices, which enable the determination of the quantitative or qualitative characteristic of ionizing radiations and radioactive substances, have recently appeared.

Devices for measuring ionizing radiations are classified as follows:

— dosimeters (for measuring doses, power of doses);

— radiometers (for determining the total activity of drugs, measuring the levels of radioactive pollution of a surface, determining radioactive pollution);

— spectrometers (for determining the energetic spectrum of radiations and on this basis — determine the qualitative and quantitative radionuclide structure of drugs).

Quantities and Units which are Used in Radiation Medicine

Activity (A) — quantity, which is determined by the ratio of spontaneous transformations of the nuclei dN in a period of time dt.

$$A = dN / dt$$

The unit of measurement — Becquerel (Bq). One Becquerel equals one transformation per a second. The non-system unit of activity — 1 Curie (Ci).

$$1 \text{ Ci} = 3.7 \cdot 10^{10} \text{ Bq}$$

Gray (Gy) — the unit of absorbed dose of ionizing radiation (in the SI system).

Non-system unit — rad.

$$1 \text{ Gy} = 100 \text{ rad} = 1 \text{ J/kg}$$

Sievert (Sv) — the unit of equivalent and effective dose in the SI system.

Non-system unit — rem.

$$1 \text{ Sv} = 1 \text{ J/kg}^{-1} = 100 \text{ rem}$$

Electron-volt *(eV)* — non-system unit of energy of ionizing rradiation.

$$1\text{eV} = 1.6 \cdot 10^{-19}\text{J}$$

2.5. SOURCES OF IONIZING RADIATIONS

The source of ionizing radiation (source of radiation) is the object which contains radioactive substance, or the technical device which creates or can create ionizing radiation in certain conditions.

In view of modern knowledge, it is possible to distinguish natural and technogenically amplified sources, which create the natural radiating background and technogenic radiating background correspondingly.

2.5.1. NATURAL SOURCES

Among the natural sources, space radiation and ground sources are distinguished. Space radiation, arriving from outer space, is subdivided into primary and secondary. Primary space radiation is radiation of high energy, entering the earth's atmosphere from outer space. During the interaction of the primary radiation with the atoms' nuclei, located in the Earth atmosphere, secondary particles and electromagnetic radiation are initiated, which is called secondary space radiation. While entering the Earth atmosphere particles of high energy of primary space radiation take part in reactions with the atoms nuclei contained in the air. Thus, neutrons, protons, π-mesons and K-mesons, as well as space nuclides (^{3}H, ^{7}Be, ^{10}Be, ^{22}Na, ^{24}Na) appear.

Radionuclides of terrestrial origin include: nuclides making up the radioactive families ^{235}U, ^{238}U, ^{232}Th; cosmogenic radionuclides which are constantly formed in an environment under the influence of space radiation, primary radionuclides of the Earth which were formed during its formation, i.e. 4.5–5 billion years ago. Among these radionuclides, potassium-40 and rubidium-87, from the point of view of irradiation of the population, have the greatest value. The basic amount of natural radioactive nuclides is contained in mountain rocks, which form the thickness of the Earth crust.

The content of natural nuclides is higher in the black earth soil, than in sod-podsolic, podsolic and peaty soil.

The contents of radioactive substances in natural waters differs considerably and depends on the amount of organic substances, chlorides, alkalis and the alkaline grounds in them.

The radioactivity of underground waters is caused mainly by the contents of ^{226}Ra, ^{222}Rn and uranium.

There are constantly small amounts of ground and space radioactive nuclides such as aerosols and gases in the atmospheric air. Particles (aerosols) of uranium, radium, and thorium are a number of ground sources which are dust particles lifted from the Earth surface. Besides of radionuclides of ground origin, space radionuclides are constantly present in the atmospheric air. ^{14}C, ^{3}H, ^{7}Be, ^{22}Na bring a significant contribution to the dose.

The presence of natural radionuclides in the tissues of plants and animals is caused by the metabolism occurring between the environment and living organisms. The radioactivity of tissues of plants and animals is basically determined by the presence of ^{40}K and to a lesser degree other nuclides in them.

The total dose of irradiation of the population of Ukraine from natural radioactivity is 4.88 mSv/year (I. P. Los, 1993).

Alongside with the constant presence of natural radionuclides in the environment objects there occurs a considerable enrichment of the same nuclides from the sources, occurring as a result of human's activity. Technogenically amplified sources include: mineral fertilizers, building materials, uranium mines sewage, enterprises on the enrichment of uranium, gas-aerosol emissions into the atmosphere of burning products, sources of air pollution in the buildings.

2.5.2. INDUSTRIAL SOURCES OF RADIATION

Industrial sources of ionizing radiation (of artificial or natural origin) are those which are used in corresponding radiating technologies. Industrial sources are divided into non-radionuclide and radionuclide. Non-radionuclide sources do not contain radioactive substances, but due to acceleration and inhibition actions of charged particles (for example, electrons) are capable of generating ionizing radiation. Non-radionuclide sources are subdivided into devices which generate unused irradiation (TVs, displays, etc.), and devices which generate used irradiation (X-ray spectral and X-ray diffraction analysis, radiation diagnosis and therapy, defectoscopy, etc.).

Radionuclide sources are subdivided into closed (contact radiation therapy, metrological expertise of dosimetric, radiometric and spectrometric equipment, neutron logging) and open. Under normal conditions, exploitation of closed radionuclide sources causes external irradiation of a person, but these sources can be radioactively dangerous to people and the environment when decompressed. Even under normal conditions of exploitation with open radionuclide sources a person can be exposed to the influence of radioactive pollution and internal irradiation.

Chapter 3

BASIC FORMS OF CONTACT OF A PERSON WITH RADIATION SOURCES

The development of life on Earth has always occurred with the presence of radiation in the environment.

Radioactive radiation is not something new, created by the human mind, but an eternally existing phenomenon.

Something new that people in this respect have created is an additional radiation load to which we are exposed, for example, during radiological examination, during radioactive atmospheric precipitation after nuclear failures, as well as a result of the work of nuclear reactors, constructed for the purpose of receiving electric power. It is impossible to deny, that artificially created sources of radiation constantly raise the natural level of radiation getting to us by nature.

3.1. IRRADIATION FOR MEDICAL PURPOSES

Irradiation for medical purposes represents a special interest, because its contribution to the dose, received by the population, is the greatest. Unlike other kinds of irradiation it affects only limited sites of the body.

The basic directions of application of ionizing radiations in medicine are radiodiagnosis, radionuclide diagnosis and radiotherapy.

According to the dose size received by the patient, methods of radiodiagnosis can be arranged in the following decreasing order: radioscopy, xeroradiography, and fluorography.

Marked bonds having an optimum half-life period of the radionuclide, small radiotoxicity and characteristic biological properties are applied for radionuclide diagnosis. As an example it is possible to use such bonds, as labelled ^{57}Co and ^{58}Co, vitamin B_{12}, iodine, ^{131}J, ^{32}P, ^{198}Au. ^{60}Co, less often ^{137}Cs, is an often source of radiation in gamma-therapeutic settings. ^{60}Co needles are used during interstitial radiation therapy. ^{32}P, ^{147}Pm, ^{204}Te, ^{90}Sr, ^{90}Y are applied in manufacturing gamma-applicators.

The basic radiation factor during radiological researches is external X-ray radiation of a tube in the translucence mode, i.e. with a generating pressure of less than 100 kV, having a non-uniform character both by localization (mainly the head, chest and hands), and depth. Irradiation of the head, chest and especially the hands in a rather large dose occurs during special procedures and while working on separate types of devices (the search for foreign objects with the help of portable equipment, urographical researches, etc.). The other sites of the body (hips, stomach area) are exposed to irradiation in a part of the personnel (hospital attendants supporting sick children, and doctors-radiologists during trochoscopy).

The average annual dose of irradiation for doctors-radiologists, laboratory assistants and nurses, hospital attendants of radiodiagnosis departments of medical institutions of Ukraine in 1981–1993 was 1.2–4.4 mSv/year.

The average annual dose of irradiation for personnel of radionuclide diagnosis establishments of Ukraine for the same period — 0.8–1.8 mSv/year.

The average annual dose of irradiation for the personnel in the radiotherapy departments in Ukraine for the same period — 0.8–1.8 mSv/year.

Work with radon is also carried out in medical institutions. The average annual dose of irradiation for personnel in the radon laboratories is 0.8–4.8 mSv/year.

3.2. IRRADIATION FOR NON-MEDICAL PURPOSES

X-ray diffraction analysis. The basic radiation hazard is the chance of local irradiation of the hands, eyes, and head or of intensive working ray of rather low-energy radiations (10–40 kV). The power of the dose, in connection with the small distance from the tube anticathode and the weak rays filtration, can reach such sizes that just a few seconds of irradiation can be sufficient to catch an acute radiation damage of the integuments.

Industrial gamma-defectoscopy. The basic radiation factors are external general and local gamma irradiations of the hands and separate parts of the body. During violation of the storage rules of radiation sources, accompanied by the increased irradiation of personnel and separate persons, local radiation changes occur on the sites of direct contact with the source (the skin of the hands, the frontal surface of the hips or the thorax, when keeping the source of irradiation in the pocket of trousers or jacket). Serious cases with lethal outcomes have also been described.

Work on nuclear particle accelerators. The persons occupied with the service of accelerators, are exposed to the combined common and local action of gamma- and beta-radiations and high energy particles, including neutrons. Local damage of the lenses and radiation cataracts are described for those people that began to work many years ago.

Nuclear reactions of research purposes and energetic settings that use nuclear fuel. The basic radiation factor, connected mainly with the active zone of the reactor, is the external gamma-neutron radiation. Besides, under some special conditions, external beta- and X-ray radiation can gain an essential value and the arrival of radioactive aerosols and gases (argon, krypton, xenon, iodine, etc.) into the environment.

Manufacture of light contents. The basic radioactive factors in the given conditions are the following:

— external — gamma- and beta-radiation from luminesced substances;

— alpha and beta-irradiation of organs and tissues, in the case of radium and mesothorium, strontium and others entering an organism by inhalation or through the digestive tract;

— gamma- and beta-irradiation of the integuments, directly touching radioactive substance;

— irradiation of the respiratory organs while inhaling and exhaling radon, thoron and tritium in an organism.

Work with uranium and its bonds. While working in direct proximity to the source containing natural uraniferous minerals, the personnel is exposed to weak radiation action. The acute form of intoxication can occur only in particular situations of simultaneous reception of significant amounts of soluble uranium bonds. It is characterized by the clinical syndrome of heavy toxic nephropathy, even to the development of uremia and the liver damage, revealed during subacute course of the disease.

Investigation of minerals with the help of radioactive sources. This kind of work is accompanied by the direct contact of personnel with gamma and neutron sources of various powers.

The irradiation becomes essential only when the rules of storage, transportation and operation of sources are violated.

Radioactive substances. Today, perhaps, there is no branch of science or techniques where to some extent radioactive substances are not applied. A great interest in the use of radioactive substances is explained by those opportunities which are open before science and techniques in connection with the use of energy released during nuclear transformations. The circle of people conducting the work with radioactive substances is very wide. Physicists, chemists, metallurgists, physicians, biologists, agriculturists, archeologists and representatives of other trades work with them. Radionuclides are successfully used for pest control, disinfection of grains, production of new kinds of seeds. The use of radionuclides in so-called marked atoms has allowed the study of new laws and to make a number of important discoveries in biology, chemistry, metallurgy, and archeology.

Some artificial radionuclides, created by irradiation in reactors, have got a wide application in therapy, diagnosis and in many other scientific researches. The total amount of these radionuclides in diagnostic and research laboratories, in correctly organized work, is insignificant, but it is much higher with the use of radioactive substances in therapy. The opportunity of irradiation of personnel with an increased dose is created only during the violation of elementary rules of work.

3.3. THE ENTERPRISES OF ATOMIC ENGINEERING

While estimating the enterprises of atomic engineering as potential sources of environmental contamination by radioactive substances, it is necessary to take into account all types of enterprises which compose the nuclear-fuel cycle (extraction and processing of uranium, its transformation into fuel, heat-producing elements manufacturing, their use in nuclear reactors at the NPP and regeneration of wasted fuel).

During the thermal processing of metal uranium and the presence of personnel near the crude large blocks, as well as during laboratory research with uranium salts, the workers are exposed to beta-irradiation exceeding, on occasion, the marginal levels 2–8 times as much. Liquid, solid, and gaseous waste products could be sources of irradiation of the population living in the area of uranium mines and factories where ore concentration process takes place.

Liquid, gaseous, and solid radioactive waste products are formed during the work of the NPP. Liquid waste products contain a rather wide spectrum of radionuclides among which ^{51}Cr, ^{54}Mn, ^{65}Zn, $^{58,60}Co$ prevail and other division products ($^{89,90}Sr$, $^{131,133}I$, ^{134}Cr, ^{144}Ce, etc.), as well as ^{3}H. The composition of the emissions, emitted into the atmosphere during normal operation of reactors, is characterized by the prevalence of inert radioactive gases (^{85}Kr, ^{138}Xe), the presence of gaseous products of activation (^{41}Ar, ^{14}C, ^{16}N, etc.), as well as some division products of uranium, mainly in aerosols.

Regeneration of the irradiated fuel. The majority of technological processes on regeneration of wasted fuel is accompanied by intensive excretion of radioactive gases, therefore they are performed in conditions of full hermetic sealing and with remote control. From the number of nuclides contained in waste products enterprises on regenerations of wasted fuel, ^{85}Kr and ^{3}H present the basic danger. Besides of them, radioactive waste products contain ^{129}I, ^{131}I, ^{106}Rn, ^{134}Cs, ^{137}Cs, actinoids, etc.

Failures at the nuclear power plants, radioactive failures at nuclear reactors occurred constantly.

Data on the largest radiation failures are generalized in table 4.

3.4. MEDICAL CONSEQUENCES OF LARGE-SCALE RADIATION FAILURES

Radiation failure is any unplanned incident at any object with radiation or radiation-nuclear technology, and if during the accident two necessary and sufficient conditions are fulfilled: loss of control over the source; real (or potential) irradiation of people entailed by the loss of control over the source.

Radiation-nuclear failure is any unplanned incident at any object with radiation or radiation-nuclear technology which occurs with simultaneous loss of control over the chain nuclear reaction

Table 4. **The main radiation failures at nuclear reactors accompanied by irradiation of people**

Location of the nuclear pile	Date of the failure	Cause of failure	Amount of injured*	Death-roll*
Idaho Falls, USA	1961	Technique failure	–	3
Melekes, Russia	1966	Dispersal on instant neutrons	2	–
Beloyarsk NPP, Russia	1978	Fire	8	–
USA	1972–1973	Essential defects in the safety systems	15	2
Three-mile Island, USA	1979	Failure of pump valves providing cooling	100	1
Gundremingen, Germany	1975	Emission of radioactive steam during pipeline repair	–	2
Tsuruga, Japan	1981	Radioactive water leakage	270	–
Beloyarsk NPP, Russia	1985	Erroneous actions of inexperienced operational personnel	–	14
Selafert, Great Britain	1986	Radioactive fuel leakage from the reactors at the NPP	5	–
Chernobyl, Ukraine	1986	Severe violation of the rules of repair	238 — acute radiation sickness, 2,000 — local radiation damage, 140,000 — evacuated	29

Note. * The death-roll and amount of injured are indicated happened during the failure or immediately after it.

and the appearance of real or potential threats of spontaneous chain reaction.

All listed failures are divided into two groups:

1. Failures, which are not accompanied by radioactive pollution of industrial premises, objects and surrounding environment;

2. Failures, as a result of the occurrence of radioactive pollution of the environment of the industrial activity and residence of people.

As a result of failure of the first group, loss of the regulating control over sources can be accompanied by additional external X-ray, gamma-, beta-, and neutron irradiations of a person.

The following are attributes to failure of the second group:

— failures on objects where work with radioactive substances is carried out in an open type, which is accompanied by local radioactive pollution of objects of the industrial environments;

— failures associated with radioactive pollution of the industrial and surrounding environment, caused by the penetration of radioactive substances into them due to depressurization of the closed sources of gamma-, beta- and alpha-radiations;

— radiation failures at objects of the nuclear-energy cycle, experimental nuclear reactors and critical assemblies, as well as at the warehouses of radioactive substances and areas of burial of radioactive waste products, where gas-aerosol emissions and/or liquid emissions of radionuclides into the surrounding environment are possible.

Such radiation failures which consequences concern not only industrial premises and its objects, but also come to the surrounding territories where the population lives, are referred to the class of municipal radiation failures. The population becomes, thus, the object of real or potential irradiation.

Municipal radiation failures are divided into the following groups:

1. Local — if the failure zone contains a population of up to 10 thousand people.

2. Regional — if the failure zone contains territories of several settlements, one or several administrative regions, and the general population in the failure zone exceeds 10 thousand people.

3. Global — municipal radiation failures, which consequences are essential for a significant part or the whole territory of the country and its population. Transfrontal, when the failure zone is distributed beyond the limits of the frontiers, is a special type of global radiation failures.

As a result of global radiation failures, as it was at the Chernobyl nuclear power plant, radioactive substances (RS) as heated gases and aerosols (xenon, krypton) are thrown out from damaged nuclear power reactors into the environment. These noble gases quickly dissipate into the atmosphere, are chemically inert, and do not collect or render harmful actions in an organism. The majority of others (zirconium, molybdenum, ruthenium, cadmium, tellurium, barium, cerium, and neodymium) with a half-life period of 30 to 300 days, are not soluble in water and liquids of an organism, are not absorbed into the blood from the gastro-intestinal tract and from the surface of the skin and only with inhaled air in part detained in an organism. The radioactive aerosols radiating beta particles irritate the mucous membranes of the respiratory paths, the oral cavity, the eye conjunctiva, the skin, causing the sensation of dryness, scratching in the throat, catarrhal phenomena, the sensation of metal taste in the mouth, pricking of the skin. However, radionuclides in quantities insufficient for an intensive external irradiation do not represent a serious health hazard for people.

The entering of those few radionuclides inside an organism, which due to their solubility in water and in liquids of an organism are capable to act inside, in its tissue, and then, selectively collect in them and cause a local internal irradiation down to full disintegration or removal from an organism, represents a real danger. Radioactive iodine-131, strontium-90, and caesium-37 belong to such radionuclides.

Iodine-131 has a half-life period of 8.08 day, i.e. it breaks up rather quickly. However, a significant part of the total radioactivity comes at the initial stage after radiation failure. Owing to this, as well as because of the accumulation in an organism, it is an important source of potential radiation danger. Up to 43 % of the arrived iodine-131 collects in the thyroid gland in a person's organism. Here iodine is included in the structure of hormones of the thyroid gland — thyroxine and triiodothyronine and circulates in the blood in their structure. Collected in the thyroid gland, iodine-131 creates a local high dose in it.

Strontium-90 and caesium-137, two other radionuclides, differ essentially by greater longevity; their half-life periods are 28 and 30 years. They enter the organism of humans and animals, moving along by the common food ways.

Strontium is rather close to calcium by its qualities. As calcium, it enters from the ground into the plants, and then into animals, collects in the skeleton of people, especially of 1–2 year-old children. The accumulation of strontium in children at the time of the nuclear weapon tests in the atmosphere was 4–5 times higher than in adults. Strontium, settled in the skeleton, is difficult and slow to eliminate. Very high local accumulation of strontium in the bones leads to long local irradiation, which may represent a potential danger concerning the formation of osteosarcoma many years later.

Caesium-137 is chemically similar to potassium. It enters an organism of animals and people with vegetative food, similar to potassium, and distribute evenly in soft tissues: the muscles, the liver, the nervous system. It is present in every living cell. Vegetative (bread, vegetables, fruit) and animal products (meat, fish, milk) can be sources of caesium for a person.

Personnel, operating the nuclear-power installations, and the staff, involved in the liquidation of the consequences of failure (fire extinguishing and so forth), can undergo:

a) acute external beta-gamma-effect from radioactive noble gases and other radioactive various products, thrown out from the active zone of the reactor and located on the territory, as well as in the structure of aerosol;

b) external radioactive contamination of the skin and mucous fission products;

c) internal radioactive contamination (by inhalation or through the alimentary canal).

Combined defects, as a result of the joint action of two or all three named factors, are possible.

External beta-, gamma-irradiation usually determines the course of the affection. In the case of the chain nuclear reaction development, for example, during the accident at the reactor on fast neutrons, a person can come under the influence of external beta-gamma-neutron irradiations.

The action of radiation factors outside the NPP during failures has common features with the influence of radiation factors of nuclear explosion, but at the same time there are also essential distinctions.

The radioactive cloud of nuclear explosion rises to a big height. Mainly, large particles, in which radionuclides are strongly connected with particles of the ground, slag, etc., drop to the ground and create radioactive contamination.

The torch of radioactive emission during the reactor failure can be distributed by grasping the ground layers of the air.

Therefore, high dose irradiation of people, appearing in the way of movement of the torch, is possible. The greater part of radiation precipitation consists of the gaseous component, including radioactive noble gases, as well as finely divided aerosols of firm components. For this reason, a significant amount of radioactive products can get into the lungs by inhalation than if they were in the structure of large particles. These radioactive substances can penetrate through respirators and gas masks much easier. They sturdily connect to the skin, clothes, paint and varnish coverings and other surfaces, which complicates deactivation.

Duration of the breakdown emission can reach several days. The greatest dose of radioactive products is thrown out within the first hours. At a later time, repeated peaks of emissions, as a rule less significant, can be observed. A change in direction of the wind can affect the distribution of radioactive products essentially during long emissions. Rain can considerably increase the amount of radionuclides in the deposit zone.

The radionuclide structure of emitted products depends on the type of a reactor, time of its operation (and "duration of operating period"), from the kind of the accident. A rather large content of old, long-living debris of division in them is general for all breakdown emissions. The danger of these products during internal and external contamination is much higher in comparison with "young" products of nuclear explosions, and recession of degree of radioactive contamination of objects and levels of radiation in the area due to natural disintegration, occurs much more slowly. Therefore, though during the influence of the radioactive emission torch on its traces, the leading value of external beta-, gamma irradiations in occurrence of defects of a person is kept, the relative value of internal and external radioactive contamination in this case is higher than on the area polluted with the products of nuclear explosion.

Three basic time phases are distinguished in the development of municipal radiation accidents.

The early (acute) phase continues from several hours up to 1–2 months after the beginning of the failure. The following occurs during this phase:

1. Gas-aerosolic and liquid emissions of radioactive substances from the breakdown reactor.
2. Processes of air and ground migration of radionuclides.
3. Radioactive deposits and formation of radioactive traces.

A feature of this phase is the presence of short-lived radionuclides, in particular iodine radioisotopes, radiations of high capacities and levels of superficial radioactive pollution in the environment.

The basic ways of radiation influence on the personnel of the station and persons which participate in the liquidation of failure consequences (within the limits of station):

— remote irradiation from the damaged reactor;

— external irradiation from the torch of radioactive emission;

— contact irradiation during radioactive pollution of the skin and clothes;

— internal irradiation due to inhalation of radioactive substances, which settle from the radioactive torch.

The basic ways of radiation influence on the population in this phase are:

— external irradiation from a radioactive cloud;

— contact irradiation from pollution of radioactive deposits on open surfaces of the body and clothes;

— external irradiation from polluted radionuclides of the ground, constructions, etc.;

— internal irradiation from the use of food and potable water polluted with radionuclides.

The middle phase (stabilization phase) begins after 1–2 months and comes to an end 1–2 years after the beginning of the failure. This phase is characterized by a rather fast decrease in capacity of the dose in the area (almost 10 times as much within a 1 year). The basic sources of external irradiation at this phase are ^{134}Cs, ^{137}Cs and ^{90}Sr.

The late phase of the failure development (restoration phase). At this phase, the basic source of external irradiation is ^{137}Cs, and internal — ^{137}Cs, and ^{90}Sr in food, which is made in the polluted territories.

The question on measures of protection of the population, which were in the distribution zone of radioactive emission products, is one of the most difficult questions.

The matter is that many protective actions are connected with the known health risk of people conducting these actions, and sometimes with significant social costs.

For the population, the conducting of such measures as evacuation, deactivation of the territory, shifting cattle to feeding on prepared forage, connected with both material costs and economic losses as a result of the termination of work of the enterprise, closing of pastures, exclusion of using fields, destruction of infected products, etc., and with mental damage because of the necessity to abandon native places, dissociation of families, etc. Therefore, in opinion of ICRP, protective measures should be conducted only when their social cost and risk appear to be less than those from the further irradiation (Table 5).

3.4.1. THE CHERNOBYL NPP ACCIDENT

The accident at Chernobyl NPP occured due to a number of severe violations of exploitation of reactor installations committed by workers of this power plant. Experiments, conserning the research of operating modes of turbogenerators were carried out at night on the fourth power unit during its scheduled repairs. Thus, the chiefs

Table 5. **Protective measures from radiation influence in various ways of radioactive substances spreading (ICRP Recommendation N 40)**

The way of radiation influence	Measures of protection
External irradiation by radionuc lides in the torch of emission	Shelter, evacuation, access control of the region of pollution
Internal irradiation as a result of inhalation of radionuclides from the torch of emission (internal pollution)	Shelter, elementary protection of the respiratory organs, the taking of stabilized iodine, evacuation, access control of the region of pollution
Superficial pollution of people as a result of the sedimentation of the emitted radionuclides or radioactive deposition on the territory	Shelter, evacuation, access control of the region of pollution, sanitary treatments and deactivation
External irradiation from the emitted radionuclides on the territory	Shelter, evacuation, relocation, access control of the region of pollution, sanitary treatments and deactivation
Internal irradiation as a result of inhalation due to the rising into the air of radionuclides from the surface of the ground (internal pollution)	Evacuation, relocation, access control of the region of pollution, sanitary treatments and deactivation
Internal irradiation as a result of consumption of polluted food products and water (internal pollution)	Food products and water control, the use of prepared foods

and experts of the NPP were not prepared for this experiment and did not coordinated it with the corresponding organizations even though they were obligated to do it. At last, a proper control was not ensured during the work and appropriate security measures were not exacuted.

The Ministry of Power and Electrification of the USSR and the State Committee on the Nuclear Energy Usage failed to take control of the things at the Chornobyl station, did not provide effective measures on the maintenance of safety requirements and keeping the discipline and service regulations of this station.

Irresponsibility and negligence, indiscipline led to severe consequences. The explosion pulled off the cover of the reactor, building constructions ruined under it and there was a fire.

The accident was accompanied by the destruction of a part of the active zone of the reactor and the building in which it settled. Consequently, more than 30 foci of fire arose; there was an emission into the environment of vapor, gases and aerosols containing radionuclides. Moving by wind, radioactive emissions were distributed all over the territory of Ukraine, Byelorussia and Russia. The first jet of radioactivity and radioactive cloud were divided into two parts towards the west and the north. The cities of Pripyat (population of 20 thousand people, 3 km away from the station) and Chernobyl (population of 20 thousand people, 12 km away from the station) appeared between these streams and underwent pollution in a much smaller degree, than, for example, "red wood" where at a distance of 2 km from station the levels of radiation fields were 100 mR/h. The levels of power of radiation fields in Pripyat before evacuation did not exceed several milliroentgen in one hour. The same situation was in Chornobyl, where the average levels of gamma radiation (May, 1986) were from 10 up to 20 mR/h.

In three days, on April 29, 1986, the direction of the wind changed to the south and the radioactive cloud moved towards Kiev. By this time the power of the emissions from the reactor essentially decreased (approximately five times in comparison with April, 26, 1986).

This led to the levels of radiation in Kiev to be a little bit smaller: average of 1.5 mR/h on April 30 and 0.6 mR/h on May 1–2, 1986. After May 2, when the power of the emissions from the reactor again increased, the direction of the wind changed to southwest, and then to northwest and north.

The direction of the wind changed by 360° for the first 10 days, almost portraying a full circle. This caused the pollution of significant territories with radionuclides. The territory, where it was raining that time, the "stains" of radioactive pollution appeared.

The formation of the basic part of radioactive fallout ended within first 4–5 days. However, full formation of radioactive "traces" and "stains" proceeded throughout May.

The generalized (by many shootings) map of gamma radiation dose power was the base for making many decisions — finally the isolines of evacuations of the population was determined: the evacuation zone (more than 5 mR/h), the alienation zone (20 mR/h) and the control zone (3–5 mR/h) with temporary evacuation of parts of the population (pregnant women, children).

The zone of alienation occupies an area of 982 km^2. The Pripyat NPP, 15 settlements, 4,697 court yards and 4 collective farms, 9 industrial enterprises, 11 educational institutions are placed at its territory. There lived 62,852 people there.

The zone of evacuation has an area of 3,300 km^2. 23 settlements, 9 thousand court yards, 5 collective farms, 8 industrial enterprises, 27 educational institutions are placed at its territory. The population is 93 thousand people.

The zone of rigid control has an area of 1,500 km^2, at which 86 settlements, 3 thousand court yards, 22 collective farms, 16 industrial enterprises, 40 educational institutions are located. The population in this given zone makes up more than 46 thousand people.

Deposits of radioactive products were revealed in many areas of the western part of the European territory of the USSR. At stations of the State Hydrometeorologic Committee of the USSR the deposits or air pollution by iodine-131 are found up until May, 2, 1986: in Ukraine — in Kiev, Vinnitsa, Ivano-Frankovsk, Rovno; in Belarus — in Minsk, Brest, Mogilyov; in Baltic countries — in Klaipeda, Riga and in both many other cities and rural settlements.

Appreciable radioactive deposits were found also in foreign countries — in Austria, Germany, Italy, Norway, Sweden, Poland, Romania, and Finland. The greatest pollution was made by caesium-137 — about 1 Ku/km^2.

Shootings of radiation conditions in the European territory of the USSR revealed zones of pollution (besides the basic one where there were rather high levels of radiation): to the northeast from the basic zone (on a joint of the Mogilyov, Gomel and Bryansk areas, to the south from Orel, to the south from Tula (Plavsk); to the west from the basic zone (in the area of White Church and Kaneva, in the region of Ivano-Frankovsk), and subsequently — on the southern gulf coast of Finland, on the Kola peninsula and on Caucasus. The general polluted area on the isoline 0.2 mR/h during first days was about 200 thousand km^2.

In June 1986, the mass isotope analysis of tests of the ground from the given areas was unwrapped and by June 10–15 it was established that the structure of the radioactive pollution was rather enriched with long-living isotopes — caesium-137 and caesium-134. The contents of these isotopes reached 50 % of the general contents of radionuclides in tests.

In May 1986, temporary norms for pollution density of the ground were established: caesium-137 — 15 Ku/km^2, strontium-90 — 3.0 Ku/km^2, plutonium-239 and -240 — 0.1 Ku/km^2.

During the accident at the Chernobyl NPP some conditions arose when radioactive products could act in water both because of direct sedimentation on the water surface, and because of the drainage from a polluted district, as well as because of migration with underground waters. During first weeks and months of the failure, the most actual was the finding of pollution degree of the Pripyat River and the Kiev water basin — a source of water consumption in Kiev. During the depositing of radioactive particles, a short-term surplus of established norms of water pollution in the Pripyat River was observed. Within the first two months after the failure a total of beta activity of the water in the Kiev water basin was (1–6) $\cdot 10^{-9}$ Ku/l and was within the limits of the permitted norms (10^{-8} Ku/l).

The contents of radioactive substances was monotonously reduced downstream by the Dnieper waters in all the cascade Dnieper water basins. The Kremenchug water basin had the strontium-90 concentration about $5 \cdot 10^{-12}$ Ku/l (May 1986), which is essentially lower than the norm (practically 100 times).

The coefficient of the wind rise of radioactivity was insignificant; therefore the concentration of various isotopes (including plutonium) in the air at the wind speed up to 10 km/s even in the zone of alienation practically everywhere appeared to be below permissible.

Employees of the NPP and the auxiliary personnel found on the industrial platform in immediate proximity to the emergency zone, exposed to a combined action of the following radiation factors:

1. Short-term external gamma- and beta-radiation of gaseous cloud of emission for people who were found at the moment of explosion in the emergency zone.

2. Decreasing in power external gamma- and beta-radiation from fragments which dissipated on the industrial platform of the damaged active zone of the reactor.

3. Inhalation of gases and aerosol dust particles, containing a mix of radionuclides.

4. Their application on the skin and mucous membranes at the moment of intensive steam formation and dust or damping clothes.

Thus, the general external rather uniform gamma irradiation of the whole body, beta-irradiation of extensive surfaces of the body with practically insignificant (except for 2 cases) importance of inhalation of a mix of radionuclides with a determining contribution to the dose of iodine and caesium are leaders.

3.4.2. RADIOMETRIC AND DOSIMETRIC INSPECTION OF THE PEOPLE WHO WERE IN THE CONDITIONS OF INCREASED RADIOACTIVE ENVIRONMENTAL CONTAMINATION

Data on the levels of radiation influence are necessary for the carrying out organizational and medical actions with the goal of reduction of irradiation consequences and normalization of conditions. With the absence of individual dosimeters dose load on people from external radiation, frequently, can be determined by methods of dosimetry without dosimeters. So, the dose for people who died during the nuclear bombardments in Japan was restored by the signal of electronic paramagnetic resonance (EPR) from bones samples.

Radioluminescence (RL) is used for the definition of a dose from samples of hair, nails, skin and clothes of people irradiated during a failure.

RL is measured using a sample of tissue with a weight of 10–100 mg, which is sunk in a pan with the corresponding solvent and the luminescence, occurring with the dissolution of the sample, is measured. To measure EPR samples of the same mass are placed in the resonator of the radiospectrometer and the EPR signal is measured, which is caused by the presence of free radicals in the sample.

The absorbed doses distributed in the skin are measured by multilayered thermoluminescence dosimeters; the effective energy of acting radiation is evaluated on the basis of the measurements of the distributed deep dose, which are carried out with the help of a set of thin-layered detectors, placed in tissue-equivalent containers.

For mass operative control the contents of radioactive ^{131}I in an organism, was determined mainly with the help of elementary methods — by the power of the exposition dose of gamma radiation on the neck surface, measured by serial dosimeters and radiometers. The calculation of the contents of ^{131}I in the thyroid gland is carried out on the basis of the measured power of the exposition dose of gamma radiation with the use of the scaled coefficient, calculated with the help of the given phantom spectrometer measurements.

In case of the absence of data on the contents of radionuclides in the thyroid gland, the individual dose can be estimated by the average dose for inhabitants with the corresponding age in the given settlement with similar modes of behavior and meals after the failure.

Defining the individual and collective doses of internal irradiation from ^{137}Cs and ^{134}Cs is carried out on the basis of multiple radiometry taking into account the data about the receiving of caesium with milk, meat, early vegetables.

Biological indicators of possible radiation influence at a population level give an idea of the value and degree of such influence. The cytogenetic method is the most mastered among methods of such indication.

3.5. EXPERIMENTAL NUCLEAR EXPLOSIONS AND EMERGENCY SITUATIONS

About 250 various radionuclides, being both direct fragments of the heavy elements division (^{233}U, ^{235}U, ^{239}Pu, ^{238}U), and products of their disintegration are formed during nuclear explosions. These radioactive substances have various half-life periods. A part of them break up in the nearest seconds and minutes after the explosion, another one — has a half-life period of several hours. Such radionuclides as ^{86}Rb, ^{89}Sr, ^{91}Y, ^{95}Zr, ^{115}Cd, ^{125}Sn, ^{125}Te, ^{131}I, ^{133}Xe, ^{140}Ba, ^{156}Eu possess a half-life period of days; ^{85}Kr, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{137}Cs, ^{147}Pm, ^{151}Sm, ^{155}Eu — from one year up to several decades. The group consisting of ^{87}Rb, ^{93}Zr, ^{129}I, ^{135}Cs, ^{144}Nd, ^{137}Sm is characterized by extremely slow disintegration, happening millions of years.

The majority of formed radionuclides are β- and γ-radiators (^{131}I, ^{137}Cs, ^{140}Ba, etc.). However, some let out only β- (^{90}Sr, ^{135}Cs, etc.) or α-particles (^{144}Nd, ^{147}Sm).

The unreacted part of the nuclear fuel, which represents non-divided nuclea of uranium or plutonium atoms, which are α-radiators, belong to the number of formed radionuclides. Due to a big half-life period of plutonium, and of uranium in particular, the activity of the rest of the nuclear fuel makes an insignificant share of the total radioactivity of the division products mix.

The induced radioactivity, arising as a result of the influence of neutron streams serves during a chain reaction of division of uranium or plutonium into the nuclea of atoms of various substances of an environment (reaction of activation) serves as an additional source of radioactive pollution of a district in the area of nuclear explosion. The capture of neutrons by the nuclea of atoms of many chemical elements results in the occurrence of radionuclides (products of activation) in the atmospheric air (^{14}C, ^{3}H, ^{39}Ar), in water (^{24}Na, $^{31,32}P$, $^{53,54}Mn$, ^{35}S, ^{65}Zn, etc.), in the ground (^{45}Ca, ^{24}Na, ^{27}Mg, ^{31}Si, etc.), in building materials of constructions, etc.

Formed radionuclides, as a rule, break up with the emission of β-particles and γ-radiations. The majority of the artificial radionuclides have a rather small half-life period; therefore radioactive pollution in the area of nuclear explosion is quickly reduced.

From a large number of nuclear debris and their daughter products of disintegration the greatest interest by radiotoxicological and physical characteristics (size of output of a product during division, half-life period, type and quality of radiation, behavior in an organism and other factors) only 10 radionuclides are represented: $^{89,90}Sr$, ^{95}Zr, ^{95}Nb, $^{103,106}Ru$, ^{131}I, ^{137}Cs, ^{140}Ba, ^{144}Ce. Only two of them — ^{103}Ru and ^{106}Ru — are direct debris of division, and the other 8 represent a product of the second-fourth acts of β-disintegration of nuclea debris.

^{131}I, ^{140}Ba, ^{89}Sr within the first months after the nuclear explosion, and later on — ^{90}Sr, ^{137}Cs represent the greatest danger in the mixes of division debris.

The radioactive deposits, formed during nuclear experiments are subdivided into local, deposited within the limits of up to 100 km from the place of explosion or failure, tropo- and stratospheric. Tropospheric deposits drop on to the surface of the ground with a distance of several hundreds and many thousands kilometers from the place of explosion. The average time of tropospheric deposits stay in the atmosphere about 30 days. Stratospheric deposits include, as a rule, the basic part of radioactive division products and cause the most part of global radioactive pollution of the environment with division products.

Radioactive products of nuclear division, deposited by themselves (dry deposits) or more often with an atmospheric precipitation (wet), are included in abiotic components of the biosphere (water) and biotic (flora, fauna), take part in the biological cycle of circulation of substances. Thus, division products can enter a person's organism directly with vegetative food and by means of animals, which eat plants or forage containing radioactive substances.

Radioactive division products represent a mix of radionuclides, which have an unequal rate of decay. Therefore their ratio in this mix eventually will continuously change to the side of enrichments by long-living fission products due to the disintegration of short-lived radionuclides. The activity of products of nuclear explosion is quickly reduced within the first hours and days, because in the general mass of all radioactive products the greatest amount of isotopes have a small half-life period. So, within the first days, the general activity because of the short-lived radionuclides is reduced 50 times. The general activity of the mix of explosion products decreases much more slowly in the process of disappearance of short-lived radionuclides.

The radioactive substances formed during the nuclear explosion tests, create radiation influence — an internal irradiation (inhalation of radioactive substances contained in the ground layers of the air, and the use of polluted with radionuclides food products) and an external irradiation (radioactive substances present in the ground air or floating on the surface of the ground).

The Scientific Committee of the United Nations on the action of Nuclear Radiation (SCANR) allocates 21 radionuclides, definitely influencing the irradiation of the population: ^{3}H, ^{14}C, ^{54}Mn, ^{55}Fe, ^{85}Kr, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{103}Ru, ^{106}Ru, ^{131}I, ^{136}Cs, ^{137}Cs, ^{140}Ba, ^{141}Ce, ^{144}Ce, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am. 8 radionuclides, each of which in an expected effective equivalent dose of irradiation of the population of the whole world makes more than 1 %, are allocated among them. They are (according to decreasing of their contribution to the dose) ^{14}C, ^{137}Cs, ^{95}Zr, ^{106}Ru, ^{90}Sr, ^{144}Ce, ^{3}H, ^{131}I.

^{90}Sr and ^{137}Cs present the greatest danger among radioactive fission products. They have rather high energy of radiation and a large half-life period, a special capability to be included in the biological circulation of substances (ground — plants — animals — people), as well as are held for a long time in an organism of animals and people. During research of the laws of movement of ^{90}Sr and ^{137}Cs from one object of biosphere to another one it was noticed, that the first behaves similar to calcium, and the second — to potassium. It was established, that under equal conditions in the objects of the biosphere polluted with radionuclides, the maximal concentration of ^{90}Sr is always found in organs (products) rich in calcium (bones), and ^{137}Cs — in objects rich in potassium (muscles). Thus, additional sources of irradiation are nuclear explosion tests and failures on NPP during which about 225 radioactive isotopes are formed. ^{90}Sr and ^{137}Cs, which are included in the circulation of substances, can be held for a long time in a person's organism, present the greatest danger.

Emergency situations are met not only on nuclear power plants. The case, which took place in Brazil, was published in January, 1988. The chief of the radiological center, transferring the clinic into a new building, decided to leave old medical equipment in the building destined to destriction included the apparatus with the "caesium gun" where a capsule with caesium-137 was placed. The apparatus was left without supervision for a year. Then the apparatus met an unemployed person's eye who gave the capsule for utilization. The owner of the utility wastes place noticed that the capsule shone at night, broke it and began to present a "wonder" to friends, they rubbed the luminous powder before participating in a carnival. The caesium, which was in part woken up at the dump, was distributed also in other ways — on the soles of shoes, pleated clothes, on automobile tires. Everyone, touching the caesium, felt badly, and in those who took the powder into their hands, rubbed it into the skin, terrible burns, ulcers began to appear. In total, 248 victims and the doctors rendering help were revealed.

3.6. INDUSTRIAL NUCLEAR EXPLOSIONS

Industrial nuclear explosions are subdivided into two types:

— camouflaged, during which the charge is placed at a depth of several hundred meters from the surface of the ground, and the basic amount of formed radioactive substances stays in a cavity created by the explosion;

— excavational (on emission), as a result create corresponding funnels, and a huge mass of ground moves in the required direction.

The circle of questions which can be solved with their help is rather wide. It is the development of minerals, constructions of large hydraulic engineering constructions (channels, harbors, dikes, and dams), creation of underground cavities for the storage of gas, water, radioactive waste products.

The isotope structure of radionuclides, occurring during industrial explosions is determined by the type of explosion (nuclear, thermonuclear). In the case of application of thermonuclear charges alongside with radionuclides and the induced activity, an essential role in the pollution of objects of the environmentas played by tritium.

3.7. ARTIFICIAL SOURCES OF IONIZING RADIATIONS NOT CONNECTED WITH POLLUTION OF THE ENVIRONMENT

Roentgen installations and radioactive drugs used for medical purposes, TVs of various types, and luminous dials of household devices can be attributed to the number of anthropogenous sources of irradiation of the population with ionizing radiations which do not pollute the environment with radioactive substances.

3.8. CONSUMER GOODS AS A SOURCE OF IONIZNG RADIATIONS

These or those radionuclides enter a number of consumer goods, such as: radioluminescent goods, electronic and electric devices, synthetic devices, gases and aerosols (smokes) detectors, ceramic, glass products, products from alloys containing uranium or thorium, etc. The dose of irradiation of a majority of the listed goods is significantly low.

Chapter 4 THE BIOLOGICAL ACTION OF IONIZING RADIATION

4.1. PRIMARY PHYSICAL-CHEMICAL AND BIOLOGICAL PROCESSES

All kinds of ionizing radiations cause the formation of electrical charged particles — ions in any substance they interreact with. Hence their name — ionizing radiation. Ionization and excitation of atoms or molecules of an irradiated substance represent a major primary physical processes which causes the starting mechanism of biological action of radiations (Fig. 1).

The transfer of energy of radiations to atoms and molecules of a biosubstratum is only the very first, physical "act of the drama", taking place in a cell, and then in tissues and in the whole organism. What is the fate of these excited and ionized molecules, what are the further events, what do the further transformations of the simple molecules of a substance and especially macromolecules, biological polymers consist in? In other words, now we shall consider the next "act" called the chemical (or radiation-chemical) stage of the radiation damage to a cell.

The primary radiation-chemical changes in molecules can be produced by two mechanisms:

1. Direct effect, when the given molecule experiences change directly during interaction with irradiation.

2. Indirect action, when a changed molecule does not directly absorb energy of falling radiation, but gets it by transfer from other molecules.

Schematically, the direct action of radiation, or the process of ionization, occurring under the influence of ionizing radiation, is possible to present as follows. The quantum radiation absorbed by atom A, results in the release of an electron, which associates with atom B, therefore a positive A^+ ion and negative B^- is formed:

$$h\nu \rightarrow A \rightarrow A + e^-; \; e^- + B \rightarrow B^-$$

The primary physical and chemical changes which are turning out in the first fraction of a second, result in the formation of subsequent parts of reactions, developing already after the direct act of irradiation and causing radical changes in cells and tissue of an organism within rather significant time intervals.

Ionizing radiation penetrates into biological material and interacts with molecules and atoms (physical sphere). As a result of this effect, the damaged organ can be changed directly. However, intermediate products — mainly due to the dissociation of irradiated water (chemical sphere) are more often formed: radicals $H^\bullet$ and OH^- which can change the enzymes or the damaged organ. Besides this, active bonds of these radicals are formed: H_2O_2, HO_2 and other peroxides, which also can cause changes in enzymes and damage the irradiated organ (biochemical sphere). Chromosome changes, caused directly or indirectly (for example, under intermediate influence of damaged enzymes), result in various biological displays (biological sphere).

The chemical activity of ionizing radiations is very high, and the biological activity appears to be higher, because death of an organism occurs during the action of very small energetic doses of ionizing radiation, during which initial physical-chemical changes are outside the most sensitive analytical methods.

In these doses of energy, direct violations in the chemical bonds of biomolecules are very insignificant, and the main role in the damage belong to the processes during which there is an increase of the primary effect, developing after the influence of ionizing radiation.

The water phase of cells and tissues of organisms plays an essential role in the action of ionizing radiations.

What occurs under the influence of ionizing radiation on water?

In the radiolysis of water, a molecule is ionized by a charged particle which causes it to lose an electron:

$$H_2O \rightarrow H_2O^+ + e^-$$

The ionized water molecule reacts with another neutral water molecule to form the highly reactive hydroxyl radical $OH^\bullet$:

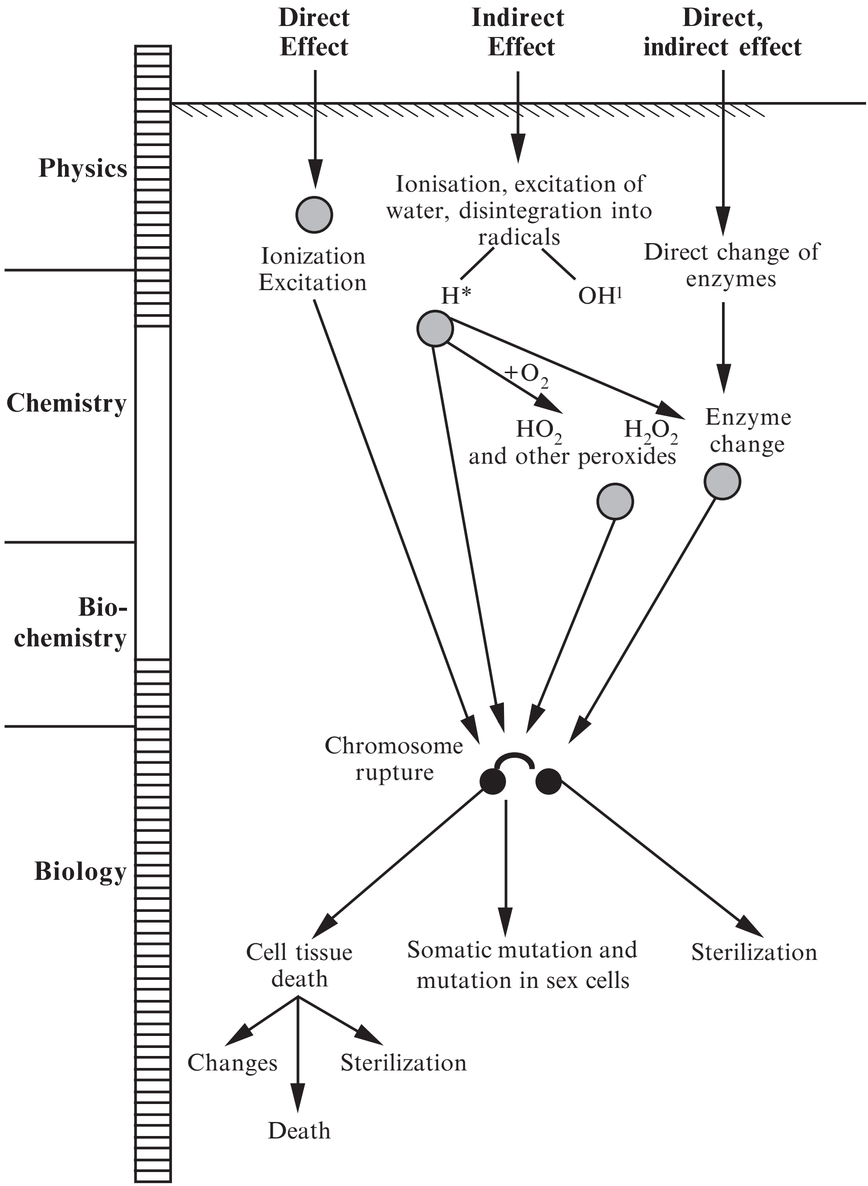

Fig. 1. A chain of reactions in the process of the biological action of radiations

$$H_2O^+ + H_2O \rightarrow H_3O^+ + OH^\bullet$$

The ejected electron interacts very quickly with the surrounding water molecules. As a result a highly excited molecule H_2O^* appears; it dissociates with the formation of the two radicals H* and OH^1:

$$H_2O^+ + e^- \rightarrow H_2O^+ \rightarrow H^* + OH^1$$

These free radicals contain unpaired electrons and they (free radicals) are distinguished by an exceedingly high reactivity.

In the presence of oxygen, other radiolysis products also form that have oxidizing properties, namely, the hydroperoxide radical HO_2; hydrogen peroxide H_2O_2 and atomic oxygen:

$$H^* + O_2 \rightarrow HO_2^*$$

$$HO_2^* + HO_2^* \rightarrow H_2O_2 + 2O$$

The situation is considerably more complex in the cell of an organism, than in the radiolysis of water, especially if the absorbing substances are large and multicomponent biological molecules. We shall designate a complex biological molecule conditionally DD. Let this molecule be ionized by the charged particle:

$$h\nu \rightarrow DD \rightarrow DD^+ + e^-$$

The positive ion DD^+ breaks up with the formation of free radical D*:

$$DD^+ \rightarrow D^+ + D^*$$

Just as water radicals, organic radical D* also possesses an unpaired electron, and, hence, extremely reactive. Possessing a large amount of energy, they can easily break chemical bonds.

Thus, in the development of radiation damage in biological objects, the primary activation is carried out by means of radicals, formed during radiolysis of water in the water phases of colloids of cells and tissues. The value of similar activation is explained in that the act of decomposition of water into radicals demands a rather small energy; the obtained radicals possess a very high chemical activity.

The water phases directly border the surfaces of biomolecules, possessing plenty of active reactionary groups. The water bridges, dividing these molecules do not exceed 3–4 molecular radiuses, to say nothing of that the water phase contains dissolved chemically active organic bonds. In these conditions, the formed radicals have an opportunity to react directly with biomolecules and the recombination processes to the lowest notch.

The radicals formed during the radiolysis of water H, OH, HO_2 oxidize and reduce various organic bonds. However, it is possible to consider, that the main role belongs to oxidation reactions in the primary stage of radiation damage, and the biological action relates to the oxidizing radicals OH and HO_2.

The action of radiation can be named direct, when molecules of organic components of a cell are ionized, and indirect, when radiation acts on the biosubstratum due to the formation of highly active products of hydrolysis of water.

The primary action of radiation is meant in the case when molecules are ionized or excited, and the secondary when the subsequent transformation of formed ions, radicals and excited molecules are meant.

A number of researchers established that far from all energy from ionizing radiations absorbed by tissues of an organism causes a biological effect. The probability of successful interaction of quantums of energy of ionizing radiations with a biosubstratum, i.e. that the ionizing act causes reactions in cells, very small, about 0.01–0.0001, and the amount of energy which causes the destruction of cells is insignificant. While explaining the given phenomenon two positions were formulated.

The first of them — the hit principle, which characterizes the features of the working agent — the discreteness of the absorbed energy. The second one takes into account the features of the irradiated object (cell), its high heterogeneity in the physical and functional relation, and, therefore, the distinction in the answer to the same hit — target principle.

The initial hypotheses of interaction of ionizing radiation with the biosubstratum started with the simplified representations of the mechanism of primary radiobiological processes on the basis of physical, and later radiochemical laws established during the irradiation of simple systems, without taking into account the specificity of macromolecules strongly complicating the very first stages of radiation reaction. More progressive is the stochastic hypothesis which takes into account both the physiological and induced radiation processes.

The stochastic hypothesis examines any biological object, in particular, the cell, as a labile dynamic system, which is constantly in a process of transition from one condition to another one. Due to the extreme complexity of the system any such transition is accompanied and connected with a set of complex and elementary linked reactions of separate cellular organelle and macromolecules. It is known that during vital activity, due to the influence of diversified, being beynd all calculation factors and the slightest uncertainty of the initial condition, there is a probability of "refusals" in the elementary links, as a result and (or) independently on them — the "wreck" of the whole system. According to the stochastic hypothesis, under the influence of irradiation, the probability of spontaneous violations of cell homeostasis supported by numerous regulation mechanisms increases, and the primary radiation physical-chemical changes are only a push for such multicomponent processes resulting in the effect being found out.

Not all radiation reactions and the mechanisms of their occurrence can be explained from the position of direct action of ionizing radiation.

The most vivid example of mediated reactions — the unhealthy condition of the patients, exposed to local radiating influence during radiation therapy, which is similar to alcoholic intoxication of the organism, received the name "X-ray hang-over".

P. D. Gorizontov gave a certain role to "radiotoxins" in the mechanism of mediated action of irradiation. In the opinion of the scientist, radiotoxins can be abnormal metabolites, as well as substances, peculiar to normal conditions, but formed in an irradiated organism in superfluous amounts. For example: hormones, products of metabolism and fission of tissue, mediators.

The occurring toxins (quinones, orthoquinones) influence the neuroendocrinal device that serves as the reason for a number of mediated effects, a typical example — the mentioned condition of X-ray "hang-over".

4.2. STRUCTURAL DAMAGES OCCURRING IN IRRADIATED MACROMOLECULES

The damages occurring in the structure of an irradiated macromolecule can lead to a change in its biological properties.

4.2.1. STRUCTURAL DAMAGES REVEALED IN IRRADIATED NUCLEINIC ACIDS

As a result of irradiation of DNA dry preparations there are the following types of structural damage of a macromolecule:

1. Single- and double-spiral breaks.
2. Intermolecular cross-section polynucleotide chains.
3. Bifurcated chains due to the total effect of single and double breaks (due to the connecting of molecule fragments, formed as a result of a double break, to places of single breaks in the DNA chain).

4.2.2. STRUCTURAL DAMAGES IN IRRADIATED ENZYMES

The analysis of the structural damages occurring in irradiated preparations of ribonucleases showed that in doses close to D_{37}, the following phenomena are observed:

— change in the amino acid structure; most visible in samples, the contents of 6 amino acids was reduced: methionine, phenylalanine, lysine, histidine, tyrosine and cystine;

— occurrence of breaks in the polypeptide chain, resulting in the occurrence of free amide groups and molecule fragments;

— occurrence of aggregates;

— break in the sulfhydryl bonds and occurrence of the free SH-group.

During the irradiation of lysozyme, some other characters of structural damages were found:

— the macromolecule configuration changes;

— some components possessing enzymatic activity appear.

Much more complex and not determined yet effects add to the primary radiating damages of macromolecules in a living cell. They are expansion of the damage due to metabolic reactions, restoration of the damaged molecule due to functioning of the repairing systems, effects connected with heterogeneity of the irradiated system, presence of water and low-molecular substrata, etc.

4.3. IONIZING RADIATION INFLUENCE ON CELLS AND CELLULAR POPULATIONS

The most universal reaction of a cell to irradiation is a temporary delay (suppression) of cellular division frequently called radiation blocking of mitosis. General concepts of radio-biochemical mechanisms of interphase and reproductive destruction of cells are shown in fig. 2.

The reduction in the number of dividing cells after irradiation had been already noted soon after the discovery of X-rays and was used to suppress tumor growth.

Various X-ray reactions of a cell (mitotic delay, induction of chromosomal aberrations, suppression of DNA synthesis, etc.) are expressed to different degrees and depend on the phase of the cell cycle. The most radiosensitive cells appear during mitosis. With irradiation in the beginning of period G_1 the survival rate appears five times greater, harshly falls with irradiation of cells in phase S and again increases with irradiation at the end of S-period, exceeding the survival rate mitotic cells 10 times. The survival rate for cells, irradiated in the G_2 period, is gradually reduced.

Results of an overwhelming majority of numerous researches gave rather convincing proofs of incomparable greater radiosensitivity of a nucleus and the main role of its damage as a result of cell irradiation. It appeared, for example, that the entrance of only one particle into the cell nucleus causes its destruction, which in the case of cell cytoplasm irradiation is registered after 15 million particles.

The far-reaching consequences can have such a change in the hereditary information, when a cell does not die but gets new properties, which it did not have earlier, or loses old qualities.

Mutation is the change of cell (organism) properties fixed in heredity; the changed organism — mutant, and the external agent causing a mutation — mutagen.

The sensitivity of cells to ionizing radiation can be increased or decreased due to physical or chemical factors, as well as with the help of influences that change the biological characteristics of cells (level of metabolites, intensity of respiration and other processes of metabolism).

Radiotherapy tries to use modifying factors, for example, selectively increasing the radiosensitivity of tumor cells, and in the protection of an organism from radiation.

At the level of cellular populations occurring under the influence of irradiation processes are defined by four cardinal parameters:

1. Relative size of the pool of stem cells.
2. Radiosensitivity of cells and their ability to restoration.
3. Cellular proliferation.
4. Speed of utilization of mature elements.

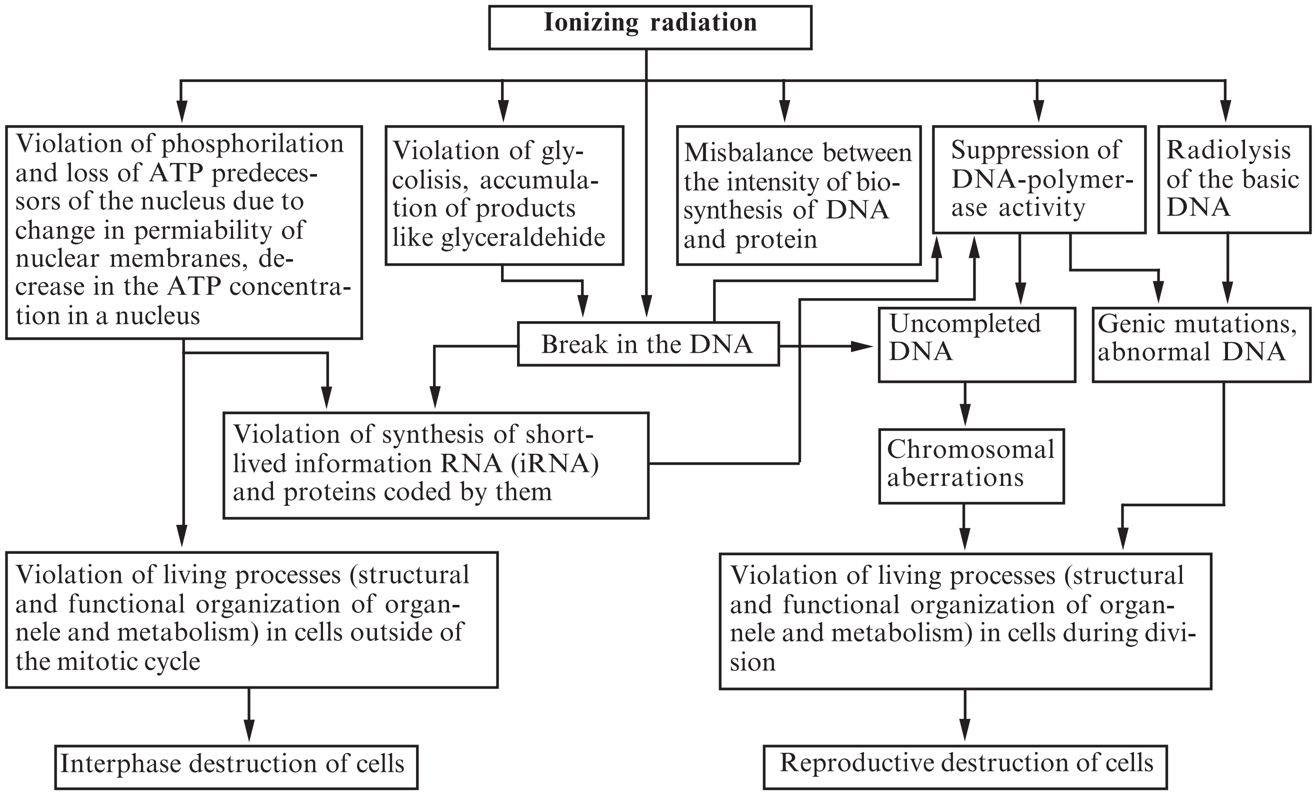

Fig. 2. Radiation-biochemical mechanisms of interphase and reproductive destruction

4.4. IONIZING RADIATION INFLUENCE ON TISSUES

Radiosensitivity of tissue is proportional to the proliferation activity and inversely proportional to the degrees of differentiation of the cells making it. This rule was formulated by J. Bergonie and L. Tribondeau in 1906, i.e. in the beginning of the studies of the biological action of ionizing radiations. This rule has not lost its role even now, despite some exceptions.

Radiating influence also does not remain traceless for radioresistant poorly renewed tissues (bone, muscular, nervous). It was established in the G. S. Strelin's laboratory, that poorly renewed tissues "remember" radiating influence and are potentially inferior in a functional respect. Consequences of such latent injuries appearing in cells of any poorly renewing tissues are cystites, rectites, and injuries to the kidneys, the heart, and the liver.

The lymphoid tissue is the most sensitive tissue of a person's organism. There is mass destruction of the lymphoid cells during the first hours after irradiation. Meanwhile, these cells, or lymphocytes, play a paramount role in the regulation of an organism's immunity against the most various infections. Radiosensitivity of lymphocytes remained a mistery for many years. In fact, usually mitotic or dividing cells appear to be more radiosensitive. Lymphocytes are non-mitotic cells, thus, their destruction is not connected in any way to division. To find ways for help to an irradiated organism it was necessary to understand the reasons of large radiosensitive lymphoid cells. As a result of the carried out researches, it appeared that the radiation action on lymphocytes results in quickly-coming changes in properties and functions of biological membranes, activity of some of the key enzymes regulating metabolism, in the energetic condition of cells and their ionic balance. Effective monitoring systems of control of enzyme activity exist in a healthy non-irradiated lymphocyte. Radiation influence violates them, an "unguided" nuclease acts on a DNA molecule which results in its disintegration and consequently, cell death.

It is essential, that the loss of cell control functions does not occur right after irradiation, but in a while. It was possible to track the stages of this process. It turned out that in irradiated lymphocytes there were specific protein factors. Nucleases decompose DNA apparently under their action. Scientists came to an essentially important conclusion that the death of irradiated lymphocytes eventually happens at the start of concrete biochemical reactions. The death process can be controlled. For example, some antibiotics suppress the synthesis of fiber and can prevent the disintegration of DNA in irradiated lymphocytes, protecting them from death.

4.5. RADIATION REACTIONS IN SOME ORGANS AND SYSTEMS

4.5.1. SKIN AND ITS DERIVATIVES

Radiation injuries of the skin were described earlier and the most often. Erythema and epilation were marked as the first evident symptom of radiation injury of the skin in people. A reddening of the skin even before served as the dose measure of irradiation, which is called hauterythemdosis (HED).

It is considered that the maximum dose of X-rays tolerable by the skin with a single external exposure is about 10 Gy. At higher doses dermatitis appears, and then ulcer. Temporary epilation occurs in a person with general irradiation dose about 4–5 Gy, consequently we observe destruction of the sebaceous and sweat glands and suppression of their secretion, constant alopecia — in doses above 7 Gy.

A. K. Guskova (1971) describes the following observations of a patient with damaged skin of the hands:

Patient G., 31 years old, an employee of the scientific research institute. The day of the incident, he carried out simple manual manipulation directly under the beam of an electronic accelerator, he was not informed of its being switched on. Modelling the conditions of irradiation allows us to assume, that the total local absorbed dose on a limited site could reach 240 Gy. The primary reaction of the skin, as transient erythema, appeared on 1st finger in 8–10 h, on other locations (2nd and 3rd fingers) — in 20–22 h. The latent period was only 6–7 days, then prickling occurred, a feeling of pressure in those same locations. Significant hypostasis was formed on the 11th–12th day, and the skin of the wrist became a continuous brown shade. The third phase of acute damage for various sites of the wrist was from 6–12 up to 40–43 days, from the moment of irradiation, when the formation and increase of hypostasis occurred, and then bubbles filled with a liquid of yellowish color consistently appeared. The maximum of clinical displays were noticeable on the 3rd–4th week of the disease, when along with the expressed hypostasis on the exposed surfaces after the tearing away of necrotic layers of the epithelium, eroded sites covered with a brownish crust is formed.

The clinical diagnosis at the final time of care (1.5 years): the residual phenomena of heavy acute professional damage of the hands as a result of irradiation by a beam of electrons, dystrophic changes of the skin, disturbance of pigmentation, sudoriferous and sweat excretion, violation of nail and hair growth.

Ukrainian scientists S. A. Biryukov and N. F. Romanenko consider, that besides the damage of mature cells of the skin during local radiating influence on the skin and the accumulation of toxic products of disintegration in it, the reflex exit into the skin of biologically active kinins and histamine-like substances play an important role. Significant violation of cellular, vascular and tissue membranes penetration is observed in the late stages of damage, the outflow of blood and lymph is broken, and there is hypostasis of the nervous endings. A decrease in the tissue immunity, which results in the accumulation of infection and activization of conditional-pathogenic flora of the skin has special value.

According to the same authors formation of acute radiation sickness can be divided into 4 phases:

1. The early radiation reaction or primary erythema.
2. The latent period.
3. The period of pronounced clinical displays.
4. The period of full or partial recovery.

According to clinical course there are distinguished four degrees of severity of acute radiation sickness: mild — acute erythematic dermatitis, moderate — acute aggressive dermatitis, severe — necrotic-ulcer dermatitis, and extremely severe — necrotic dermatitis. The absorbed dose in the basal layer of the skin comprises accordingly 8–12, 12–20, 25–30 Gy and more. Chronic radiation dermatitis is formed in places where aggressive dermatitis was, and represents sites of hyper- and hypopigmentation. The skin in these sites is inclined to haemorrhage. There are sites of hyperkeratosis and warty growths in 6–8 months after irradiation. Trophic ulcers appear at the place of the skin radiation damage.

A rather often disease which develops in people working without a proper protection in the sphere of ionizing radiation action is post-irradiation carcinoma. It almost does not differ from other kinds of a skin cancer by its basic displays. Some clinical features consist of the occurrence in people irregardless of age and of the rather unusual localization for cancer — on the hands. Sometimes tumors appear simultaneously in several places, differing by acute morbidity and propensity to grow deep into the skin.

By histological structure, three types of radiation cancer are distinguished: epidermoid with an inclination to keratinization, basal without keratinization and mixed. Epidermoid cancer with all of its characteristic features is more often seen. The clinical course of post-irradiation carcinoma is slow and lingering. The death rate from post-irradiation carcinoma is about 20 %.

4.5.2. HAEMOPOIESIS DURING RADIATION SICKNESS

Changes in the lymph nodes, the spleen and then thymus gland appear with the absorbed dose of irradiation 25–50 sGy, and in the cells of the bone marrow — with 50–100 sGy already after the first day of irradiation. Irradiation of the haemopoietic organs results in progressing devastation of irradiated lymphoid tissue from several days up to 1–2 weeks, however, later on rather full reparation occurs. Serious damages by the absorbed dose of 400–800 sGy leave more steady infringements with slow haemopoiesis restoration in the irradiated area.

Cellular devastation is the most important display of radiation sickness of haemopoietic organs. This process is usually subdivided into three stages.

The first stege, continuing about 3 h, is characterized by a relative constancy of contents of cells in haemopoietic tissues.

The second stage covers an interval of time from 3 up to 7 h after irradiation. It is typical acute and deep devastation of the bone marrow and lymphoid tissue (the amount of cells in the bone marrow tissue can be reduced more than half). The major mechanism of this stage is interphase destruction of the cells, determining a high radio-struck of haemopoietic organs.

The speed of cellular devastation is slowed down at the third stage and the further reduction of cells amount happens in the bone marrow as a result of reproductive destruction, as well the proceeding differentiation of part of the cells and their migration in the blood. It has been marked that the duration of the third stage is proportional to dose of irradiation.

When comparing the radiosensitivity of cells of various haemopoietic organs, it was found that the erythroidal cells of the bone marrow are the most sensitive to ionizing radiation action, the striking of the lymphoid cells of the thymus, spleen and bone marrow, basically, is similar and expressed, apparently, more poorly in comparison with erythroidal cells of the bone marrow; the cells of granulocytic growth are the most radioresistant. It is established, that the interphase destruction of cells is the principal cause of lymphoid cell loss; a decrease in the amount of erythroidal and granulocytic cells substantially depends on other reasons: toxemia, infringement of immune reactions, nervous and hormonal regulation.

A decrease in number of leukocytes in a person up to 1,500 cells in 1 mm^3 means that the sick has few chances of recovery, a fall in the level of leukocytes to 400 cells in 1 mm^3 testifies to the most probable lethal outcome within 2 weeks after irradiation.

Morphological changes of white blood are observed in radiation pathology: hypersegmented neutrophils appear, phragmentosis of the nucleus of neutrophils increases. Soon this picture is replaced by a shift in the leukocytic formula to the left with the absence of hypersegmented neutrophils and the reduction of their phragmentosis of the nucleus. Damage of the lymphocytes consists of pyknotization of the nucleus, karyorrhexis, karyolysis and then lympholysis. Besides these changes, the condensation of leukocytes, their swelling, increase in size, accumulation of pigments, an abundance of grains, breaking up of the structures of the nucleus are frequently observed.

A reduction in the number of thrombocytes frequently follows a decrease in the number of neutrophils and is already distinctly noticeable during first hours after radiation influence. Thrombocytopenia results in an increase of blood coagulation time. It is considered that the contents of thrombocytes in 1 mm^3 of blood less than 80 thousand are dangerous to a person.

A change of erythrocytes contents is considerably less expressed in comparison with other blood cells; however, the process of restoration of red blood cells takes months or more. The number of erythrocytes, the contents of haemoglobin in the blood practically do not change in the initial stage of radiation sickness. However, the stability of erythrocytes to haemocatheretic agents is broken soon after irradiation.

The least expressiveness of changes in the blood picture is observed during irradiation of an area of the head, thorax, extremities and the greatest — during irradiation of the organs of the hips and abdominal cavity.

4.5.3. CARDIOVASCULAR SYSTEM

Direct and remote changes of the myocardium after local irradiation of doses 5–10 Gy are found with the help of biochemical, morphofunctional and electro-microscopic methods. The basic role in the development of radiating myocardiofibrosis is played by the infringement of microcirculation due to obliteration of the endothelial cells of capillaries. There are data testifying to the significant radiosensitivity of the endothelia of the endocardium, which damage results in the formation of intraventricle blood clots.

Large blood vessels are moderately sensitive to irradiation, while capillaries permeability is broken already after irradiation in a dose 1.0 Gy.

4.5.4. RESPIRATORY ORGANS

The respiratory organs contain cellular structures considerably differing by stability to radiation. So, cartilaginous tissue of the pneumatic ways and pleura are radioresistant, lymphatic tissue and the vascular system of the lungs, as well as bronchial epithelium and the cells covering the alveoli, are radiosensitive. As a result of general irradiation of an organism, respiratory organs undergo changes, which are taking place in full conformity with the development of clinical and anatomic attributes of radiation pathology. For example, swelling and partial disintegration of argyrophylic fibers, hyperemia, emigration of the erythrocytes and hypostasis in alveoli, and subpleural emphysema are observed at the first phase of changes during first 3–4 days of acute radiation sickness.

After the latent period a new phase begins, described by an increase of vessel permeability, perivascular output of the blood, haemorrhages, frequently observed necrosis, bacterial infection, and hypogranulocytic bronchopneumonia. In the survivors resorption and regeneration with proliferation of the connecting tissue, sclerotic phenomena occur. Changes in the respiratory organs develop against a background of sharply suppressed cellular reactions, therefore at the height of the disease there are no phagocytosis either of bacteria, or of products of tissue disintegration. The doses, which are not rendering significant action on the epithelium, cause only weak fibrosis.

The pneumonias, described as secondary infectious complications, can have a deciding part in the lethal outcome of radiation damage of an organism.

4.5.5. NERVOUS SYSTEM

As opposed to other critical systems — the haemopoietic organs and the gastro-intestinal tract — mature nervous tissue represents an unproliferated cellular system, consisting of highly-differentiated cells, which could not be replaced in the organism.

The sequence of morphological, biochemical and physiological changes of the nervous system during various syndromes of radiation sickness is schematically presented in table 6.

Clinical displays of local irradiation of the brain in big doses are described in literature.

Patient K., 22 years old, a healthy person in the past, underwent roentgenoepilation concerning microsporia of hairy parts of the head, skin, neck, and shoulders. The exposition dose was 0.38 Ku/kg. However, the seriousness of clinical displays and severe localness of tissue damage that underwent irradiation, in comparison with the literature data, allows us to consider that the dose received by the patient's head area is near 50–100 Gy. Loss of hair began in a week, long-healing ulcers appeared. Hair growth on the head was not renewed during 2.5 years of supervision. The general state of health of the patient was good. Changes in the blood picture are not revealed. The patient 3–4 times temporarily lost consciousness in the 1 year after irradiation. Simultaneously the skeletal muscles were relaxed. After 1.5 years the patient for the first time noted involuntary twitching of the right foot, and after even another week general epileptic attacks developed, which began with convulsive twitching of the right foot with the subsequent increase of weakness in it and general psychomotor excitation. The attacks repeated in 10–12 days.

Further the attacks gained a character of impellent and sensitive Jackson epileptic attacks. A precise right-sided pyramidal symptomatology was established, increasing after each attack.

Morphological changes in the spinal cord are expressed more poorly than in the head. The clinical picture of focal postradiating necrosis of the spinal cord, most of all, resembles the subacute forms of myelitis, and the changes in myelin in the conducting paths are rather close in clinic to such slowly developing demyelization processes as funicular myelosis or the spinal form of multiple sclerosis. The most resistant in the nervous system is the peripheral neuron. The occurrence of regional multineuritis is observed only in cases when the radiation loads reached several thousand santigrey.

Table 6. **Diagram of the time succession of morphological, biochemical, and physiological changes in the CNS**

Time after radiation	Morphological changes	Biochemical changes	Physiological changes
Minutes	Change in structure of the brain cortex nervous cells biomembranes	Violation of the ion biomembrane penetrability; decrease in the contents of K^+ and increase of Na^+ in cells	Increase in bioelectrical activity of the brain cortex
Radiation in "supralethal doses," causing cerebral syndrome			
Hours	1. Pathetical and focal haemorrhages in the nervous tissues; swelling of endothelium, muscular cells of the connecting tissue fibers of blood vessels 2. Destruction of actively functioning nervous cells as a result of direct radiation action 3. Destruction of a part of cells	1. Oppression of oxidizing processes; dissociation of oxidizing phosphorylation processes; carbohydrate-phosphoric metabolism discoordination 2. Increase in the autolytic processes	1. Violation of selective permeability of the hematoencephalic barrier 2. Direct damage to the brain tissue in combination with the influence of other irradiated systems on it, first of all — blood vessels 3. Destruction of the organism
Irradiation in lower doses, causing acute radiation sickness			
Hours — the first day	Feebly marked individual haemorrhages in the brain tissue; insignificant damages to the blood vessels	1. Increase in the activity of cytochrome oxydase and decrease of succinodehydrogenase 2. Violation of the nitrogenous and nucleinic metabo	1. General cerebral and diencephalic symptoms; violation of the functions of the hypothalamic area of the mesencephalon and diencephalon brain; cardiovascular changes

		lism in the cerebral hemispheres 3. Increase of acidic products in the blood and urine	2. Weakening of the inhibitory processes in the brain; increase of the conditional-reflex activity, observed at the background of increased bioelectric activity of the brain cortex
Height of the illness	1. Externally the brain looks like slightly changed; hypostases and haemorrhaged, disorder of blood circulation; blood vessel walls of the brain are damaged 2. During late stages of the illness in separate sites of the brain parenchyma there occur necrotic processes 3. The high-functioning nervous cells perish first as a result of direct radiation action, as well as because of mediated influence of other damaged systems action	Phase changes of enzyme activity: oxidation and phosphorylation, nucleinic, nitrogenous, albuminous, carbohydrate metabolism	1. Oppression of excitation processes in the brain cortex; weakening of the conditional-reflex activity, observed against a background of increased bioelectric activity of brain cortex 2. Deterioration in the oxygen supply to the brain 3. Violation of central-peripheral ratios in the nervous system of an organism; mutual influence of the CNS and other systems in an irradiated organism; aggravation of pathological processes
Outcome of the illness			Depending on the dose of irradiation — restoration of an organism from radiation injury or its destruction (bone marrow or gastrointestinal syndromes)

4.5.6. ORGAN OF VISION

Two types of eye damage are known: inflammatory processes in the conjunctiva and sclera in doses close to causing skin damage, and cataract with radiation doses of 3–10 Gy. Neutrons, efficiency of which is 3–9 times higher than gamma rays, are especially dangerous in this respect. The reasons for the cataract formation are not found out completely. The point of view about the leading role of primary damage of the lens growth zone cells and concerning the less value of its malnutrition is most convincing.

It became known in 1948 that four experts in physics, about 31 years old, fell ill with cataracts. It was established that the physics were under the action of neutrons. When investigated, 11 more people, working on the cyclotron, 10 of which had cataracts, and 3 of which found visible turbidity in the back part of the lens, their sight worsened, 4 turbidities were insignificant in the back part of the lens, with minimal decrease in sight, and only fine defects were found in 3 men. Investigation within 1–3 years, on the average, underwent the action of 50 n, and their blood picture did not changed.

It was established, that the survivors after the explosion of nuclear bombs in Nagasaki and Hiroshima 8–10 times more often got cataracts than those who were not exposed to irradiation. Defects of the lens were observed mainly in those who were at a distance of up to 1 km from the hypocenter during the explosion.

There are no blood vessels in the lens, and it therefore is very poorly supplied with oxygen. But the action of neutrons does not depend on the contents of oxygen, which explains their especially harmful influence on the lens, whereas X-ray and gamma-rays do not show all their action in the lens medium poor with oxygen. The radiation injury of the eye has cumulative character — fractionated doses influence similar to a full dose in a single application.

By way of illustration, the following observations characteristic for the dynamics of clinical displays in the eye structures are presented.

A patient P., 24 years old, carried out checks on the technical conditions of X-ray equipment in cabinets of medical institutions, and conducted dosimetric control of workplaces and adjacent rooms protection for 8 months. At the day of the incident he was carrying out dosimetry in the local hospital and eliminated the defects of a diaphragm on the R2-440 device at a pressure of 87 kV, current force of 5 mA within 15–20 min. During the work, the safety precautions were roughly broken, adjusting a diaphragm under a continuous irradiation on a close distance from the anticathode. He used only a lead apron as the protective mean. Rough calculations of geometry and conditions of irradiation allow us to assume that the exposition dose on the face surface was about 2.57 Kl/kg.

30 min after terminating the work, the sensation of burning in the right eye and small hyperemia of the skin around the eye appeared. In 27–30 h, strong headache, pain in the right eyeball, dizziness appeared. Hyperemia of the integuments and mucous of the eye increased in intensity and prevalence, vomiting appeared continuing about 5 h. Within the second day, the headache and vomiting continued. The victim stayed away from surrounding events and renewed work outside of direct contact with radiation, although during the next 2 weeks hyperemia of the face, injection of the sclera and a blunt headache continued. On the 15th day, hypostasis of the facial skin and eyelid appeared again, hyperemia of the face and conjunctiva amplified, gripping eye pain with abundant mucopurulent discharge and a rash on the mucous membrane of the mouth occurred. On the 16th day, a loss of hair in the frontal parts of the head was noted. On the 17-18th days, the general condition (weakness, sweating, strong headache) worsened. On the 20th day, superficial bubbles with a size of 2x1 cm appeared on the forehead, more to the right, the puffiness of the eyelid increased. The victim sought medical aid and was immediately hospitalized. During examination on the 20th day — acute hyperemia of the mucous membrane of the eyelid and eyeball, more on the right side. Mucopurulent discharge — moderate amount. Cornea is transparent. Its sensitivity is lowered, more in the right eye. The anterior chamber is of average depth, the liquid is transparent. The color and figure of the iris are not changed. Pupils are of spherical form, even, with reaction to light and convergence. The refracting environments during research with electroophthalmograph and a slot-hole lamp are without pathological changes. Small hyperemia of the optic nerve disk, moderate expansion of the vessels and hypostasis of the retina through the vascular bunch are on the bottom of the eye. Visual acuity on each eye is 1.0.

On the 40th day the signs of cataract occurred: oedema of the cornea, multiple erosion, lacrimation, and photophobia. Changes in the cornea were visible in the beginning only with the slot-hole lamp. Keratitis had a remittance course. Cornea ulcer was diagnosed on the 5th month of the disease. On the left eye nictitating spasm, lacrimation, light hyperemia of the mucous of the eyelid and eyeball were periodically observed. The cornea was transparent and shiny all the time, but its sensitivity harshly went down. Changes were not observed at the bottom of the eye. Visual acuity fluctuated between 0.7–1.0.

6 months after irradiation, the victim had strong pains, and changes in the right eyeball began to increase: cornea ulcer, iridocyclitis and, apparently, obliteration of the vessels resulted in the development of glaucoma. In connection with this at the 7th month after irradiation, an operation for the removal of the right eye was done. After the operation, the

stump within a month did not heal; growth of the eyelashes and eyebrows on the right eye and in the medial side of the left eye are not renewed. The external part of the left eye was not changed. Visual acuity is 1.0. Haemorrhages and some exudative foci with languid clinical course appeared periodically on the fundus of the eye.

During the second year of observation, pains in the saved eyeball Appeared, eye sight weakening, a periodic increase in the intraocular pressure up to 28–31 mm Hg were revealed. During an examination, the eye is easily irritated; a light photophobia and lacrimation are observed. Vessels of the eye conjunctiva are dilatated. The cornea is transparent, shiny. Its sensitivity from the nasal side is lowered. The anterior chamber is of average depth. The pupil is slightly extended in the vertical direction. Only the external part extends with drops of 3 % ephedrine solution. Reaction to light and convergence is absent. The iris figure is atrophic. While examining with an electroophthalmoscope and a slot-hole lamp, new growth vessels and atrophy of the pigmentary layer, giving the iris from the nasal side a sieve look, are visible.

A radiation cataract of the IV stage was generated in the lens. Fogging is located under the anterior and posterior capsules in the decomposition zone as a thin layer, consisting of points and vacuoles. It occupies 2/3 of the surface, leaving free only a small part of the lens from the lateral side. Changes under the anterior capsule are gentler; under the posterior — rough, fibrous, strong reflective. In the rest of the zone the lens is precise, optical condensation moderate, the color of the tissue is darkish. In mature nucleus individual points, under the posterior capsule through the fogginess the site of granularity and color is iridescent. The veins are dilated on the bottom of the eye, individual small haemorrhages and centers of exudation are marked.

4.5.7. DIGESTIVE APPARATUS

The most radiation-damaged cells are in the crypts of the germinative layer of the small intestine. By the size of threshold dose (1–2 Gy) and dose, causing serious damage of the cells of the crypts (8 Gy), the small intestine should be related to highly radioactive structures. Damage of the small intestines causes an intestinal syndrome. Further, according to the degree of the decrease in radiosensitivity there follow: the oral cavity, the tongue, the salivary glands, the esophagus, the stomach, the rectum and the colon, the pancreas and the liver.

The gastrointestinal syndrome is characterized by a complex of violations, determining the destruction of irradiated organism — this is damage of the epithelium of the gastrointestinal tract, destruction of the crypts and fibers and their devastation, basically, due to interphasial destructions of cells; infectious processes due to intestinal flora; blockage and damage to blood vessels; violation in the balance of liquids and electrolytes; change in active transport; increase in activity of autolysis enzymes, change in others enzyme processes; decrease in the permeability of intestines for nutrients.

If the irradiation occurs in lower doses, i.e. in the doses causing the marrowy syndrome, it is possible to observe cellular epithelium restoration on the fifth day after radiation, and by the end of the first week — other morphological, biochemical and physiological violations. At the same time radiation violation of the gastrointestinal tract occurs, characteristic for the period of the expressed symptomatology of the marrowy syndrome: all sorts of haemorrhages develop, sometimes as separate haemorrhagias, but more often as big foci spreading through out the intestines. Ulceration and necrobiosis of epithelial integument, increase in autolytic processes are observed in the late stages of damage. In the intestines, rather frequently, in the necrosis zones, there is a congestion of a huge amount of intestinal flora, spreading with the lymph and blood flow and causing infectious complications in the irradiated organism. Violations in the gastrointestinal tract develop according to the seriousness of the radiation injury, being in some cases the reason of destruction of an organism with the marrowy syndrome. Some remote adverse consequences of damage of the mucous membranes of the gastrointestinal tract are revealed during external irradiation like vesicovaginal, rectovaginal fistulas, cicatrical deformations of the esophagus and throat entrance.

4.5.8. LIVER

The liver possesses high radioresistency, connected with a big regenerative activity of this organ. Morphological changes in the liver are mostly expressed during late stages of acute radiation affection and manifest themselves as violation of blood and lymph circulation, degenerative-necrobiotic changes of the parenchyma and stroma of the organism, hypostasis and anemia. Functional violations of the liver occur with non-lethal doses of radiation. Thus, oppression of biliation and motor function of the non-hepatic bilious tracts with subsequent deterioration of decomposition and adsorption of lipids in the small intestine is observed.

Depending on the radiation dose and time after irradiation, it is possible to observe any change in the biochemical process of the liver; the majority of biochemical violations, as a rule, have phase shifts, corresponding to the phases of acute radiation sickness. In the initial phase and at the height of radiation sickness there is a dissociation of oxidizing phosphorylation processes and respiration in the mitochondrion of the hepatic cells, phosphorylation processes are suppressed, levels of inorganic and stable phosphorus are reduced, and the consumption of oxygen grows. Violation of the protein metabolism in the liver, in general, reflects the developing picture of radiation affection. In particular, it is visible by the change of autolysis enzymes activity; enzyme activation in the primary reaction phases and expressed clinical changes, decrease in activity, and temporary normalization in the latent phase.

Denaturation and disintegration of nucleoproteins, as well as the more radioresistant monoproteins, glycoprotein, chromoprotein and the simple protein molecules occur under the influence of both indirect and direct action of radiation.

An increased allocation of metabolism products of nucleinic acids (deoxycytidine, pseudouredine, purine (uric acid and xanthine), beta-aminoisobutyric acids, desoxyuredine and thymidine) is observed in the initial stage of radiation sickness. This manifestation is a result of the changes in metabolism of nucleinic acids in the liver. One of early signs of violation of pigmentary metabolism in the liver is an increased content of urobilin in the urine of irradiated animals. Significant changes occur also in the contents of vitamins, hormones, and some trace elements of the liver. Biochemical researches of the lipid and carbohydrate metabolism confirm and supplement the data on morphological violations of the liver during acute radiation sickness (for example, one of the attributes of radiation pathology — fatty regeneration of the liver). The accumulation of neutral fat is found in cells of the liver soon after irradiation. Simultaneously cholesterol, phospholipids, fatty acids and products of their oxidation, as well as lipoproteins and products of their disintegration enter the blood circulation. A decrease in antioxidizing activity of lipids occurs in the liver, after the first minutes of irradiation. Along with fatty regeneration, the glycogen-production function of the liver is broken: a long period of progressing glycogen loss by the hepatic cells ends frequently with the full disappearance of glycogen in the liver; hyperglycemia is also observed.

4.5.9. ENDOCRINE GLANDS

Endocrine glands belong to the radioresistant group, though the endocrine system reactions to general irradiation are well-known.

In acute radiation sickness an increase in the activity of the endocrine glands is observed at the initial stage, especially adrenal glands, anterior lobe of the hypophysis and to a lesser degree the thyroid gland; there is a swelling of the secretion elements, change in the cellular structure and contents of the secreted hormones. The development of radiation sickness is characterized by an increase in dystrophic changes in the endocrine organs, and some of them (anterior lobe of the hypophysis, adrenal glands, thyroid gland) have the phenomena of hypertrophy and hyperplasia of the secreted elements. Attributes of suppression and discoordinational functions of the endocrine system as well as distorted reactions of the organs on the action of hormones in an irradiated organism are shown. Radical changes in the activity of the organs of internal secretion is usually observed during the period of expressed clinical changes, degenerative-necrobiotic and atrophic processes develop.

The most radiosensitive organs of the endocrine system are the sex glands. Other endocrine glands are less sensitive to the action of ionizing radiation, arranged in the process of increasing radioresistency (by morphological features) in the following sequence: the adrenal glands, the hypophysis, the thyroid gland, the islets of the pancreas, and the most resistant one — parathyroid gland. Radioresistency of these glands is connected with the fact that their tissue consists of highly differentiated functional cells, practically not capable of physiological regeneration.

The reactions of the Hypophysial-Adrenal System

Ionizing radiation, as well as the usual stress factor, is capable of exciting the anterior lobe of the hypophysis, which results in sharp increase in the ACTH synthesis with a decrease in the contents of cholesterol and ascorbic acid in the cortex of the adrenal glands; activization of the secretory functions of the cortex of the adrenal glands; occurrence in the blood of unusually high amounts of steroid hormones influencing the whole organism.

Thus, serious violations in the functional activity of the hypophysis, resulting in abnormal regulation of biochemical and physiological processes, loss of the ability to constantly support homeostasis occur in an irradiated organism.

Thyroid Gland

A human's thyroid gland is irradiated under various conditions (therapeutic and diagnostic purposes, professional conditions, extreme situations in time of peace and war). Various age contingents are exposed to radiation under different conditions of external, general and local irradiation as well as internal irradiation from incorporation of radionuclides of various types of distribution.

Due to rather low activity of cell division in the thyroid gland interphase destruction of cells is found within the second week after irradiation of doses 50–100 Gy, created in the thyroid gland by iodine-131.

There is a probability of thyroiditis development, hypothyroidism, benign and malignant tumors, parathyrocrin syndrome and other violations during the influence of ionizing radiations on the thyroid gland.

The threshold dose of radiation thyroiditis is a dose equal to approximately 200 Gy. Each increase in the dose by 100 Gy above 200 Gy will cause thyroiditis in additional 5% of the irradiated.

The changes of the thyroid gland connected with hypothyroidism, are caused, mainly, by the development of degeneration and fibrosis of thin vessels both of the interfollicular stroma and secondary degeneration of the follicular epithelium. Hyperplastic reactions can be seen in less irradiated places; nodular structures with a small content of colloid appear as a result.

25–30 Gy with fractionated irradiation within 30 days is the threshold for the occurrence of heavy functional damage to the thyroid gland in adults with its total irradiation. There is a probability of the occurrence of subclinical damage in lower doses.

A feature of the thyroid parenchyma reaction at the influence of low dose radiation is the regrouping of secretory elements by means of wedging-in and forming new follicles. But high-grade restoration of the thyroid cells does not occur.

The reaction in children is more expressed than in adults, and children hypothyroidism can occur in single remote gamma irradiation in combination with the introduction of ^{131}I up to the general absorbed dose 4–12 Gy, and in adults the distant irradiation of tumors on the neck result in hypothyroidism with a total dose in the thyroid gland of 26–48 Gy.

Inefficient dose for the thyroid gland of a child is less than 1 Gy.

Pancreas

The pancreas in irradiated animals is less sensitive to irradiation, than the thyroid, and its changes also are insignificant. The contents of insulin in the blood undergo phase changes during acute radiation sickness. Free and general insulin can grow 1.5–2 times as much within the first week after irradiation. Hypoinsulinism is sometimes observed during the terminal period.

Testicles

Azoospermism and complete impotence within one year was observed in the people who suffered from a severe form of acute radiation sickness as a result of the bombardment of Hiroshima and Nagasaki. Histological researches of the testicles according to autopsy data revealed hyalinization of the vessels and sclerosis of the spermatic canal in men who were at a distance of 1,400 m from the epicenter at the moment of the explosion.

Similar changes were marked in patients who had acute radiation sickness due to failures in the Los Alamos research laboratory as well as in the Aragon national laboratory.

Severe damages (destruction of the most part of cells of spermatogenetic epithelium with the subsequent aspermia and sterility) were observed in doses of general irradiation of 3–4 Gy, and first signs of this damage (destruction of separate cells) are revealed after the influence of 0.5 Gy of general irradiation.

It is established, that the man's sex cells have different radiosensitivity. Spermatogone type B are the most radiosensitive. A part of spermatogone type A survives under irradiation in doses up to 258 mKu/kg. The radiostability of sex cells grows in the process of their maturing. So, spermatocytes are more radiostable than spermatogone. Spermatids and spermatozoons finish the development and do not lose the ability of fertilization even after irradiation with high doses of gamma-radiation. Obviously, the specified features in the radiosensitivity of various types of cells of spermatogenetic epithelium are explained by the various speeds of their disappearance after acute gamma irradiation. Spermatogone disappear first, then spermatocytes and spermatids, and at last — spermatozoons.

Massive cellular devastation of the testicles occurs at doses 0.5–1 Gy, and doses higher than 2–4 Gy cause sterility in a person because of the high radiosensitivity of sex cells in the early stages of development. Mature cells (spermatozoa), on the contrary, are extremely radioresistant. The number of spermatozoa, their morphology, mobility and ability for fertilization do not change after irradiation at doses up to 1 kGy. Fertility in irradiated mammals is kept while there is a reserve of viable mature sex cells. But still afterwards sterility has a temporary character, because there is a gradual restoration of spermatogenesis from the saved viable spermatogone type A.

A similar ratio of radiosensitivity of various types of cells of spermatogenetic epithelium is revealed in conditions of chronic irradiation as well.

There are essential changes in the metabolism and chemical compound of the testicles in atrophy of the testicles caused by X-rays: reduction in the content of residual nitrogen by 40%, 3-fold reduction of kreatin, protein phosphorus — by 45%, decrease in the amount of ATP — by 28%. Decrease in the general contents of ascorbic acid and cholesterol is observed during 60 days after the influence of ionizing radiation.

The degree of restoration of spermatogenesis depends on the degree of acute radiation sickness which the patient had in the past. A full devastation of the seminal tubuls when only the Sertoli cells preserve was observed after a severe form of radiation sickness. Restoration of spermatogenesis (cells of the epithelium in all stages of development — from spermatogone to spermatozoa — were found in the majority of tubuls) is observed after a less serious form of acute radiation sickness.

One of the important consequences of the action of ionizing radiation on the testicles is the occurrence of dominant lethals in sex cells. So, the probability of the occurrence of dominant lethal in the sex cells by a unit of a dose (mutational rate) made up $(5.8 \pm 0.2) \cdot 10^{-3}$ irradiating spermatozoa affecting by fast neutrons; $(0.7 \pm 0.04) \cdot 10^{-3}$ — by protons and $(1.1 \pm 0.13) \cdot 10^{-3}$ — by gamma rays. The mutational rate for X-rays was $(1.6 \pm 0.12) \cdot 10^{-3}$. Spermatids appeared to be genetically more radiosensitive than spermatozoa in all types of irradiations.

Reflex mechanisms of the sexual act in men developed before the beginning of irradiation do not suffer essentially even with the occurrence of irradiation sterility. The occurrence of impotence is more natural with the absence of a fixed reflex connection of the sexual act. If after the sterile period a period of fecundity occurs, it is characterized by a population which has cells with violations of chromosomes that can cause destruction of the zygote or death of an embryo, i.e. nuclear violations, which arise in spermatogone at the moment of irradiation, are shown some time (about several years).

The specificity of sex cells reaction at low radiation doses chronic action is established. It appeared that in low radiation doses the division of spermatogone type A is stimulated, but the process of their differentiation is broken. Violation in the processes of division and differentiation of spermatogenic cells results in the change in the frequency of occurrence of various stages of spermatogenesis, which is characteristic for chronic action of low dose radiation.

30.3% of the men taking part in the liquidation of consequences of the accident at the Chernobyl NPP, complained of importance of a various degree of severity. And an impairment of adequate erection was the leading sexological complaint of patients.

A more expressed impairment of spermatogenesis is observed in patients who had acute radiation sickness in comparison with the patients with vegetative dystonia. A decrease in the concentration of spermine and an increase in the contents of their pathological forms testify to impairment of spermatogenic epithelium at early stages of spermatozoa maturing.

It is revealed, that one of the essential pathogenetic mechanisms of the decrease in sexual functions after radiating influence is the impairment of the subthalamic-pituitary link function.

An increase of the follicle-stimulating and luteinizing functions of the adenohypophysis and a decrease in the androgenic functions of the testicles is revealed in men who took part in the elimination of the consequences of the failure at the Chernobyl NPP and underwent ionizing radiation influence on the whole body in a range of doses up to 1 Gy.

The changes in the system hypophysis — gonads in the men who were taking part in elimination of consequences of the Chernobyl NPP accident, was characteristic for testicular forms of the sex glands hyperfunction.

Ovaries

According to degree of radiosensitivity the structures of the ovaries are in the following descending order: nucleus and protoplasm of the ovule of the most mature follicles, internal layer of the granuloma of the mature follicles, ovules of the young follicles, external layer of cells of the granuloma of the mature follicles, primary follicles, vascular *(theca interna)* and fibrous *(theca externa)* capsule of the follicles, corpus luteum, the endothelium of the vessels, the rest stroma and at last, germinal epithelium of the ovaries. Radiosensitivity of cells of the follicular epithelium and ovules is in direct dependence upon their functional activity. As follicular epithelium is functionally the most active part of the ovary tissue, it is impaired by irradiation first. Damage of the follicular epithelium results in the impairment or the full termination of trophic processes in the follicle, which ends in the death of the latter.

First signs of damage to the follicles occurs in a dose of 50 sGy, temporary sterility for 1–3 years occurs with an irradiation of the ovaries in a dose of 250–350 sGy. The dose, providing full castration is 500–600 sGy in every woman's ovary under the condition of irradiation from two anterior-posterior fields. Suppression of the hormonal function of the ovaries occurs in much smaller doses. Changes of excretion of sexual hormones without any clinical displays of violation of menstrual functions are revealed in general irradiation in a total dose of 0.3–0.6 Gy. Thus, it is observed a lability in the excretion of estrogens with a tendency to decrease at certain days of the cycle and reaching the lowest point of the norm.

An increase in the number of disordered menstrual function was not observed in women professional total irradiation during all the working years in doses of about 0.7 Gy. The disordered menstrual cycle was observed more often than in the control in total doses of 1.5–2 Gy. These disorders can be shown either as changes in the menstruation course within the limits of physiological norm (duration from 2–7 days, blood loss of 50–150 ml, duration of the cycle 21–35 days), or as dysfunctional uterine bleedings or the hypomenstrual syndrome.

Quite often changes of the menstrual cycle precede the steady disorders or periods of menstrual function disorders alternate with changes in the menstruation course. Uterine bleedings are more naturally observed in irradiation of doses close to 2.5–4 Gy. With an increase in the total doses, impairments get a more stable and distinct character: hypomenstrual syndrome (frequently hypo-, opso- and oligomenorrhea, amenorrhea) is observed more often.

Cytological examination of vaginal smears is indicative of a slower and insufficient, in comparison with the control, increase in the number of keratosic cells in the first half of the cycle in the ovulation phase. The parameters of the karyopyknotic index are lower, than in the adequate control.

The excretion of estrogen with urine is reduced. Simultaneously with hypoestrogenia, impairments of the ratio of separate fractions of estrogens, more often as an increase in the relative amount of estriol, are found. Changes in excretion of estrogen by fractions correlate with a form of menstruation disorders. The excretion of pregnandiol in the luteinizing phase tends to decrease. Symptoms of "pupil" and "fern" are expressed insufficiently.

After the cessation of work with sources of ionizing radiation in chronic irradiation in a total dose of up to 1.5 Gy, the menstruation function, as a result of correlated therapies, and frequently without treatment, is restored.

The climacteric period for those who work with sources of ionizing radiations, as a rule, comes earlier. Climacteric bleedings are observed seldom due to previous hypofunction of the ovaries. Vegeto-vascular display characteristic for climacteric syndrome are rare too. Menopause in women with large total absorbed doses comes at an earlier age (2–4 years earlier).

Radiating damage, even of a large amount of normal ovule, does not influence the ability of reproduction, because it is compensated by a simple decrease in the cases of physiological regeneration. It is possible, that the genital period can come to an end a little bit earlier, but it will not affect the birth rate in those societies where the birth of children is the function of young woman and is usually avoided at the age more than 30 years.

The basic clinical forms of the revealed impairments in menstruation functions during chronic professional X-ray and gamma irradiation are:

a) pre-clinical changes of physiological character;

b) impairments like dysfunctional types of uterine bleedings or hypomenstrual symptoms.

Special gynecologic tests of functional diagnosis have confirmed the presence of changes and impairments of menstrual functions, characteristic for a decrease in hormonal activity of the sex glands and violation of the metabolism of sex hormones.

4.5.10. ORGANS OF EXCRETION

The kidneys are sufficiently resistant to the action of radiation. During local and general irradiation, morphological and functional changes are observed only in doses of tens of Gy. Irradiation of both kidneys in a dose more than 30 Gy for five weeks can cause irreversible chronic nephritis, capable of leading to a fatal outcome.

Post-irradiation changes of the ureter, bladder and urethra rather frequently complicate radiationtherapy.

4.5.11. MUSCLES, BONES AND TENDONS

The muscles are highly radioresistant tissues of an organism. Weak muscular atrophy is observed only in doses of 60 Gy, and microscopic and histologic changes arise after 500–1000 Gy (in 24 h — haemorrhagia, in 72 h — necrosis). The opportunity of isolated radiating damage of muscles is unlikely, because cellular restoration is practically absent in muscles.

Bones and cartilages are rather radiosensitive during the growth period, and in adults they are significantly more resistant.

Osteonecrosis formation as well as the occurrence of spontaneous fractures in the irradiation zone may be an example of radiation sickness of the bones. Radiation damages of the bone clearly revealed by the delay of the healing of fractures, down to the formation of false joints.

4.6. BASIC LAWS OF THE IONIZING RADIATION INFLUENCE ON THE ORGANISM

It is necessary to consider that during the transition from an ionized cell to tissue, organ and organism all phenomena become complicated. It occurs because not all cells are damaged equally, and the tissue effect is not equal to the sum of the cellular effects, or the tissue and furthermore the organs and systems cannot be examined like a simple set of cells. Being in structure of tissue, cells are substantially dependent upon each other and the environment. Mitotic activity, degree of differentiation, level and features of metabolism as well as other physiological parameters of separate cells are not indifferent for their direct “neighbours”, and consequently for the population as a whole.

A big influence on tissue radiosensitivity is provided by other factors: degree of blood supply, size of irradiated volume, general condition of an organism, etc.

Any increase in the function of tissue or organ results in an increase in radiosensitivity. As an example, the large sensitivity of the mammary gland during lactation, rather than in usual conditions, or the tissue of the thyroid gland during hyperthyroidism in comparison with its tissue under usual conditions. Radiosensitivity of various biological objects alters within a very big range.

Each biological type has a peculiar sensitivity to the action of ionizing radiation, which characterizes its radiosensitivity.

The bacteria, which were found in the channel of the American nuclear reactor, where the power of a dose was about 12 Gy/sec, and the absorbed dose for a day was about 106 Gy serves as an evidence of the lowest radiosensitivity. Bacteria not only unperish, but multiple in these conditions, and consequently, “felt” perfectly, that is why they were named *Micrococcus radiodurus* — radioresistant micrococcus.

The degree of radiosensitivity strongly varies within the limits of one kind (individual radiosensitivity), and for certain individuals it depends also on age and sex. Besides, even in one and the same organism has various cells and tissues which differ in radiosensitivity very much and alongside with sensitive ones (haemopoietic system, epithelium of the mucous membrane of the small intestines) there are resistant tissues (muscular, nervous, bone), which are named radioresistant.

The knowledge of natural radiosensitivity and mechanisms of its regulation promise the most important practical results, focusing on an opportunity of artificial management of tissues radiation reactions: their weakening, the protection of an organism is meant, or active increase — in irradiation of malignant tumors.

The damaging effect of radiation can be strengthened by an increase of intensity of metabolic processes in an organism. On the contrary, radioresistency increases in a weakened metabolism. Traumas, various diseases, physical loads and other strong extreme stimuli, as a rule, affect negatively the clinical course and outcome of radiation damage as well.

Hence, the sensitivity of a person’s organism to irradiation is not constant and invariable: it can change under certain conditions one way or the other.

The most radiosensitive process in an organism is transinduction of DNA. Deoxyribonucleic acid of a germinal cell contains apparently, the basic information necessary for the given kind of the working of all phases of its development in its structure. However, the delivery of this information from DNA through the system of information RNA — ribosome — protein synthesis — enzymes undergo a number of critical periods. During these periods DNA changes its volume and quality of information produced, which promotes the developing organism (this or that tissue, or organ) to enter the following phase of development. These changes of information production have been conditionally named transinduction of DNA. Hormones (of the polypeptide, glucopolypeptide nature) play a leading part in the change of phases of development and, hence, in transinduction of DNA.

The biological efficiency during external influence of radiation is in a certain dependence upon the dose and its capacity, frequency rate (divisibility) of irradiation, the kind of ionizing radiations, etc. The lighter the particles and more their energy the more their penetrating ability. Beta-particles that poorly penetrate through the skin, and alpha-particles absorbed by the epidermis cause damages limited by the place of their application, whereas the stream of gamma-quantum, protons and electrons penetrate through all thickness of a person's body. The higher ionization the more biological efficiency.

The final radiobiological effect depends on the amount of energy absorbed by tissues: the more the absorbed dose, the sooner the damaging effect. In irradiation in doses higher than 50–100 Gy (life expectancy about 2 days), the leader in pathogenesis of damage is direct action on the central nervous system. In doses of 10–50 Gy (life expectancy about 7 days), the damage to the gastrointestinal tract (GIT) prevails in the clinic of the disease and mechanism of death development. Radiation sickness, which major importance in pathogenesis is impairment of the haemopoietic organs, haemorrhagic and infectious complications (Table 7), develops in lower doses (1–10 Gy).

On autopsy of animals that died during general X-ray irradiation with a dose of 150 Gy and higher, congestive huperemia of the internal organs, inconstant large haemorrhages, swelling of the small intestines, are observed.

One can see on histologic preparations impairments of blood circulation in the internal organs, expressed by hyperemia and haemorrhages, redistribution of leukocytes in the blood with their accumulation in some organs. Changes in the cells of organs of haemopoiesis can occur within a short period of irradiation affection: pyknosis of the nucleus of megacaryocyte of the bone marrow, pyknosis

Table 7. **Life expectancy of people in irradiation by fatal and superfatal doses**

Irradiation dose, Gy	Life expectancy	The leading system (organ) in the pathogenesis of damage
150 and higher	Death under irradiation or some hours later	CNS
50–100	About 2 days	CNS
10–50	About 7 days	GIT
1–10	Typical acute radiation sickness. Fatal outcomes are possible depending upon the irradiation dose and efficiency of treatment	Haemopoietic system

and fragmentation of the nucleus of cells of myeloid tissue in the bone marrow and in the red pulp of the spleen, pyknosis and fragmentation of lymphocytes in the spleen and lymph nodes.

The mechanism of such damage can be connected with the fact of structural mass damage of macromolecules. Sometimes radiation syndrome caused by irradiation in such high doses of ionizing radiation is called "molecular death".

Irradiation in doses exceeding 100 Gy brings to the death of mammals, occurring in the first days or even hours with the appearance of the central nervous system damage, therefore the described radiation syndrome is called cerebral. The cerebral syndrome proceeds in the following order: atactic phase, lethargic phase, convulsive phase, death in several hours after irradiation with expressed spasms. The basic reason for radiation damage with this type of death is acute suppression of nervous cells viability, which reaction to irradiation essentially differs from the reaction of bone marrow and intestines by the absence of cellular losses.

The average life expectancy of mammals in the interval of doses from 10 to 100 Gy practically does not depend on the size of the absorbed dose and averages 3.5 days. The effect of independence of the average life expectancy on the size of the dose of irradiation has got the name "3.5-day effect", or "Raevsky effect", and the occurring radiation syndrome — "gastrointestinal". The lethal outcome of the gastrointestinal syndrome is connected with the damage of the mucous of the intestines and the stomach, high sensitivity to ionizing radiation of the fast-dividing epithelial cells, and stripped villi.

The typical form of acute radiation sickness is presented as a disease with an expressed clinical syndrome, developing in doses of general irradiation from 1 to 10 Gy.

The clinical picture of irradiation damage depends upon the uniformity (or non-uniformity) of distributions of a dose in the volume of a body.

The following kinds of non-uniform irradiation are distinguished:

1. Non-uniform irradiation on the vertical axis of a body:

— with maximum irradiation of the head;
— with maximum irradiation of the thorax;
— with maximum irradiation of the stomach;
— with maximum irradiation of the lower part of the body.

2. Non-uniform irradiation on the horizontal axis of the body:

— with maximum irradiation of the anterior surface of the body;
— with maximum irradiation of the posterior surface of the body;
— with maximum irradiation of the lateral surface of the body.

3. Non-uniform local irradiation.

Non-uniform irradiation is less effective, than uniform, and the clinical picture of damage depends upon the critical system, exposed to irradiation.

Depending upon the duration of the influence, short-term (more than $3 \cdot 10^{-4}$ Gy/sec) and prolonged (less than $3 \cdot 10^{-4}$ Gy/sec) and fractional (irradiation at different or identical intervals of time) are distinguished.

Reduction of capacity of the irradiation dose and an increase in the interval of time results in a reduction of damaging action of ionizing radiation because of reparation processes.

4.7. REGENERATIVE PROCESSES DURING RADIATING DAMAGE

A decrease in the biological efficiency during extended and fractionated irradiation testifies that the organism possesses an ability to restore the basic parts of damaged tissue. The general theory of damages and restoration was offered by Blair. On the basis of numerous researches the conclusion was made that pure damage (without restoration) considerably decreases with an increase of time during which the organism is exposing to irradiation.

The speed of regenerative processes is not always constant in an organism after irradiation. It is most expressed in the dose range, causing mild radiation damage. The speed of post-irradiation restoration is slowed towards both sides from this dose level.

It is caused by the fact that during low dose irradiation the amount of changes occurring in an organism decrease, being the incentive reason of development of regenerative processes. In higher doses, biological mechanisms providing post-irradiation restoration are destroyed. Besides, the speed of regenerative processes depends upon the capacity of a dose (irradiation intensity).

Blair estimated the size of the irreversible part of radiation damage to be 1.5–8%, and Davidson (1960) considered it to be 10% as an average size from 5 to 15%. According to I. G. Akoev (1970), the relative size of the irreversible part of radiation damage is 10–15%. The indicated sizes are characteristic for a single irradiation.

The distinction in the effect under unequal duration conditions of radiation influence is the influence of the factor of time. According to the Raevsky's definition, the factor of time is characterized by the ratio of doses of extended or fractional irradiation to the dose of a single short-term influence, which causes identical biological effect.

$$\text{Irradiation time factor} = \frac{\text{Extended or fractional dose of irradiation}}{\text{Dose of a single short-term irradiation, necessary for producing an identical effect}}$$

If in identical biological effect an extended or fractionally given and a single short-term doses will be identical, i.e. their ratio will equal 1.0, the factor of time is insignificant in these conditions.

If the dose in extended or fractional irradiation is less than the dose of short-term influence, the ratio will be less than 1.0, and it means, that the extended or fractional irradiation aggravates the damaging action of radiation.

If the dose of extended or fractional irradiation is more than a short-term influence in identical biological effect, the ratio will be more than 1.0, and, hence, the prolong irradiation will have a milder damaging effect in comparison with a short-term.

The factor of time is taken into account by irradiation therapeutists, who aims at a rational choice of dose and time ratios during the treatment of malignant tumors.

Chapter 5
RADIATION SICKNESS

5.1. ACUTE RADIATION SICKNESS

Acute radiation sickness is a nosological form, which develops in external gamma and gamma-neutron irradiation in a dose which exceeds 1 Gy, taken in one stage or during a short time interval (from 3 up to 10 days), as well as in radionuclides penetrating inside, which form an adequate absorbed dose. The intestinal-brain form of acute radiation sickness and with primary defeat of the haemopoietic system has the greatest clinical importance.

Depending upon the size of the absorbed doses acute radiation sickness is divided into 4 phases. Acute radiation sickness is characterized by strict periodicity of the clinical course. 4 periods of disease are allocated:

1. The period of primary reaction.
2. The latent period.
3. The period of the height of the sickness.
4. The period of recovery.

Primary reaction of an organism arises rather quickly (first minutes, hours) and is shown in all cases of irradiation in doses exceeding 2 Gy (Tables 8, 9).

The beginning, the end and frequency of occurrence of primary reaction in a person has a certain dose dependence. There are nausea, vomiting, amplifying after receiving liquids, and appetite disappears. Dryness and bitterness are sometimes felt in the mouth. Victims feel heaviness in the head, headache, general weakness, drowsiness. The phase lasts for 1–3 days.

The time of the occurrence of nausea and vomiting, as well as the duration dyspeptic syndrome has the greatest diagnostic, and in some cases prognostic, value. The most damaged victims during the explosion of the nuclear bomb had the primary reaction arose in 0.5–3 h which proceeded for several (3–4) days.

Shock-like conditions with decreasing arterial pressure, short-term loss of consciousness, subfebrile temperature, diarrhea are prognostically unfavorable signs, which predetermine a very severe desease course (and, hence, are evidence of the total dose of irradiation 10 Gy).

Transient sunburn-like hyperemia occurs on parts of the skin, which underwent irradiation in doses of 6–10 Gy.

Neutrophilic leukocytosis with a shift to the left as well as absolute and relative lymphopenia are observed in the peripheral blood on the first day after irradiation.

It is possible to find more or less clear changes most visible on 2nd–3rd day in the bone marrow of a person during a usual hematological analysis of punctuate. They are reduction in the general number of myelocariocytes, decrease in the mitotic index and a disappearance of young forms of cells.

As for biochemical changes of the blood and urine it is possible to note that the level of sugar and bilirubin increase in the blood and the contents of chlorides decrease in doses of 3–4 Gy as well as aminoaciduria occurs (it is probable, due to the increased disintegration of protein in collapsing cells).

Clinical displays of the first phase of acute radiation sickness are the result of not only direct damage of radiosensitive systems (lymphopenia, delay of cellular division, reduction of the number or disappearance of young forms of haemopoietic cells, and aminoaciduriais is possible), which precisely testifies to the transient but obviously early violations of nervous-regulatory and humoral mutual relations (dyspeptic, vascular disorder, dizziness, etc.).

Table 8. **The beginning, end and frequency of the occurrence of primary reaction in people depending upon the dose of irradiation**

Dose, Gy	Beginning of reaction, h	End of reaction, h	Frequency of the occurrence of symptoms of the primary reaction, %
1	3–4	10–11	1–5
1.5	2–3	14–16	30–60
2	1–2	20	75–80
3 and more	1–2	23	100

Table 9. **Diagnosis of the degree of severity of acute radiation sickness during the primary reaction**

Parameter	Degree of severity of radiation sickness			
	I	II	III	IV
Dose, Gy (±30%)	1–2	2–4	4–6	6
Vomiting (beginning and intensity)	In 2 h and more; single	In 1–2 h; repeated repeated	In 30–60 min; multiple	In 5–20 min; unrestrained
Diarrhea	Absent as a rule	Absent as a rule	Absent as a rule	May be
Headache and the condition of consciousness	Short-term headache, consciousness clear	Headache, consciousness clear	Headache, consciousness clear	Strong headache, consciousness can be confused
Body temperature	Normal	Subfebrile	Subfebrile	38–39 °C
Condition of the skin and visible mucous membranes	Normal	Weak transient hyperemia	Moderate transient hyperemia	Expressed hyperemia
Duration of primary reaction	Absent or some hours	Up to 1 day	Up to 2 days	More than 2–3 days
Motor activity	Normal	Natural changes are not present		Adynamia

The symptoms of primary reaction disappear and the state of health of the patients improves or even normalizes in 2–4 days. The desease enters the latent period.

The duration of the latent period depends upon the seriousness of the damage and deviates from 14 until 32 days. This period is absent at all in a very severe degree of damage (doses more than 10 Gy) (Table 10).

The clinical signs of the latent period are hair loss (if the dose exceeds epilational) and neurological symptomatology, which gradually smooth away.

The appearent or so to say imaginary well-being can be easily revealed. While researching the blood, lymphopenia is easily found, as well as a decrease in the number of neutrophils, and later — thrombocytes and reticulocytes. Aplasia is brightly expressed in the bone marrow already within the first days, and from the 2nd–3rd week regeneration features are visible. Atrophy of the ovaries and

Table 10. **Diagnosis of the degree of severity of acute radiation sickness in the latent period**

Parameter	Degree of severity of radiation sickness			
	I	II	III	IV
Dose, Gy (±30%)	1–2	2–4	4–6	6
Number of lymphocytes in 1 mcl of blood on the 3rd–6th day ($\cdot 10^3$)	1.0–0.6	0.5–0.3	0.2–0.1	0.1
Number of leukocytes in 1 mcl of blood on the 8th–9th day ($\cdot 10^3$)	4.0–3.0	2.9–2.0	1.9–0.5	0.5
Diarrhea (begins on the 7th–9th day)	None	None	None	Expressed
Epilation (time of beginning)	As a rule, not expressed	May be on the 12th–20th day	In the majority on the 10th–20th day	In the majority on the 7th–10th day
Duration of the latent period, days	30	15–25	8–17	None or less than 6–8

suppression of the early stages of spermatogenesis take place during this period.

Mass destruction of cellular elements of the bone marrow and the subsequent restoration of the bone marrow with a parallel leaving of cellular elements for the peripheral channel is actually an acute radiating hematological, or marrowy syndrome. The basis of the occurrence of the marrowy syndrome is a “direct” destruction by ionizing radiation of parent cellular elements and, the most important, of the “stem” cells.

The whole process of the marrowy syndrome development can be divided into a number of phases, naturally following each other:

1. ”Primary” devastation or the degenerative-necrotic phase.
2. ”Abortive” rise (from 7–10 approximately up to 14–21 days).
3. ”Secondary” devastation, or the period of formation of radiation aplasia (after the end of the “abortive” rise, approximately on the 14th-36th day).
4. Regenerative phase, or the period of true restoration.

The patient’s state of health worsens again acutely by the end of the latent period, asthenia increases, the temperature raises, the erythrocyte sedimentation rate (ESR) grows. A severe clinical picture of the disease develops, due to which this phase is called the height of the desease. A haemorrhagic syndrome appears, namely, petechial, mucous membrane, gastro-intestinal, intracranial, cardial, and intrapulmonary haemorrhages (Table 11).

The danger of haemorrhages in the vitally important organs attended by thrombocytopenia and the appearance of infectional complications because of acute and prolonged (over 2 weeks) agranulocytosis is the main threat to the life of patients during this period.

The morphological composition of the blood is presented by almost only lymphocytes because all the rest elements of the white blood are present in a very few cells or disappear completely; this results in relative lymphocytosis in absolute lymphopenia. Anemia appears and begins to progress by the end of the phase (or earlier at large doses and a pronounced haemorrhagic syndrome). This time regeneration is clearly noted in the bone marrow and the lymph nodes, except for extremely severe degree of damage resulting in early death with phenomena of complete aplasia.

Moreover, hypoproteinaemia and hypo-albuminaemia, increased content of basic nitrogen, and a reduction of the amount of chlorides are in the haemopoietic system. The sharp drop in the body mass reflects disturbances of metabolism and dyspeptic disorders (loss of appetite and diarrhea).

The following data from the case record are an example of the typical form of radiation sickness in the mild degree:

A female patient G., 27 years old, was exposed to general short-term (<10 c) rather uniform gamma- and neutron irradiation with a total dose within the limits of 150–250 sGy. The primary general reaction of the patient was distinctly expressed: headache, nausea, moderate unstable lymphopenia (10% or 1,100 cells in 1 mm^3).

General health condition for 5 weeks is quite satisfactory. Only gradual decrease in the knee and Achilles reflexes and their changeable asymmetry were marked. A reduction in the number of plates was essential but short from the 18th day after the moment of irradiation, leukocytes from 21st to 37th day — up to 3,700 in 1 mm^3. The transition to the III phase is vague. The phase of expressed clinical symptoms of disease consisted of insignificant, but natural decrease in the number of leukocytes up to 3,300 in 1 mm^3 and thrombocytes up to 72,000 in 1 mm^3. A moderate reduction of the number of myelocariocytes from 200,000 up to 100,000 in 1 mm^3 with a primary reduction in the relative contents of cells of the red line, components accordingly 16.4; 12.1 and 10,4% were observed in the punctate from the bone marrow taken on the 1st, 5th and 16th day of the sickness. The myelogram normalized by the 38th day. Changes in the neurological status looked like feebly marked disturbances of the neuro-vascular regulation had been keeping within a year from the moment of irradiation. The victim had been observed for 10 years: she remained practically healthy. There were no essential abnormalities even with the usage of special clinical-physiological examination. The peripheral blood, punctate and trepanate of the bone marrow picture were found within the norm during the 10-year observation. Rare chromosomal aberrations, inclinations to endoreduplications of chromosomes were found in cytogenetic analysis of peripheral blood culture.

The woman became pregnant on the 5th year from the moment of irradiation and gave birth in time to a healthy child who developed normally.

The next clinical case is an example of acute radiation sickness of the moderate degree:

A male patient M., 27 years old, was exposed to a short-term general external gamma and neutron irradiation with a dose of approximately 300 sGy as a result of disturbances of the regulations of an experimental reactor. During the accident, the victim was within immediate proximity to the reactor. Acute asthenia, drowsiness, headache, and nausea developed in 20 min after irradiation. Plentiful vomiting appeared in an hour, which periodically occurred during 6 h and stopped only after repeated washing of the stomach.

Next morning, i.e. in 6–8 h after irradiation, the victim suffered from general asthenia and nausea. He remained in bed willingly, received plentiful drink, and refused to eat. A poor health condition, general asthenia, and a reduction in a motor activity were keeping for 3 days. The body temperature was normal, the pulse was non-rapid, rhythmic and of satisfactory filling. The arterial pressure — 105/60 mm Hg. The Nesterov's capillary fragility test was negative. The internal organs had no abnormalities. Abdominal reflexes fast emaciation was observed. No more disturbancies in the neurological status were revealed. In the peripheral blood: Hb 66%, erythrocytes 4,800,000, color parameter 0.68, reticulocytes — 9%, thrombocytes 52% or 250,000 in 1 mm^3, leukocytes 5,600 in 1 mm^3, eosinocytes 0–0.5%, stab neutrophile — 11%, segmentonuclear — 65.5%, lymphocytes 11%, monocytes 12%, ESR 7 mm/hour.

The number of nucleus-containing cells, especially of the red sprouts, was a little reduced — about 12% on the myelogram in the punctate of the bone marrow, taken on the 3rd day after irradiation. The young cells (haemocytoblasts, proerythroblasts, myeloblasts) were completely absent, and the contents of basophilic erythroblasts (0.5%) and promyelocytes (0.25%) were sharply reduced. The amount of cytolysis cells and "naked nuclei" were a little increased.

The patient's health condition has considerably improved since the 4th day of the disease. Weakness, dizziness, and nausea passed, appetite appeared. The state of health remained satisfactory until the 24th day of the illness.

The amount of leukocytes changed within the limits of 3,000–4,000 in the peripheral blood during that period, the leukocytic formula expressively shifted to the left, relative lymphopenia (15%) and monocytosis (up to 16%) were observed. Thrombocytopenia (150,000–100,000 in 1 mm3) appeared and quickly progressed from the 15th day of the illness. While researching the punctate from the bone marrow on the 23rd day of the illness, the amount of nucleus-containing cells was sharply reduced (18,000 in 1 mm^3). Haemocytoblasts, proerythroblasts and promyelocytes were completely absent.

The health condition sharply worsened by the 24th day of the illness: expressed general weakness appeared, sleeplessness, the rise of temperature up to 37.5–38 °C. There were haemorrhage dots on the skin of the breast, a loosening and bleeding of the gingiva appeared, the place of injection bleeding. The Nesterov's capillary fragility test became sharply positive.

Fast decrease in peripheral blood leukocytes amount was observed from the 24th day of the illness; their number had fallen to 780 in 1 mm^3 by the 33rd day, thus the amount of neutrophils decreased to 9.5% (70 cells in

Table 11. **Diagnosis of the degree of severity of acute radiation sickness during its height**

Parameter	Degree of severity of radiation sickness			
	I	II	III	IV
Dose, Gy (±30%)	1–2	2–4	4–6	6
Duration of the latent period, days	About 30 or more	15–25	8–17	None or less than 6–8
Clinical displays	Asthenic phenomena	Infectious complications, bleedings, epilation		General intoxication, fever, intestinal syndrome, hypotonia
Number of leukocytes in 1 mcl of blood ($\cdot 10^3$)	30–1.5	1.5–05	0.5–0.1	Less than 0.5 or not enough time to develop
Number of thrombocytes in 1 mcl of blood ($\cdot 10^3$)	100–60	50–30	30	Less than 20 or not enough time to develop
Terms of the beginning of agranulocytosis (leukocytes 1.0 thousand/mcl), days	None	20–30	8–10	6–8
Terms of the beginning of thrombocytopenia (thrombocytes 40 thousand/mcl), day	None or on the 25th–28th	On the 17th–24th	On the 10th–16th	Up to 10
ESR, mm/hour	10–25	25–40	40–80	60–80

1 mm^3). The relative contents of lymphocytes has been increased up to 77%, unsharp monocytosis was marked. The amount of thrombocytes decreased up to 5% (17,000 in 1 mm^3). The number of reticulocytes was not lower than 2%, an acceleration of the ESR up to 22 mm/hour was marked. The amount of haemoglobin and erythrocytes decreased little, however this decrease was long. The number of nucleus-containing cells equaled 12000 in 1 mm^3 in the punctate of the bone marrow, taken on the 28th day of the illness. The amount of reticular cells increased. Haemocytoblasts (0.5%) and basophilic erythroblasts (2%) appeared in the smear. The relative amount of lymphocytes (36%) and plasmatic cells (4.75%) increased.

The patient's health condition improved visibly after the 20th day. General weakness gradually decreased, sleep and temperature normalized, appetite improved.

The amount of leukocytes gradually increased and reached 4,500 in 1 mm^3 in the peripheral blood by the end of the second month after irradiation. The number of neutrophils simultaneously increased; there was a left shift in the leukocytic formula. The number of thrombocytes increased gradually up to the norm too. ESR slowed down. The amount of haemoglobin and erythrocytes returned to the initial level after a prolonged decrease.

According to the bone marrow punctate research, almost full normalization of haemopoiesis was marked.

The patient was permitted to work with exception of irradiation opportunity in 3 months after the beginning of the disease. Medical observation for 10 years revealed full restoration of capacity to work and absence of health abnormalities, including sex function. The wife of the victim gave birth to a healthy boy in 5 years after irradiation.

The most serious form of acute radiation sickness, as a result of neutron and gamma ray irradiation, because of a set of mistakes, each of which could not lead to an accident, is described by Shipman:

Ataxia and disorientation were marked in the victim in 30 s after the failure on installation for plutonium obtaining from liquid waste products. He could not stand without outside assistance and repeated only: "I am burning, I am burning". The nurse from the medical aid station arrived at the place 10 min after the accident and was surprised to see a seriously shocked patient unconscious, but with pink complexion. It did not occur to her that this color was none other than radiation erythema. The victim almost did not have a pulse and the only thing that she could do was calling for urgent help. The victim was delivered to the emergency room of the Los Alamos medical center 25 min after the accident. By the time of arrival to the clinic his condition has changed. If 10 min after the accident when he was seen for the first time by the nurse, he was unconscious, he arrived at the clinic in a semiconscious state, although, disoriented of his surrounding. He moved on the stretcher restlessly. All visible sites of the skin were dark-purple. He seemed to be suffering from pain, apparently, in the stomach. Acute hyperemia of the conjunctivas was marked, but the expressed anxiety of the victim complicated the conduction of a careful inspection. He had vomiting movements frequently, but only a small amount of aqueous liquid discharged. There were liquid feces approximately 10 min later.

Blood pressure is 80/40 mm Hg, pulse — 160 beats per a min. A mild fever was temporarily observed, and the anxiety was so strong, that the victim had to be restrained.

The main task was to bring the blood pressure to a satisfactory level and support it at this level. "Heroic" doses of presser amines were applied.

The condition of the victim was satisfactory 5 h after the accident. He was conscious, quiet, and in a good mood. By this time dosimetric researches made it clear that he underwent supralethal irradiation. The dose of neutrons and gamma-rays, got by victim K. on the breast area, hence, on the right half of the heart and anterior wall of the stomach, was about 120 Gy, on the area of the head — 100 Gy, on the lower half of the legs — 10 Gy.

The general number of leukocytes steadily grew, reaching the maximum 28,000 in 1 mm^3; lymphocytes practically disappeared from the blood in 6 h. Oliguria caught our attention. The total amount of urine excration was only 600 ml, while the victim had been given 14 l of liquids.

It was absolutely clear for the doctors that the lethal outcome should come in some hours. Uttermost comfort had been created and researches were practically denied.

The third period had a rather calm course. He was permitted to drink, though everybody understood that it was not recommended. Starting with the 8th hour after irradiation up to the 30th hour he did not have nausea and in general any complaints. Whenever possible he was not disturbed.

30 h after the accident his condition worsened acutely. He had increasing pains in the stomach and he began to get anxious, which could not be removed by sedative preparations. The anxiety gradually passed to a completely uncontrollable condition: the victim pulled out a needle from his vein. At that moment the blood pressure was 160/110 mm Hg. Despite the continuous submission of oxygen, cyanosis amplified, the victim was given soporifics, and he entered coma, which he never came out of. Death came because of cardiac arrest in 34 h and 45 min after the accident. The victim's heart appeared to be the main target; it received 120 Gy of irradiation.

Prognosis of an outcome of acute radiation sickness on the basis of revealed symptoms are shown in table 12.

Many examples of person's affection during strong non-uniform, mainly local irradiation, in various, sometimes very big doses

(30 Gy–5 kGy) are mentioned in in the literature when various organs and tissues are critical: separate parts of the intestines, the soft tissue, the nervous tissue (the nervous bunch of the heart), the skin, etc.

The lethal outcome developed in these cases due to peritonitis, sepsis, serious distress of haemodynamics, etc., and death came earlier than there was damage to haemopoiesis, or irrespective to it. Hence, the more carefully analysed the geometry of the position of the injured person in relation to the source of radiation taking into account quantitative and time characteristics of display of damage in different organs and tissues (and their role in the outcome of the expected disease), the more correctly predicted its form, possible prognosis, and tactics of therapy are determined. The above-said is illustrated by the case, described by A. K. Guskova and G. D. Baisogolov in which a non-uniform irradiation contacted significant segments of the body.

The female victim K. was exposed to extremely non-uniform gamma-neutron irradiation for less than 1 s. The average dose was 5.8 Sv (gamma rays — 1.1 Gy, neutrons — 4.7 Sv), the average tissue dose for the left half of the body reached 10 Sv, and on the superficial (up to 5 cm) layer — 16–20 Sv, for the right half of body — 2.8 Sv (Fig. 3).

The primary reaction developed during the first 2 h after irradiation: already in 5–10 min the feeling of "struting" was felt in all the body, and then nausea, often vomiting, weakness and numbness of the skin on the left half of the thorax appeared.

The increased temperature (+38°C) was kept towards the end of the first day and for 25 days, simultaneously symptomatology of damage to the

Table 12. **Prognosis of outcome of radiation syndrome on the basis of revealed symptoms**

Prognosis of survival	Symptoms
Improbable	Vomiting immediately or within several hours after irradiation. Fever, diarrhea, fast falling of the number of leukocytes within 48 h after irradiation
Possible	Vomiting may occur at the first day after irradiation, but then asymptomatic (hidden) period follows
Probable	The absence of nausea and vomiting at the first day after irradiation. The absence of leukopenia down to the 10th day after irradiation

skin of the face, mucous membrane of the oral cavity, nose, and later — GIT and extremities appeared and increased. The clinical picture of the skin and mucous membranes injury was the most severe from the 10th till the 20th day: many blisters, erosions, dotted haemorrhages, painful inflammation of the eyelids and epilation of the hair, significant loss of body weight — 8 kg within 24 days, were marked.

Since the 24th day, the body temperature decreased to normal, the state of health began to improve quickly, cuticularization of the erosions in the oral cavity and the skin injuries healing began, the hair growth renewed by the 3rd month. Simultaneously hydrated edema of the affected tissues of the whole left half of the body began to form.

Soon the victim was discharged from the hospital with the presence of unpleasant sensations (dryness) in the oral cavity, pains in the left half of the thorax, as well as with feeling of heaviness in the left half of the head. In the process of the edema disappearance, deep atrophy of the hypodermic fatty layer began to appear, a bald spot occured on the damaged sites, and hair growth has not renewed for 10 years in the left temporal area.

Neutrophilia (93.5%) leukocytosis (14,900 in 1 mm^3) and deep lymphopenia (2.5%) were observed in the peripheral blood of the patient already 4 h later after irradiation. The amount of leukocytes began to decrease by the 4th day and it was 375 cells in 1 mm^3 by the 7th day. Despite the early and fast decrease, the number of leukocytes did not continue to decrease, but gradually increased and reached the initial level — 4,000 in 1 mm^3 by the 20th–27th day. The other parameters of the peripheral blood had the similar kinetics (abrupt and early falling with the subsequent fast restoration).

Fig. 3. The position of the victim K. at the moment of irradiation (the side facing the source of irradiation is darkened)

Analyzing this observation, we should notice, that the non-typical course and outcome of the sickness were due to the extreme non-uniformity of irradiation, when the early reduction in all the formative blood elements occur because of the rapid depletion of large volumes of the bone marrow exposed to doses of 10–20 Sv and temporarily excluded from the haemopoietic system. At the same time, the presence of only slightly damaged sections of haemopoiesis that received a low dose first stabilized the number of formative elements at a reduced level, and then, beginning with the 3rd week, haemopoiesis rapidly recovered because the more injured sections began regenerate in the more injured parts too.

A decrease in the effect of biological action of radiation is marked in non-uniform general irradiations. A patients bears the local irradiation more easily, than the general one. The more the area of irradiation, the more the absorbed dose of radiation, so, the more the biological effect. The part of the body irradiated is of importance as well. Irradiation of the stomach only has a more expressed biological effect than irradiation in the same dose of equal area of other sites of the body.

The following period — the period of recovery occurs in patients, who underwent treatment after the period of height lasting for one to three weeks, in cases with a favorable outcome.

The beginning of the period of restoration is characterized by normalization of the temperature, improvement of health condition, the appearance of the appetite, and the restoration of sleep. The haemorrhages stop and the dyspeptic phenomena disappear or weaken. As a rule, the mass of patients generally grows quickly. Gradual recovery of the blood indices occurs, which in surviving patients begins already at the height of the sickness as a result of regeneration of the marrow.

5.2. FEATURES OF THE COURSE OF RADIATION AFFECTIONS AFTER THE CHERNOBYL ACCIDENT

The operators of the 4th block, the attendant and support personnel of the turbine hall, firefighters as well as private citizens who had nothing to do with the liquidation, who were near the station for different reasons, got acute radiation sickness as a result of the Chernobyl accident. There were no data on individual dosimetry. According to the cytogentic estimation (calculation of chromosomal aberrations in preparations from the bone marrow or cultures of lymphocytes of peripheral blood) the absorbed dose was in the range from 1 to 13.8 Gy and corresponded to the seriousness of acute radiation sickness — from light degree of the marrow form to the clinical displays of the intestinal form.

The influence of the penetrating radiation on the whole body was the main reason of development of doses of the general clinical syndromes typical for this range: marrowy, intestinal and transitional forms.

Separate centers of deep local radiation injuries caused by contact with polluted radionuclide products formed sometimes against a background of widespread superficial radiation damage.

The clinical course of acute radiation sickness II–IV degree corresponded to that one developed earlier. The majority of patients with serious bone marrow syndrome had combined damage to the skin and mucous membranes. The radiation burn complicated and even determined the lethal outcome of the disease.

The clinical manifestations of the marrowy syndrome were determined subsequently by the depth and duration of pancytopenia: neutrophils (0.1–0.5) $\cdot 10^9$/l, thrombocytes (10–20) $\cdot 10^9$/l. The basic displays of the bone marrow syndrome (BMS) were fever, infectious complications and petechial haemorrhages on the skin and mucous membranes of the mouth.

Widespread radiation damage to the skin, caused by the influence of beta radiation was a distinctive feature in the damage to people in the given accident.

Radiation burns to the skin in the firemen and the personnel victims were observed only in combination with radiating damage of haemopoiesis being a component of the general clinical syndrome with ARS.

The given situation must be treated as a variant of extremely non-uniform distribution of the absorbed dose, when in the skin it was 10–20 times as much than in the bone marrow. This representation proves the presence of a certain parallelism in the severity of the damage of these two critical systems.

Skin damages were observed in half of the patients suffering from ARS, and with III and IV degrees of the BMS — practically in all the patients.

The aggravating contribution of radiation injuries to the skin in the general clinical syndrome of ARS was determined not only by the prevalence of the process, but also the degree of expressiveness of pathological changes as well as the duration of the course with original relapses of the pathological process.

Burns located on different sites of the body were observed in one person. The hand brush, face, neck, feet were affected at the onset of the disease. Later the thorax, back, then on the shins, hips, and buttocks were injured. On occasion this sequence was broken.

Dispersed hyperemia on the 1st day (primary erythema) was replaced by the latent period on the 3rd–4th day. Secondary erythema in the most serious cases arose on the 5th–6th day and for a majority of patients from the 8th to the 21st day. Depending upon the degree of damage it ended with dry epidermitis (I degree radiation burn) or wet with the formation of blisters (II degree) or ulcers and ulcer-necrotic dermatitis (III–IV degree). Cuticularization of the desquamative-erosive surfaces proceeded for 2–3 weeks after the moment of the occurrence of visible changes on the skin. Healing of the burn wounds did not start until the end of the 2nd month in 6 patients on the sites of deep necrosis of the skin. A prominent feature of the formation of burns, which were observed in the given group of victims, was the occurrence of waves of erythema, beginning at the end of the 4th week up to the 45–60 days. These changes were characterized by hyperemia in sites on the skin that were not earlier changed or an increase in clinical displays in the centers of "old" healing burns. For example, late secondary erythema appeared on the anklebones and feet or on the hips and buttocks in those patients who had "blossoming" burns on the shins during the first three weeks. By the moment of occurrence of this late erythema frequently cuticularization of erosions appeared before already existed. Late erythema was accompanied, as a rule, by hypostasis of the hypodermic cellulose, especially visible on the shins: there was pain during walking. Palpation of the skin and the underlying tissues (muscles, tendons) was painful. It was necessary to resort to additional therapeutic measures in the most serious cases, for example, giving glucocorticoids, which quickly enough removed all the general and local displays of dermatitis.

Burns covered from 1 up to 100 % of the surface of the body in patients with ARS. Thus it is possible to note that relatively early (from the 5th–6th day) II–III degree burns, even on an area of 30–40%, with a subsequent spreading of hyperemia were incompatible with life. 19 of 56 patients with radiation burns died. Naturally, when the early secondary erythema appeared on the body surface more than 40% the patients developed the feverish-toxicaemic syndrome firstly, then adrenal and hepatic insufficiency and encephalopathic coma with edema of the brain, which resulted in death in 14–18 days after irradiation. The genetic connection between adrenal and hepatic insufficiency and encephalopathic coma proves to be true in that the similar evolution of these fatal syndromes was observed in some patients without the serious BMS and the intestinal syndrome. However, fatal burns were combined with the BMS of the most severe degree and with severe acute enteritis (the radiation intestinal syndrome).

The intestinal syndrome was one of the most terrible displays of the ARS. It developed in the period from the 4th to the 8th day in 10 patients, which indicates an instantaneous gamma irradiation of at least 10 Gy and more (all these patients died during the first 3 weeks after irradiation), the occurrence of diarrhea after 8 days (in 7 people) — about a milder degree of damage.

The oropharyngeal syndrome (OPS) — acute radiation mucositis of the mouth and pharynx — occurred in 80 patients. Its mildest manifestations (I–II degrees of severity) were characterized by an oedema and desquamation of the mucous membrane of the cheeks, and tongue and loosening of the gums, observed from the 8th–9th up to 20th–25th days. The basic symptoms of severe OPS (III–IV degree) were erosion and ulcers of the mucous membrane of the mouth, sharp pain, a large amount of rubber-like mucus appeared, sometimes affecting the threshold of the throat and destruction of respiration. The first symptoms appeared on the 3rd–4th day, reaching a maximum by the 10th day and returned after 18–20 days with agranulocytosis. The process had no selective localization that is inherent in erosive-ulcer damage on the palatal tonsils and gum area with agranulocytosis. However, in a significant amount of cases, radiation mucousitis was complicated with a secondary microbic and virus infection that delayed its treatment. Primary early (on the 3rd–4th day) occurrence of rash similar to herpes, forming massive sores on the lips and facial skin was pecular and observed in almost 30% of the patients with BMS of a severe degree.

Expressed radiation parotitis with damage to salivation and a substantial increase in the level of amylase in the blood from the 1st to the 4th day was observed in patients of the given group, mainly with ARS of the IV degree. The parotis glands decreased without special treatment, but the secretion of the salivary glands did not restore as fast.

Acute radiation pulmonitis was observed in 7 patients with ARS of the III–IV degree of severity. Its characteristic attributes quickly increased in the visible shortness of breath, during auscultation — "fulminatory", like "an iron roof in the wind", crackles in the lungs; progressing for 2–3 days ventilation insufficiency; lethal outcomes came from a hypoxemic coma. When dissected, large blue lungs, with expressed interstitial hypostasis without signs of destruction of the mucous membrane of the trachea and bronchial tubes of all calibers, were found. Interstitial pulmonitis develops, as a rule, a few days prior to death, combined with severe damage to the skin and intestines. The time of death — 14–30 days after irradiation. Apparently, radiation pulmonitis was complicated with secondary, incompatible with life, virus infection.

Haemorrhagic diathesis reached the thanato-genetic importance only in one case (haemothorax and haemoperitoneum, provoked by mechanical trauma during manipulation — catheterization of the vein).

Severe endogenous intoxications in connection with extensive radiation destruction to tissue, deteriorated with infectious — septic complications, were found almost in all the cases before the lethal outcome.

It manifested itself in the following disorders:

1) insufficient liver function;

2) insufficient kidney function;

3) signs of discirculatory-toxic encephalopathy in combination with respiratory and vascular insufficiency.

The dynamics of the changes in the organ of vision had certain laws. The damage was characterized by an early and consecutive pathological process in all the tissue of the eye.

There were no changes on the dose up to 1 Gy, changes have not been marked. The ARS of the I degree patients had changes only in the anterior part of the eye. Mild erythema of the skin of the eyelid and an increase in the vascular figure of the conjunctiva and eyeball occured within first 2–4 days.

The skin of the eyelid reacted with the occurrence of erythema in 6–12 h after the moment of influence (the first wave), and the second wave of erythema arose 2–3 weeks later in 40% of patients suffering from ARS of the II degree and 100% of the III degree. Changes on the skin disappeared completely, thus there were hyperpigmentation and peeling. The first and second waves of erythema occured at 1–2 and 8–12 days accordingly in all patients suffering from ARS of the IV degree.

Changes in the conjunctiva of the eyelid and the eyeball were marked with the same frequency, as the changes on the skin in a corresponding range of doses, and consisted of an increase in the vascular figure, dilatation of the venules, capillaries, less often arteriole, the aggregated blood circulation slowed down.

2 patients with *the combined radiation and thermal damage* of the II degree on the skin and conjunctiva of the eyelid had macerative erosions on the skin around the eyes that do not epithelizate for a long time.

Epilation of the eyebrows is marked on the 15th–17th day in 16% of the patients with ARS of the II–III degree, 67 and 100 % accordingly — with III–IV degrees. Epilation was partial and incomplete. Growth of the eyebrows was completely restored. The eyelashes remained in everyone.

Damage of the cornea was shown by a decrease in sensitivity of the cornea in early terms, coinciding with the first wave of erythema. A decrease in sensitivity of the cornea was not observed during ARS of the I degree. Superficial radiation keratitis was marked in later terms (35–55 days) during ARS of the II, III, IV degrees — in 45, 50 and 100 % accordingly. Dotted, merging defects of the superficial epithelium of the cornea were found frequently. Radiation keratitis regressed in 1–1.5 months, thus turbidity did not remain.

Attributes of disturbance of the haemodynamics of the retinas also was found in connection with the dose and degree of severity of radiation sickness. A decrease in the level of diastolic pressure (DP) in the central artery of the retina (CAR), and later — attributes of hypotonic angiopathy of the retina have been marked since the 1st day.

Coinciding with the terms of the period of height of the illness, hypostasis of the retina along the way of the vessels and the increased permeability of the retinal vessels as plasmorrhagia and haemorrhage join this. A low level of DP in the CAR was kept during the whole period of supervision.

Signs of angioretinopathy with haemo- and plasmorrhagia against a background of a continual low level DP in the CAR (up to 8–10 mm Hg) occurred again in one most seriously ill patient (ARS of the IV degree) in 4.5 months.

Clinical recovery during the direct restoration of patients suffering from BMS of the I–II degree of severity came to an end by the 3rd–4th month. Patients with serious radiation burns and the results of BMS of the III–IV degree demanded a longer treatment. The haemopoiesis restoration process came to an end within 1.5 years in 84% of the patients.

Results of long supervision (V. G. Bebeshko, V. I. Klimenko, I. S. Dyagilo, N. M. Bilko) are evidence of the significant abnormalities of the haemopoietic system during the remote period after an endured acute radiation sickness.

Qualitative changes in the blood elements and bone marrow are revealed practically in all the patients. 3 fatal cases of myelodysplasistic syndrome — refractory anemia, refractory anemia with a change in the blasts and aplastic anemia occured within a 10-year period among the patients of this group.

The following extracts from the case records published by O. M. Kovalenko (1995) are presented to illustrate the hematologic syndromes in ARS convalescents:

1. A 52-year old patient B. was under supervision in a clinic since the accident when he was diagnosed ARS of the III degree. Since 1992, moderate leukopenia (up to $3.5 \cdot 10^9$/l) and thrombocytopenia ($100 \cdot 10^9$/l) had been observed in the patient. Periodically, lymphocytosis up to 58% was observed. In 1993, 2 months after having had viral infections, the health condition acutely worsened, gum bleedings appeared, haemoptysis, anemia began to progress, thrombocytopenia. A moderate increase in the peripheral lymph nodes was observed. After profound hematological inspections the patient's diagnosis was established: myelodysplasitic syndrome, a variant of refractory anemia with ring sideroblastics. Despite the conduction of active therapy, the patient died very quickly.

2. A 54 year-old patient D. was observed in the clinic after he had been diagnosed ARS of the III degree. The patient had significant burns on the lower extremities. The course of the acute period of ARS was classical. The disorders of the haemopoietic system had not been revealed till 1996. Then moderate anemia and thrombocytopenia appeared without an evident reason. During inspection the diagnosis of myelodysplasitic syndrome with a surplus of blasts was established. The conducting of corresponding therapy brought no effect and the patient was lost very quickly.

Thus, irradiation in high doses can result in radiation induced changes at the level of stem cells and, probably, genome.

Works of the Ukrainian scientists O. P. Nastenko and V. V. Talko gave a possibility to determine some features of pathological processes in bone marrow cavities of patients suffering from ARS due to the Chernobyl accident. The authors presented the new facts unknown in the world literature before, which had been observed simultaneously with the well-known decrease in bone marrow cellularity in acute radiation sickness. They are the following:

1. Disturbance of the histotopographic organization of the bone marrow.

2. The general character of disturbances had an identical direction for both the parenchyma and stroma of the bone marrow.

3. Sites of the bone marrow with increased contents of cellular elements were found.

Ukrainian scientists examined the ultrastructure of haemo- and lymphopoiesis cellular elements during the height of acute radiation sickness and revealed ultrastructural symptoms of destruction in cells of all lines of haemopoiesis. A profoundly new conclusion about the value of incorporation of radionuclides for radiation damage as a result of the Chernobyl NPP accident was made on the basis of comparison of spectra of the bone marrow to the ultrastructural data (O. P. Nastenko and V. V. Talko). It is shown, that not only elements, forming organic and nonorganic compounds (hydrogen, carbon, nitrogen, calcium, iron, copper, etc.) regenerated in the spectra, but also those ones which presence can relate to the pollution of an organism by nuclear fuel division products (caesium, lead, bismuth, plutonium, etc.) were recycled.

Ukrainian scientists D. A. Bazika, Yu. A. Chumak, N. V. Belyaeva characterized the condition of the immune system in ARS patients in terms from 3 months to 4–5 years after irradiation as an acquired immunodeficiency of a radiation genesis with the oppression of T- and B-unit functions, insufficiency of mechanisms of nonspecific resistance of an organism. Propositions on the resistance of the cardiovascular, respiratory and digestive systems are revised now due to the works of the Ukrainian scientists O. M. Kovalenko, I. G. Khalyavka, D. O. Byely, etc. Diseases of these systems are rather frequently seen in survivors of the Chernobyl NPP accident. These pathological changes can be the basis for the development of stochastic consequences of action ionizing radiations, i.e. promote the occurrence of solid tumors.

The influence of ionizing radiation accelerates the age and atherosclerotic processes in the cardiovascular system and cause the development of its pathology in people of the young and mature age.

A gradual growth of pathology in the bronchopulmonary system was observed in the ARS convalescents during the period of 1987 to 1994 according to the Ukrainian scientists' (O. M. Kovalenko, I. G. Khalyavka, D. O. Byely, etc.) data. Chronic bronchitis occurred more often. The development of atrophy of the mucous membrane in a majority of patients suffering from chronic pulmonary diseases was a prominent feature in the macromorphological picture of the bronchial tubes.

Chronic inflammations of the gastrointestinal tract, mostly chronic gastroduodenitis with frequent aggravations without seasonal features, prevailed during the first 4 post-accident years. Progressing changes of the mucous membrane with atrophic and hyperplastic character were revealed at the endoscopic examination of the esophagus, stomach, duodenal and small intestines. Later on the amount of patients suffering from duodenal ulcers with frequent aggravations without precise connection to the season, increased.

Erosive-ulcer processes may be caused by a steady abnormality of the neurohumoral regulation. Harmful habits in some patients influence negatively too. The opportunity to decrease the regenerational and repolarizational abilities of the epithelium of the mucous membrane of the gastrointestinal tract due to primary radiation damage is not excluded.

Among the Chernobyl NPP accident survivors, the amount of chronic persistent hepatitis with periodic aggravations with damage to pigmentation, protein-synthesizing functions of the liver or enzymemia accumulates.

Neuro- and psychophysiologic researches executed by the Ukrainian scientists A. I. Nyagu and K. M. Loganovsky revealed organic damage to the central nervous system of a radiation genesis — postradiation encephalopathy in the remote period of acute radiation sickness.

In these cases, when against a background of acute radiation sickness, cerebrobulbar pathology (essential hypertension, atherosclerosis) quickly developed with the presence of permanent haemodynamic damages; organic damage to the brain can be diagnosed as postradiation discirculatory encephalopathy.

Ukrainian scientists V. M. Gayday and Yu. V. Gayday showed that the absolute majority of people, which had been ill with acute radiation sickness as a result of the Chernobyl NPP accident in 1986, had late consequences of the influence of penetrating radiation to the organ of vision in the post-accident period. They are pathological changes of the tissue structures of the eye and different diseases, which result in impaired sight function.

5.3. EQUIPMENT AND THE WORK OF SPECIALIZED MEDICAL ESTABLISHMENTS FOR RENDERING ASSISTANCE TO PEOPLE WHO ARE EXPOSED TO THE INFLUENCE OF IONIZING RADIATIONS

The specialized medical aid to the injured at the Chernobyl accident was rendered 12 h after the accident by specialized emergency brigades. The brigade together with personnel from MSC examined more than 350 people within 36 h, about 1,000 blood analyses were done (2–3 analyses per person).

During the acute period of the accident, the overexposed were urgently hospitalized in specialized establishments in Kiev and Moscow. Within the first 3 days 299 people with the assumption of ARS were directed for examination to the specialized hospitals of Moscow and Kiev, later on about 200 more people. The basic stream of victims were taken by the Kiev Radiological and Oncological Institute, the Kiev Scientific Research Institute of Hematology and Blood Transfusion, the 6th Clinical Hospital of the Institute of Biophysics of the Ministry of Health of the USSR (Moscow). Victims were delivered to Moscow by aircraft with medical assistence. The choice of medical institutions was given by a number of requirements: the presence of experts of the top skills, possessing experience of diagnosis and treatment of radiation pathology; the ability to adequate researches of haematogenic tissues and on their basis define the severity and prognosis of radiation injuries; ability to use blood, its components and bone marrow with therapeutic purpose; ability to apply modern methods of disintoxication therapies; presence of conditions for preventive measures of intercurrent infections, treatments for local radiation traumas and diagnostic radiation control. The Moscow clinical hospital N6 had experience and proper conditions of such patients treatment.

The basic criteria for establishing diagnosis and definition of sequence of hospitalization were presence, the term of occurrence and intensity of nausea and vomiting, primary erythema of the skin and mucous membranes and a decrease in the number of lymphocytes in the peripheral blood lower than $1 \cdot 10^9$/l during the 1st day after irradiation.

Repeated control of pollution and, if necessary, sanitary processing (washing in a shower with soap and change of linen) were conducted in the admission ward of the specialized hospital. Blood and urine tests for express-estimation of the incorporation of radionuclides were taken, as well as the contents of radioactive iodine in the thyroid gland were measured (researches were repeated within the first 6–10 days 4–6 more times). Counters on the base of scintillation and semi-conductor blocks of detecting were used for measuring the activity of radionuclides in a person's body.

The basic diagnostic task during the first days after the accident at Chernobyl NPP was the estimation of the degree of severity of BMS by the dose of external general irradiation. It was possible in the early terms on the basis of the developed methods (A. K. Guskova) by the number of lymphocytes and chromosomal aberrations in a culture of lymphocytes from the peripheral blood or by the amount of aberrations in preparations from the bone marrow. Experience in rendering specialized help on a large-scale radiation accident at Chernobyl NPP was generalized by A. G. Guskova and described below.

Victims were divided into groups according to the predicted severity of BMS of the light degree (1–2 Gy), medium (2–4 Gy), severe (4–6 Gy) and extremely severe degree (6 Gy and more) as well as survivors which were exposed to the irradiation dose less than 1 Gy were separated.

A special attention during the first days was given to patients with an extremely severe (irreversible) degree of myelodepression, demanding an urgent decision on the transplantation of the bone marrow. The additional signs specific for this group were vomiting within the first half hour and diarrhea within first 1–2 h after the beginning of irradiation, an increasing of the parotid glands during first 24–36 h.

All patients suffering from BMS of the II degree and more were also placed one by one in the common hospital chambers, adapted for providing aseptic observation of patients: sterilization of the air by ultra-violet lamps, strict observance by the personnel of hands scrubbing before entering and leaving the chamber, obligatory use of individual or single dressing gowns, masks, caps, processing of footwear with antiseptics, change of linen in patients no less than 1 time a day, washing the walls, chamber floor and article for care with antiseptics. The specified mode provided the contents of microorganisms in the air of the chamber no more than 500 colonies in 1 m^3. The food was usual, raw vegetables and fruit, tinned products were excluded.

At the beginning specialized medical actions were directed at removing of incorporated radionuclides and products of tissue disintegration from the organism of the victims. Intensive disintoxication therapy by washing the stomach, intestines, forced diuresis, haemo- and enterosorption, stable iodine prescription was used. Active symptomatic therapy was carried out simultaneously by indications, albuminous and water-electrolytic metabolism were corrected. During supervision, the doses of external general gamma irradiation were specified and counted, the degree of severity of the marrowy syndrome, which is the basis of grouping patients, was estimated.

A specialized treatment was based on the anti-infectious principles and the supporting therapy, providing isolation of the patient, decontamination of the intestines, the presence of system antibiotics and replaceable transfusion of the replaceable components of the blood. The transplantation of allogenic bone marrow or the cells of a human embyronic liver was applied in case of the prognosis of irreversible myelodepression. The accepted diagram of therapy of acute radiation sickness was individualized depending upon the clinical picture, the determined syndrome (or syndromes) in the dynamics of the height of the illness, and the condition of the local radiation damage and the arising complications.

Preventive measures of endogenous infections was carried out with Biseptolum-480 and Nystatin — 6 tablets and 5,000,000 UA per day accordingly for 1 and 2–3 weeks before the development of agranulocytosis (leukocytes 1–10^9/l, and neutrophils 0.1–0.5–10^9/l).

In case of fever, 1 or 3 antibiotics of a wide antibacterial spectrum were appointed intravenously — one from the aminoglycoside group (Gentamycin), cephalosporins (Cefazolin, Cefamezinum, Cefobid) and semisynthetic penicillins with anti-pyocyanic activity (Carbenicillin) — all in maximal doses. As a result, no less than half of the patients' fever stopped. Gamma-globulin was applied in absence of effect for 24–48 h.

Amphitherricin was used intravenously in doses of 1 mg/kg per day, if the fever did not stop within a week, the specified antibiotics in a combination with intravenous injections of gamma-globulin were prescribed.

For the first time Acyclovir gave a good effect for the treatment of ARS patients with the herpes simplex infection, which affected no less than 1/3 of the patients suffering from ARS of the III and IV degrees. It was not appointed as a preventive measure, experience showed that it is necessary to use in general high dose irradiation. Acyclovir containing ointment had good effect in the treatment of herpetic damage of the skin.

The specified mode of empirical anti-infectious treatments appeared to be highly effective: practically there were no lethal outcomes caused by the infection, in patients with bone marrow, even severe and extremely severe forms of ARS, which was not complicated with burns, radiation enteritis or acute secondary illness (ASI) due to transplantation of the bone marrow. Moreover, during the autopsy of patients who were lost from non bone marrow damage, doubtless macroscopic signs of bacterial and mycotic infections (septico-necrotic centers) were not found.

The rational use of fresh donor thrombocytes for preventive measures and treatment of bleeding was one of the basic successes in the treatment of BMS in the given group of ARS patients.

Thrombocytes, received from one donor (on the average 300–109 thrombocytes in a volume of 200–250 ml of blood plasma) were used on one transfusion. Transfusions were started while a decrease in the thrombocytes level in the blood was less than 20–109/l or even lower, only with the occurrence of bleeding signs, the introduction was repeated in 1–3 days.

The specified mode of thrombocytes transfusion provided the absence of not only life threatening bleedings, even in patients with long (more than 2–4 weeks) and deep thrombocytopenia, but also any attributes of bleedings in a majority of patients.

Leukocytic mass for preventive measure and treatment of agranulocytic infections were not applied. The need for packed red blood cells appeared to be more than expected even in patients with complicated severe radiation burns with ARS of the II–III degree. The indication for the transplantation of cells of allogenic bone marrow (TCABM) and cells of human embryonic liver (TCHEL) was the dose of general gamma irradiation, estimated by the number of lymphocytes in the peripheral blood and chromosomal aberrations of about 6 Gy and higher. It is considered that the given dose of irradiation corresponds to irreversible or extremely deep myelodepression. 13 TCABM were executed.

6 TCHEL containing stem haematogenic cell (SHC) and a minimum of immunocompetent cell were also executed. All patients after the TCHEL were lost early (within 14 to 18 days after irradiation) from damage to the skin and intestines, except for one woman of 63 years of age who lived 30 days after irradiation with a dose of

8–10 Gy. A number of mitoses were revealed for the first time in the bone marrow against a background of deep pancytopenia on the day of her death (17th day after TCHEL). All cells had female karyotype, that is regeneration of the bone marrow began.

Similarly in terms from the 2nd to the 19th day after transplantation (15th–25th day after irradiation) 7 patients died after TCABM from incompatible with life acute radiation damage to the skin, intestines and lungs.

2 people survived (dose of gamma irradiation 5.8 and 9 Gy) of 6 patients who did not have damage of the skin and intestines incompatible with life, and doses of general irradiation were estimated as 4.3–10.7 Gy. The donors in these two cases were the victims' sisters. Rejection of a partly functioning transplant by the 32nd–35th day and restoration of myelopoiesis (began by the 28th day) was marked in both of them. Four patients were lost from the 19–27 days after TCABM because of mixed viral-bacterial infections.

Treatment of radiation burns and other extramedullar syndromes and their complications is a complex multilateral problem. 15 sessions of haemosorption were done to 13 patients with severe damage of the skin from the 2nd to the 8th day. Three of the patients exposed to doses of general irradiation of 2–4.6 Gy survived, they were conducted a single haemosorption on the 5th–8th day, i.e. much later than is recommended during the treatment of BMS. This method did not affect the survival of patients.

It is possible to note, that already in the process of haemosorption, and especially towards the end of the session, many patients noticed a short-term for some hours–days improvement of their health condition, reduction or disappearance of pain in the damaged extremities, and reduction of swelling in tissue.

Plasmapheresis was used widely with the purpose of opposition of the natural development of renal and hepatic insufficiency and fatal encephalopathic coma. The indications were severe burns from beta-radiation — 30–40% and more of the surface of the body. Plasmapheresis was carried out from the 18th to the 37th day for 17 people, and some patients — daily up to 6 times. Positive influence of repeated plasmapheresis was expressed in the reduction of bilirubinemia, transaminasemia and a decrease in the level of nitrogenous remains with renal-hepatic syndrome of the burn genesis. Separate sessions of plasmapheresis were accompanied by non-severe reactions like chills and fever; fatal complications were not observed. One more reception in toxicosis of the burn genesis was the injection of 1,000 ml of chilled plasma against a background of round-the-clock heparinization (1,000 UA/h) with forced diuresis, adequate to the entered volume. The precondition to this was the assumption of subclinical and even sublaboratory (there were no atypical coagulogic violations) dissiminated intravascular coagulation (DIC) as a principal cause of encephalopathy and renal-hepatic syndrome. Two patients were conducted the method of heparinization for 7–15 days. The impression was created that these patients lived longer than people similar to them by severity and spread of burns. The renal-hepatic insufficiency was less expressed in them, however, the fatal outcome from encephalopathic coma was not prevented.

Local treatment of burns required an assistance of a group of surgeons and nurses. A wide spectrum of preparations and agents of anti-inflammatory, bacteriostatic, and stimulating regeneration action was used. The aerosol lyoksanol, anti-burn ointments on the basis of Hydrocortisone with antibiotics of local action, Balis-2 solution, collagenic coverings — Combuten, adhesive-remisive, etc. were recommended.

Preparations were changed according to the stage of pathological process in each individual case. It is especially necessary to note the experience of use of bactericidal tissue as a dressing, and for the additional covering of beds for patients with widespread burns.

The struggle against the pain syndrome, as always in radiation injuries, was sufficiently difficult and ineffective. Patients suffering from severe radiation stomatitis and enteritis had a certain positive effect was due to the application of total parenteral feedings (on the basis of hydrolysate-alvesine or amino acid mixes — Aminonum and a 40% solution of glucose as an energetic material).

The phase of clinical recovery in a majority of patients with BMS of the I–II degree of severity came to an end by the 3rd–4th month. Patients required longer treatment with severe radiation burns and consequences of BMS of the III–IV degree.

5.4. CHRONIC RADIATION SICKNESS

Chronic radiation sickness (CRS) can be caused by general radiation (I variant) and mainly local irradiation from external sources (II variant), as well as rather regular intervals of distributed radionuclides (^{3}H, ^{24}Na and to a certain measure ^{137}Cs). Expressed syndrome of CRS develops in intensity of 0.001–0.005 Gy/day after a total dose of 0.7–1.0 Gy. It is a complicated precisely outlined clinical syndrome involving practically all organs and systems in the reaction. It is characterized by the periodicity of its course associated with the dynamics of formation of the radiation load.

Clinical displays of CRS, in contrast to acute radiation sickness, are more stretched in time. The disease is notable for a wavy course that reflects the combination of slowly increasing effects of damage to attributes of regenerative processes and adaptive reactions.

Tissues and structures, having a big reserve of immature cells and intensively change their cellular structure in physiological conditions (epithelium of the skin, intestines, haematogenic tissue, spermatogenic epithelium) react at the action of repeated irradiation in rather small total doses by early damages of a part of the cambial elements and change in the intensity of mitosis divisions, which allows to keep for a long time morphological recovery of the tissue, i.e. true reparation of structures. Opposite to them systems deprived of cambial cells or are rather limited in regeneration in physiological conditions (nervous, cardiovascular, endocrine), answer to chronic radiation influence, mainly with a complicated complex of functional shifts, a slow increase in dystrophic and degenerate changes in their structure.

Initial background and obtained features of individual reactivity of some organs and systems render a certain influence on the expressiveness of symptoms of some organs and systems.

The blood circulation system's reaction to chronic irradiation in the above mentioned range of doses consists of regional damages to the peripheral blood circulation in the skin, extremities, less often in the brain, revealed, basically, with the application of special methods of research.

Regional insufficiency of blood circulation is provoked by overheating, hypokinesia, inconvenient position of the body and head in relation to the torso, static effort. One of the characteristic variants of the syndrome of regional insufficiency of blood circulation is pain in the depth of the shins and forearms, simplification while moving, cooling.

The gradual development of oppression of secretory functions and enzymatic activity of the excretory glands, as well as changes in the stomach and intestines motility are characteristic for the reaction of the digestive path to irradiation.

The following symptoms are characteristic in the neurological anamnesis: asymmetric increase in the tendon and decrease in the skin reflexes, passing vestibular, oculovestibular and oculostatic disturbances. The complaints of the patients testify to the damage of adaptation to the loads, demanding, first of all, perfect regulation of haemodynamics (occurrence of unpleasant sensations during physical loads, change in body position, overheating). Fatigue, headaches, pains in extremities, dizziness, hyperhidrosis are typical.

The peculiar phenomena occurring in haematogenic system during chronic irradiation is an increasing cytopenia, caused by the reduction of the number of neutrophils, lymphocytes, and later thrombocytes. The expressed anemia is observed only in the greatest total doses of intensive irradiation, and its occurrence is an unfavorable prognostic signs.

Conditionally, three degrees of disease are distinguished: light, moderate and severe chronic radiation sickness. The criteria of severity of chronic radiation sickness are presented in table 13.

The light form of CRS begins usually completely imperceptibly for the patient. Frequently the disease is found only during periodic medical survey. The first symptoms of the light degree of CRS are shown in constant weakness, fatigability, flabbiness, headache, deterioration of appetite, drowsiness. For the first time, the specified symptoms show themselves only by the end of the week, after one day of rest the state of health improves. Subsequently, an increase of symptoms is observed and for the recovery the longer rest is needed. The above-mentioned symptoms can be observed during other diseases. The structure of the blood also changes in radiation sickness. An increase in the amount of leukocytes is found in the blood in the first degree of CRS, and then their number decreases up to 2–4 thousand in 1 mm^3. The amount of erythrocytes decreases not so considerably (to 3,500,000 in 1 mm^3), and the contents of thrombocytes remains normal.

Thus, the distinction of the light form of CRS is that it is far from damaging all the organs with ionizing radiation, and the main thing — they have not lost an ability to compensate the harmful action of irradiation. Elimination of irradiation promotes the termination of the development of the illness and full recovery.

A wavy course is typical for the moderate degree of CRS. There is an alternation of improvement and deterioration of the condition of the patient. Work capacity is acutely reduced. Painful headaches do not give in to medicamentous treatment. Patients extremely badly endure loud music, light, even usual informal conversation. They become irritable and substantially lose their memory. AP is decreased, normal digestion is not working. Gastritis, accompanying with the absence of appetite, develops, frequent vomiting. Progressing anemia is observed in patients. The ability of blood coagulation decreases. There is a further deterioration in the blood structure. The amount of leukocytes in 1 mm^3 is less than 2 thousand, and is sometimes reduced to 900. The amount of erythrocytes is at the border of normal, and thrombocytes are less than normal.

The timely detected CRS of the second degree under the influence of medical measures can be suspended, but full recovery of health of the patient occurs slowly and not in all cases.

People, suffering from chronic radiation sickness of the severe degree, are seriously ill patients requiring bed rest. Attributes of damage of the human body are the same as in the second degree of the disease, but they become much more expressed. The disease process, as a rule, is irreversible. Acute changes in the blood are observed. The amount of leukocytes decreases to hundreds and even tens in 1 mm^3, erythrocytes — to 1.5–3 million in 1 mm^3, and thrombocytes — to several thousand. Death comes with catastrophic de-

Table 13. **Criteria of severity of**

Degree of severity	Nervous system			Changes in the	
	Organic changes	Functional changes		Red blood	Thrombocytes
		CNS	VNS		
Light	None	Asthenia	Vegetodystonia	No change	Border line
Moderate	None	Expressed asthenia	Vegetodystonia	Moderate anemia, hypochromic erythrocytosis to $(2\text{–}3.5)\cdot10^{13}$/l	Decrease to $10\cdot10^{9}$/l
Severe	Encephalomyelitis, polyradiculoneuritis	Deep asthenia	Severe vegetative disturbances	Erythrocytosis less than $2\cdot10^{12}$/l	$(20\text{–}50)\cdot10^{9}$/l

struction of the haematogenic organs, as well as a result of sepsis caused by a loss of immunity.

The second variant of chronic radiation sickness (caused mainly by local irradiation) has different degrees of severity of damage, which are determined by the parameters of the period of expressed clinical displays.

Chronic radiation sickness of the light (I) degree (the second variant) is characterized by damage of the functional activities, which are found during clinical-laboratory research with the application of certain loadings.

Chronic radiation sickness of the moderate (II) degree (the second variant) is characterized by a distinct clinical syndrome of damage of this or that critical organ with satisfactory functional compensation or light insufficiency of its activity.

Chronic radiation sickness of the severe (III) degree (the second variant) is accompanied by rough and progressing changes in the structure of the basic critical organs or ones that underwent the greatest irradiation. Along with the insufficiency of the function of the damaged organ in severe cases there is a complex of secondary changes in other organs and systems.

chronic radiation sickness

blood system			Changes in the internal organs	Infectional complications
Leucocytes	Bone marrow	Bleeding		
$3.4 \cdot 10^9$/l compared to lymphocytosis and granulopenia	Non-sharp inhibition of the maturity of myeloid cells	None	Passing hypotonia, damage to the function of the stomach, endocrine glands	None
Lymphocytosis 40–50% $(1.5–2) \cdot 10^9$/l	Depression in the growth of haemopoiesis	Expressed	Hypotonia, trophic damages, dystrophy of the myocardium, damage to the mucous membrane, oppression to the endocrine glands function, GIT	Possible
Less than $1 \cdot 10^9$/l, agranulocytosis	Devastation (meylokaryocytes less than $1 \cdot 10^9$/l	Acutely expressed	Hypotonia, deep trophic metabolism disturbances	Multiple

Chapter 6
GENETIC AND EMBRIOTOXIC EFFECTS OF IONIZING RADIATION. REACTION OF THE GROWING ORGANISM ON IONIZING RADIATION INFLUENCE

6.1. GENETIC EFFICIENCY OF VARIOUS TYPES OF IONIZING RADIATION

Genetic effects of radiation can be conditionally divided into three groups: hereditary disorders, physiological inferiority and an increasing in cancerogenic risk.

1. Hereditary effects are serious disorders in the development of the posterity of the irradiated parents (embryonic death, congenital defects, decrease in fertility), in the basis of which are "significant" mutations: chromosomal, genomic, important structural genes.

2. Physiological inferiority of the posterity (decreasing stability to unfavorable influences, functional shifts, predisposition to so-called multi-factorial diseases, destabilization of the genetic apparatus, etc.)

3. Increase in the posterity of irradiated parents of the risk of cancerogenesis of both spontaneous and under the influence of promoters.

The cause of the two last types of effects is a set of so-called "small" recessive mutations of the viability polygenes as well as the regulative character of the DNA disorders arising in the sex cells of parents. Because of the absence of natural selections, the importance of these consequences of ionizing irradiation effects in the human population may appear to be large, which is necessary to take into account when predicting the genetic effects of radiation.

The dose-effect dependence for all types of genetic effects has no threshold because the mechanism of genetic changes is molecular. However, the biological processes put between the molecular changes and somatic appearance of genetic changes. The molecular changes that arise in nonviable embryonic cells or zygotes before their implantation prevent the development of living individuals.

The mutational rate, i.e. probability of occurrence of the dominant fetal in the sexual cell per dose unit with irradiation of the spermatozoid was the highest under the influence of fast neutrons but under the influence of irradiation protons gamma- and X-rays — 5–10 times lower. Spermatids were found genetically more radiosensitive, than spermatozoids during all types of irradiation. The most vulnerable stage of germinal cycle is the spermatogone stage, moreover the genetic disorders, which appeared in these cells, are kept during all the reproductive periods.

6.2. EMBRIOTOXIC EFFECTS

During intrauterine irradiation, nonstochastic (deterministic) consequences (mental retardation, microcephalia, etc.) and stochastical (probable) effects (cancerogenesis) are observed.

Three phases of embryogenesis, distinguished by their reaction to the same dose of irradiation, are known.

1. Irradiation during the preimplantation period leads to high intra-uterine death but does not cause deviations in the surviving posterity.

2. Irradiation during the basic organogenesis brings about high frequency of abnormalities at birth but significantly less intrauterine death.

3. Irradiation in the fetal period, when growth and weak organogenesis are going on, does not cause intrauterine death or abnormalities at birth.

The main mechanisms of anomalies of development can be mutations, chromosomal aberrations in the fetus cells, mitotic block, lack of normal predecessors of nucleinic acids, energetical starvation, osmotic disbalance, fermental system block, changes in the cell membrane, etc.

The greatest risk in the development of mental retardation is observed during irradiation on the 8th–15th week after conception. Within the limits of this critical period the frequency of cases of developing mental retardation depends upon the dose of irradiation. Radiation-induced intellect disorders were not revealed in the radiated *in utero* within the first 8 weeks of pregnancy.

Attacks are frequent consequences of the development of brain disorders. The frequency of attacks were the greatest during irradiation on the 8th–15th week by doses more than 0.1 Gy and had linear dependency on the fetus dose of irradiation.

The spreading of schizophrenia is significantly higher in the irradiated *in utero* Nagasaki inhabitants than in the whole population. Schizophrenia was significantly frequent in people affected in uterus by the nucleus bomb explosion in the middle pregnancy stage, than in the late stage.

The problem of intrauterine brain disorders was recognized by the WHO as one of the priority in structure of the medical consequence of the Chernobyl accident. The results of investigations in three countries (Ukraine, Belarus, Russian Federation) 2,189 *in utero* irradiated children and their mothers in comparison with 2,021children and mothers from the radio-ecological "clean" areas indicated: the frequency of occurrence of intellectual retardation of the light degree is higher in children irradiated *in utero* than in the control group; the frequency of psychological disorders in parents of the children irradiated *in utero* is higher than in the control.

It is established that disorders of the neuro-psychological health of children, who underwent acute prenatal exposure in doses of 10.7–92.5 mSv per fetus and 0.2–2.0 Gy per thyroid gland are etiologically heterogeneous but the deposit of Chernobyl accident factors is determinate — 55% (29% — intrauterine irradiation, 26% — non-irradiation stress-factors of the mother).

Irradiation of the central organs of immunogenesis of the fetus resulted in disorders of the immune homeostasis in the postnatal period. The changes of the immunological indices had one-directed character and manifested itself primarily by oppression of cellular link of immunity, disbalance of immunoregulation of subpopulation and disimmunoglobulinemia in early time.

Children at the age of 1–3 (1982–1989) affected by acute *in utero* irradiation in doses of 10.0–376.0 mSv and children, affected by irradiation not only *in utero* but after birth as well (in doses 4.7–38.7 mSv) had lower, in comparison with the control, levels of haemoglobin, leukocytes and thrombocytes; changes in the leucogramm were registered more frequently.

Cytogenetic researches indicate that in the late post-accident period the children with an equivalent dose of irradiation of the red bone marrow from 10.0 to 376.0 mSv, which was received *in utero*, the quantity of aberration cells (11.44 ± 1.01%) and the average frequency of chromosome aberrations (12.19 ± 1.25%) are higher than in the control groups ($P<0.05$). The most part of chromosome damage is represented by aberrations of the chromosome type (10.08 ± 1.54%). Thus, stable structure abnormalities (translocation, inversions, deletions, and dicentrics without accentrical fragments) formed 9.36 ± 1.42%, which is higher than in the control.

The children at the age of 3.5–5, irradiated *in utero* following the Chernobyl accident have psychomotor development retardation and speech developing retardation by 0.5–1.5 years of age, a change in the maturing of the bioelectric activity of the brain, a decrease in the threshold of convulsive readiness, retardation of the myelinization process.

The most dangerous consequence of the Chernobyl NPP accident is the ^{131}I entering to the fetus through the placenta. The absorbed doses in the thyroid gland of the fetus are 2–3 times higher than in the mother. Radiation-induced disorder of the thyroid gland is an initial chain of the involving in pathological process of other endocrine glands through the system of the thyroid gland — hypophysis — hypothalamus. The disorder of the endocrine status can appear as a disorder of the mental and physical development of children irradiated *in utero*, especially children with a dose expose of the gland of 1 Gy and more.

6.3. THE REACTION OF THE GROWING ORGANISM TO IONIZING RADIATION ACTION

While comparing the picture of the radiation reaction in children, appearing in radiotherapy, with the picture of the common radiation reaction in adults, a number of features are noted:

1. The clinical picture of the common radiation reaction in children appears less vivid. The children of a more early age do not have such signals as fever, vomiting, olfactory hallucinations, polydipsia, itching, etc.

2. The period of pronounced radiation symptoms in children starts earlier than in adults.

3. Lability of the vessels reaction, especially on the facial skin is observed.

4. A pronounced decrease in appetite, absolute refusal of food, selectivity to some types of food.

5. The body mass does not increase or decrease.

The children of advanced ages (especially at the age of 13–15) have a clinical course richer with symptoms than preschool age children have, and it approximates in character to the adults' clinical course.

The observations of children who underwent radiotherapy in early childhood indicate that a subdivided irradiation of the healthy bones which were in the irradiation zone leads to significant disorders of growth and development in these bones.

The sensitivity of some organs in a fetus and a child to the induction of tumors is not always higher than in adults and it turns out for some organs that after exposure in childhood benign tumors form but after exposure in adult age — malignant tumors (Publication 14 of ICRP).

When a growing organism is exposed, changes in the nervous, muscular, skeletal systems, endocrine and other systems and organs in late times are more expressed and arise in lower doses than in adults, which are already developed.

As a result of local irradiation of bones that are near the exposure zone, including the skull, retardation or growth stoppage of the long bones is revealed after roentgen or radiotherapy concerning bone hematomas in early childhood. Retardation of the development of the antirum on the side of the face which was exposed is described. Some cases of the underdevelopment and atrophy of the mammary glands which were in the exposed zone, are known. Atrophy of the alveoli part of the jaw and the underdeveloped of the tooth are established. Changes of the skin (atrophy, pigmentation disorders, telangioectasis) are described.

The analysis of comparative radiation sensitivity of different departments of the brain with close dose level indicates the preferential influence of ionizing radiation on the subcortical structures and trunkus cerebri, in particular, on the hypothalamus-hypophysis structures. After exposure of the diencephalon and hypophysis in doses of 0.2–0.4 Gy (20–40 rad) functional disorders of the vegetative nervous system, especially hypothalamic centers were found in more than half the cases. While increasing the absorbed dose to 0.54–1.3 Gy (54–130 rad) distinct vegeto-vascular disorders with vegetative and vegeto-visceral paroxysms, neuroendocrinal disorders and a decreasing of the cortex neuro-dynamics were observed in almost all of the children. The connection between the frequency of memory disorders, attention, speed of mental activity, emotional sphere, cerbrastenical, and clinical displays from the dose of radiation in the hypothalamo-hypophysis department is establiched.

6.4. THE STATE OF HEALTH OF CHILDREN LIVING AT THE RADIOACTIVE CONTAMINATED TERRITORIES AFTER THE CHERNOBYL NPP ACCIDENT

The morbidity of cancer of the thyroid gland has increased significantly after the Chernobyl accident in Ukraine, since 1990 in children up to the age of 15 in comparison with the 1981–1985 periods: 2.2 times — in 1986–1990, 7.7 times — in 1991–1995, more than 10 times — in 1996. The morbidity growth in adolescents is registered later than in children, and by degree of clinical displays concedes to the children's contingent.

The common quantity of cancer of the thyroid gland in children in Ukraine by 1999, according to the National register reached 1,109 in the contaminated territories, the morbidity exceeded the average state indices 6 times. The dependence of distribution of the affected from on average and collective dose exposure of the thyroid gland is observed. Additional growth is observed in all the dose ranges but it was more seen in doses more than 1 Gy. As a population group of the irradiated children grows, a further increasing in the frequency of cancer of the thyroid gland among adolescents and adults is expected.

The threshold dose of irradiation for the thyroid gland for non-tumorous diseases (chronic thyroiditis, hypothyroid) is 0.3 Gy. A significant dependence dose-effect was seen in irradiation doses of the thyroid gland more than 0.3 Gy.

The dynamic of the intensified study of the state of the immune system in children living in radionuclide contaminated territories, established that the development of the spreading secondary immunodeficiency state and autoimmune pathology of this contingent takes its start from intrauterine activation of separate chains of immunity of the fetus with further exhaustion with disorders of the endocrine regulation of the immune homeostasis, first of all, due to changes in the hypophysis-thyroid system.

Chapter 7
LATE EFFECTS OF IRRADIATION

The late consequences arise in people in 10–20 years and even more after irradiation influence. The remote consequences are the following: reduction of life expectancy, occurrence of additional cases of leukosis, malignant tumors and cataracts of the lens (in comparison with the average level), nephrosclerosis as well as the balance disorder in the function of the endocrine glands, decrease in fertility, sterility, disorder of embryonic development.

During the clinical well-being, continuing sometimes years and decades, the discord between the normal picture of peripheral blood and anomalies in the condition of bone marrow haemopoiesis, between the clinical picture of normal skeleton and constant processes of reorganization, neoplasm and proliferation in bone tissue, etc. takes place. The latent course of the processes promoting the development of remote effects against a background of clinical health is caused by the perfection of compensatory reactions. The depletion of compensatory reserves ends in the realization of this or that type of remote consequences. All remote effects develop against a background of distinct vascular disorders, first of all — against a background of rather essential reduction of general area of vascular channel by 25–50% due to the empting of capillaries, fine veins and arteriole, disorder of vascular regulation, damage of walls of capillaries, a thickening of the basal membranes, narrowing of the pericappilary cavities, increase in the amount of connecting fibres in them, fine veins (phlebitises, thromboses, phlebothrombosis) and arteriole (plasmatic permeating, sclerosis of the walls, etc.).

According to N. G. Darenskaya, a person's life expectancy is reduced by 1–15 days under a single irradiation, and under chronic action — 0.01 days for every 0.01 Gy of absorbed ionizing doze.

Early radiation senescence is characterized by certain properties:

1. Heterochronous — the distinction in time of the appearing of visual displays of senescence of various tissues, organs and systems.

2. Heterotopic — the unequal expressiveness of the senescence process in various organs and structures of one and those organisms.

3. Heterokinetic — various speed of development of senescence changes.

4. Heterovector — various directions of senescence changes, connected with the activation of one and suppression of other vital processes in an senescent organism.

Radiation senescence on the tissue level is explained by the damage of endothelial cells of fine blood vessels which, in turn, results in fibrosis of the arterioles and interstitial collagenic substances. Further, due to the loss of parenchymatous cells they are replaced with fibrous with the loss of functional ability and with an increase in the propensity to trauma, stress and illnesses.

A reduction of the life expectancy under radiation senescence is not necessarily connected with an increase in the cases of death from any specific reasons, but is caused by untimeliness of all frustrations, observable with natural senescence of the non-irradiated population.

The accelerated radiation senescence is caused not so much by the accumulation of "mistakes" in the code of DNA molecules, as by the accumulation of the products of metabolism (as a result of the action of ionizing radiation), the forming of inactive complexes with nucleinic acids and fibers which break the normal function of a cell, etc. So-called radiotoxins — low-molecular biologically active substances formed as a result of the influence of ionizing radiation play a certain role in the pathogenesis of early radiological senescence. They are strong oxidizers and cause peroxide oxidation of lipids (POL).

The energetic processes in a cell change in accelerated radiation senescence: activity of respiratory enzymes is reduced, the amount of mitochondria (generators of energy) decreases, the function of the cellular membranes is broken. The fatty acids ability to oxidize is reduced in some organs, the ratio between oxidizing phosphorylation and glycolysis changes. Basic metabolism is decreased. Regulation of the functions of organs and systems considerably changes. Thus, there are not only quantitative, but also qualitative shifts of activity of various organs and systems.

Clinically all these signs are displayed as the deterioration of mobility of the nervous processes and memory, atrophy and sclerotic processes in the endocrinal, respiratory system (frequency of breath increases, vital capacity decrease, respiratory arrhythmias arise). The functions of the articulation-skeletal and muscular apparatus, the gastrointestinal tract and the excretory system are disturbed.

Active free radicals play an important role in the development of accelerated senescence. They belong to compounds, which possess a short period of existence and big reactivity, caused by the existence of unpaired electrons. Nonenzyme free radical oxidation essentially affects on the metabolism of lipids along with enzyme oxidation, providing energetic and plastic requirements in living organisms. It leads to lipid peroxidation, characterizing original biochemical syndrome, which is realized in an organism by a number of alterations and, first of all, alteration of cellular, subcellular and nuclear membranes, mitosis, enzyme systems and accumulation of polymers. Therefore alterations in an organism, connected with free radical oxidation, acquire the leading significance in such condition.

The toxic influence of products of free radical oxidation is shown by a series of biochemical shifts, first of all such as the inactivation of the sulfhydric proteins, alteration of their modular condition, activization of the lipases, alteration of fat dispersion in the cell protoplasm, separation and suppression of oxidative phosphorylation. The consequences of the specified processes are pathological changes, and in some cases, total alteration of cell substances — mitochondria, activation of autolytic processes and chromosomal aberrations. Thus, there is a nonspecific alteration of the microstructure and functioning of plasmatic and subcellular membranes due to the processes of metabolism and cell reproduction changes.

A prevalence of dystrophic phenomena and processes determinant over regenerative phenomena and processes take place on the level of the complete organism as a result of the integration of various deviations from norm.

Dystrophic processes and the changes accompanying senescence are closely connected with diseases of the cardiovascular system, for the first instance with atherosclerosis.

Atherosclerosis is the most widespread chronic disease of the elastic and musculo-elastic type of arteries, with the formation of single and multiple centers of lipid, mainly, cholesteric deposition — atheromatous patches — in the internal tunica of the arteries.

It is known, that atherosclerotic processes are accelerated in irradiated people. The stages of atherosclerosis formation replace each other faster.

The first stage — neurometabolic — manifests itself in the common or cardiovascular neurosis, changes in lipid metabolism (increase of cholesterol and beta-lipoproteins); decrease of the production of glucocorticoids by the adrenal glands, some increase in the activity of aldosterone; the effects of hormones on the functional condition of the liver, resulting in changes in the coagulation and anticoagulation systems of the blood and in changes in the mucopolysaccharide walls of vessels with an increase in their permeability. The pathological process is reversible at this stage; therefore treatment-and-prophylactic measures are most effective.

The second stage is organic, when apart from cholesterol deposition on the vascular walls, fibrous tissue develops in it. The stage proceeds with obscure and vivid clinical displays.

The third stage is the stage of outcome. It is characterized by residual irreversible changes in some organs (brain, heart, etc.).

Non-tumoral forms of the late effects are represented by three groups of pathological processes, which can be characterized as follows:

1. Aplastic and hypoplastic conditions of parenchymatous structures of various organs.
2. Sclerotic processes.
3. Dishormonal disorder.

Hypoplastic conditions as one of the non-tumoral forms of the late effects arise as a rule in haemopoietic tissues, mucous membrane of the gastrointestinal tract, genital organs, etc. This group of reactions arises under high enough doses.

The hypoplastic condition of haemopoiesis under the conditions of chronic radiation can be formatted by people due to dose accumulation of about 150–400 sGy (total influence). Hyperchromic anemia in combination with leukopenic syndrome of this or that degree of severity with bad regeneration was found for 7–9 years after the explosions in Hiroshima and Nagasaki in 12.5–34% of the people irradiated in a 50–500 sGy diapason.

Aplastic and hypoplastic changes of the functional structures of the genital glands result in partial or total sterility of the irradiated individuals.

The second big group of non-tumoral forms of the late effects is defined by the term “sclerotic processes”, which develop as a result of the direct influence of radiation on parenchymatous cells, vessels and connective tissue structures of corresponding organs. The direct dependence of the process upon the dose, the presence of threshold levels of radiating influence, fast and early damage to the vascular net of corresponding organs, the development of more or less extensive focal or diffusive growths of connective tissue on the place of lost parenchymatous cells, polymorphism and atypism of the regenerative processes with the presence of essential quantity of polyploid cells are characteristic for these effects.

Sclerotic processes are represented by such pathological processes as nephrosclerosis, cirrhosis of the liver, pneumosclerosis, chronic radiation dermatitis, lesion of the nervous system, radiation cataracts, etc.

Nephrosclerosis. An irradiated person's kidneys are characterised by atrophy of the epithelium of the renal tubules, spreading and hyaline degeneration of the interstitial connective tissue, enlargement of the basal membranes, substituting fibrosis, necrobiosis, swelling and proliferation of endothelial cells, swelling of the intimae and walls of vessels, which leads to the narrowing of its opening, degeneration, necrosis, atrophy and sclerosis.

The changes in vessels are supposed to play an important role in the loss of renal function and the development of nephrosclerosis which is induced by irradiation. The damage to epithelium by progressive sclerosis and substitution of renal epithelium with fibrosis tissue may also in high doses cause renal sclerosis. Death from radiation nephrosis is caused by uremia. The developing signs of secondary hyperaldosteronism are characterized by hypokaliemia and metabolic alkalosis, untill metabolic acidosis develops as a result of renal insufficiency.

The degree of severity of radiation damage of the kidneys depends upon the volume of affected renal tissue. Clinical experience shows that preventing the development of chronic renal infection after irradiation is necessary to protect 1/3 of the renal tissue volume from irradiation.

Cirrhosis of the liver develops from local irradiation of this organ with a dose of 30–59 Gy and is characterized by damage to the vessel system of the liver.

Pneumosclerosis arises approximately in 10% of the patients who underwent fractional irradiation of the chest because of different diseases. Sclerotic processes progress slowly. The damage of small arteries plays an important role in the genesis of sclerotic changes of the lungs.

Chronic radiation dermatitis. One of the original sclerotic forms of the late effects is damage to the skin, such as chronic dermatitis, keratoderma, nest alopecia, etc. These damages were found in 4–12 years in people, who underwent the action of the radiation factor (5–13 Gy) at the Hiroshima and Nagasaki nuclear explosion, as well as approximately in 13% of children who were affected by roentgen irradiation regarding angiomas.

Damage to the nervous system. One of the sclerotic forms of the late effects of ionizing radiation action is the original change of the central nervous system, developing in the chronic phase of radiation damages. Complex changes of the encephali tunica, vascular systems and parenchymatous cells arise during fractional irradiation. The changes in the pia mater encephali and brain vessels are characterized by growth and fibrosis of collagen fibers. Eventually, the intensity of glial reactions progresses and ends with the formation of glial prolifics, being the initial points of tumors growth. Late changes in the nervous system develop in the diencephalon and medulla oblongata.

Radiotherapeutic brain irradiation can lead to pronounced focal neurological symptoms. The slow development of process with the appearance of the first pathological signs (no earlier than 5–6 months after irradiation), irreversible changes, progressing, which leads to severe defects after 1–10 years, are characteristic for such complications. Pathological damage is usually revealed in both vascular and nervous structures at morphological examination. Necrosis appears mainly in the white substance of the brain, which is apparently connected with the features of the architectonic vessels in these zones (prolonged capillaries and weak development of capillaries). The death of nervous cells, demyelination of the conductors, and glial reactions are registered in the necrosis zone.

Radiation cataract. Radiation cataracts can be a sclerotic form of the late effects only conditionally, because damage to the vessels of the lens by cataracts is not observed. True sclerotic processes are absent for the same reasons. However, the damages which are characteristic for all sclerotic forms of damages are present in this pathology, namely the damage to capsule cells with damage to the natural cycle of its differentiation and death of those cells. The cataract is induced by all types of ionizing irradiation; neutrons have maximal efficiency. Cataract occurs as a result of direct radiation action. There is a linear dependence of the dose-effect curve, which is so characteristic that the cataractogenical effect of radiation is proposed as a biological dosimeter quality.

The absence of the direct dependence of the dose-effect, the low level of threshold doses (units and tens of sGy), domination of non-direct mechanisms in this genesis are characteristic for late endocrine radiation pathology. The initial mechanism for polyglandular endocrinal shifts is the initial radiation depression and damage of the function and structure of the sex glands, thyroid gland, and suprarenal glands. Obesity is a form of dishormonal non-tumorous late effects. The development of hypophysial cachexy and non-saccharin diabetes is considerably rarer than obesity.

Aldosteronism is one form of late radiation pathology, because it is possible to predetermine by morphological tests and indirect physiological indices.

Epidemiological experimentations introduced an important contribution to understanding the role of the radiation factor in the genesis of tumors. Since 1945, the basic material in the rise of leucosis and other tumors was administered by the observation of the survivors of the bomb explosion in Hiroshima and Nagasaki. The disease and mortality rate from ionizing irradiation among the survivors quickly increased and reached in 1950 sizes 30 times as much than the corresponding indicators for the non-irradiated control population. There is a direct dependence between the years of leucosis sickness rate and the radiation dose.

The precise dose dependence of radiation-induced leucosis, which developed as a result of the radiation action, the occurrence of leucosis in relatively low doses allow to consider all those acute leucosis and chronic myeloleukemia, which develop in people with high dose irradiation in anamnesis to be radiation-induced.

It is necessary to consider leucosis as indicative groups of the diseases for progressing dynamics of others tumors, because they represent one of the earliest realized radiation-induced tumors.

An increase in the amount of deaths among the first patients, who were treated with radiation therapy concerning malignant tumors, was observed, moreover the different localizations of tumors within the irradiation field were observed in many patients. Tumors of the rectum, vulva, bladder, and corpus uteri developed after radiation therapy of cervix cancer. After irradiation of the mediastinum lung cancer appears. The middle latent period made up 28.2 years.

Meningiomas and neurimyelomas develop most often after radiation therapy of the head and neck. The frequency of intracranial meningioma increases 3.5 times after irradiation of the head with roentgen radiation before 20 years of age. Doses do not exceed 8 Gy (calculated brain dose is 1.4 Gy)

25–40 year-old women, living in Los Angeles, saw often a stomatologist and did mandible X-ray films by medical indications. They had an increased frequency of meningiomas and tumors of the parathyroid glands in comparison with men.

A significant amount of malignant brain tumors were revealed in children that were irradiated because of ringworms.

There are a number of messages on the possibility of development of leucosis in late terms after roentgentherapy for cancer of the mammary glands. All patients died within 3.5 years after treatment.

There are also data on the possibility of leucosis development among patients affected by roentgentherapy for ankylosing spondylitis. The frequency of disease was 10 times higher than in the control groups of non-irradiated patients and healthy people. The frequency of disease increased in proportion to the common dose of spine irradiation. Leucosis in this group of patients developed 3–5 years after roentgentherapy. The frequency of disease increased with age.

7.1. LATE RADIATION EFFECTS IN CHERNOBYL NPP ACCIDENT CONSEQUENCES CLEANING UP PARTICIPANTS. CONSEQUENCES OF THE CHERNOBYL CATASTROPHE FOR THE POPULATION

Practically all acute radiation disease reconvalescents had quality changes in the blood elements and bone marrow, hyperplasia with fibrosis at the recovery period, but the frequency of changes registered gradually decreased with time and were not more than 23% cases. During the past period three fatal cases in different clinical variants occurred: 1) anemia with ring-like sideroblasts; 2) refractory anemia with excess blasts; 3) anemia gravis. The immunological reactivity changes after the bone marrow syndrome were connected with the cellular circle, control loss on the proliferation processes, increase in the quantity of somatic mutations, and the features of genetically determined sensitivity to ionizing radiation action.

The studying of chromosomal aberrations in lymphocytes in the peripheral blood showed that after acute radiation sickness (1st degree) the frequency of dicentral and ring-like chromosomes had a tendency for decreasing, and after ARS of the 2–3 degree — remained on the last level. Stable chromosomal aberrations were registered in 100% of the cases. The absolute and relative frequency of abnormal monocentrics increased too. Abnormal monocentrics were formatted due to symmetrical translocation and inversion. The keeping of the increased level of radiation-induced damage to the chromosomal apparatus for a long time testifies to instability of the somatic cell genomes.

Approximately 1/3 of the people that had ARS suffer from late radiation induced skin lesions of different stages of severity — from light clinical forms of chronic radiation dermatitis to severe ones with late trophic ulcers.

The quantity of radiation-induced postero-capsular cataracts is directly connected with the degree of severity of ARS. Other types of cataracts (nuclear, coronary, lamellar, presenile, and senile) do not depend upon the severity of ARS. Twelve years after the catastrophe the radiation-induced cataracts in 82% cases appeared in people with ARS of the 3rd degree, in 30% — with ARS of the 2nd degree and 5% — with the ARS of the 1st degree. Vascular pathology of the fundus of the eye and maculodystrophy had the second place after changes of the lens.

Significant increasing of leukemia (28 real instead of 8 predicted) in the liquidators as well as acute myeloid leukemia reactions were marked. In 1991–1998 a high frequency of myelodysplastic syndrome was revealed among people affected due to the disaster at the Chernobyl NPP. Clinical-hematological characteristics of 71 patients irradiated with 0.1–3 Gy were done, the development of myelodysplastic syndrome cytopenia lead to infectious processes in 27 cases. Cytogenetic violations took places in 50% of cases, and 1/3 of the patients had cytopenia of the bone marrow with fibrosis. 42% of leukopenia patients had chromosomal anomalies, a quantity of which increased during transformation into myelodysplastic syndrome.

The malignant neoplasms incidence among the accident participants in all, according to 1990–1998 data, has constantly increased and since 1995 it has exceeded the analogical indices for the corresponding age groups of the Ukrainian population. So, the malignant neoplasms incidence incidence among liquidators composed 650.0 per 100,000 in 1998, and 540 per 100,000 in corresponding age groups of the Ukrainian population. The breast cancer in the women-liquidators (1990–1998) and among the population living on radionuclide polluted territories (1993–1997) increased 1.5 times. It is known, that radiogenic solid tumors can arise 30–50 years after irradiation, which is why it seems necessary a further monitoring of the malignant neoplasms incidence among the liquidators, evacuated and the population living on radionuclide polluted territories for timely revealing the possible stochastic irradiation-induced effects.

The thyroid gland cancer incidence is 4–5 times higher in the accident participants of 1986–1987 years than in a corresponding population group that is evidence of irradiation dependence.

The most expressed increase of chronic thyroiditis took place among the participants of liquidation of the crash consequences and among the ones evacuated from the estrangement zone. The chronic thyroiditis incidence was within the limits of 25.7–35.6 cases per 10 thousand among the Chernobyl NPP accident consequences cleaning up participants during the years 1992–1995, and it was within the limits of 13.6–24.2 cases per 10 thousand among the evacuees. By 1999 the chronic thyroiditis and hypothyroidism incidence among survivors composed 33.9 cases per 10,000, including 103.0 cases per 10,000 — among the participants, 78.5 cases per 10,000 — among evacuees, 23.3 cases per 10,000 — among the contaminated territories inhabitants. Unfavorable prognosis for subsequent years is apparent on the basis of the thyroidisometrical department of the SCRM (Science Centre of Radiation Medicine).

A combined irradiation-induced acquired immunodeficiency with the oppression of the function of T- and B- immunity sections was revealed in participants of crash liquidation in a post-accident period. Gradual development of compensation of the irradiation induced affection prolonged for 3–5 years. A stable immunological insufficiency was registered in 36.3% of the liquidators in a late period.

Progressing deterioration of the health condition was registered in all the groups of the primary calculation of the Chernobyl accident victims. They had, as compared to unexposed individuals, an increased frequency of the acute disease forms conversion into chronic and relapsing ones, the disease course prolongation, and the inclination of diseases to complications and disability. The high frequency of a few diseases combination takes place. A number of healthy Chernobyl NPP accident consequences cleaning up participants in 1986–1987 decreased 9 times within 10 years. The least number of healthy people is registered among participants who received an external irradiation dose of 250 mSv and more. The same health dinamics was detected in children who were born from participants and among children evacuated from Prypat and a 30 km zone.

The participants of 1986–1997 established the dependence of a dose concerning the development of diseases of the thyroid gland, vegetovascular distonia, essential hypertension, cardiac diseases, cerebrovascular disorders, diseases of the digestive organs and the urogenital system, neoplasms, mental disorders.

The results of many years' investigations confirmed essential excess of spontaneous disease rate and spreading of hypertension and ischemic diseases among all categories of victims. They are characterized by a decreasing in physical capacity for work, negative variants of adaptations to physical loading. Heart falure and cardiovascular complications became a serious problem in the late phase. Spontaneous manifestations of risk factors for blood circulation diseases and its realization in younger age were established in victims.

Cardio-vascular system diseases in the Chernobyl accident survivors are the most wide-spread and mostly determine their health condition. The most serious ones concerning the working ability and life are hypertension and ischemic disease of the heart, which make up more than 80% from all the cardiovascular system diseases, the latter make up 55–60% of all death causes.

Endoscopic investigations of the tracheobronchial tubes in the Chernobyl NPP accident consequences cleaning up participants in 1986–1987 showed progressive atrophic and sclerotic changes in the mucous membrane of the bronchial tubes. The results obtained from the study of the local immunity and microflora testify to the activation of automicroflora and of the appearance of pathogenic and opportunistic microorganisms that is caused by the deterioration of specific and nonspecific immune defense of the participants.

Morphological investigations of bronchobioptates of the mucous membrane of the bronchial tubes, obtained during bronchoscopia of 526 accident consequences cleaning up participants in 1986–1987 revealed inflammation, atrophic, sclerotic and metaplastic processes with appearances of cellular atypia in the mucous membrane of the bronchial tubes. Consequently, there is a risk of realization not only of non-stochastic, but also stochastic effects observed within 12–25 years. At the same time, the development of complications of chronic obstructive lung diseases in the liquidators of the Chernobyl accident leads to a decrease in life quality, loss of working ability of different degrees and finally, shortening of life expectancy.

The nervous-psychological infringements of people affected by the Chernobyl accident are etiologically heterogeneous. The basic pathogenic factor is a combined effect of ionizing irradiation and psychological stress, caused by the accident and its consequences which are aggravated by the social-economical crisis in society. These factors exponentiate each other and help to worsen significantly the neuropsychological and psychosomatical health of the affected people.

The asthenic symptomatic and vegetation dysfunction 5–6 years after irradiation is replaced with an organic pathology of the brain (psychoorganic syndrome, personality disorders, and post-irradiation encephalopathy.

The quantity of the nervous system diseases is twice as much in participants of 1986–1987 than in participants of 1988–1990, and mental disorders — 5 times. The nervous-psychological disorders incidence is higher in participants irradiated in doses more than 0.25 Gy than in doses less than 0.25 Gy.

Near 3 million persons (not counting Kyiv) were affected due to the Chernobyl accident in Ukraine. Among them 5,237 people lost their working ability, 187 people caught acute radiation disease, 30,000 people had diseases which are connected with the Chernobyl accident consequences.

155,000 people who took part in the cleaning up of the disaster needed the most medical attention and 130,000 were evacuated and relocated. The liquidators of 1986–1987 with an irradiation dose of near 250 mSv and more belong to this group.

The children, pregnants, lactating women and old people are the most radiosensitive part of the population. More than 100,000 children living in Ukraine were affected by the Chernobyl accident.

The results of the medical examinations of all population categories affected by the Chernobyl accident testify to the quantity of healthly people decreased from 64 to 32% among adults and from 53 to 30% among children after 1986.

An increase in spontaneous abortions, bleeding and other pregnancy complications in women are under consideration.

A decrease in the indices of cellular and humoral immunity among the population, an increase in cytogenetic effects with an increase in the specific markers of radiation influence was established.

The malignant diseases incidence in the people evacuated during 1990–1998 does not differentiate essentially from the average morbidity in Ukraine and it was 256.3 per 100,000 people in 1991. But, the malignant neoplasms incidence is higher than in Ukraine in both males and females evacuated at the age group of 10–24 years.

The breast cancer incidence in the evacuated is at the indices which are characterized for the Ukrainian population. The breast cancer incidence increased 1.5 times in the population living on radiation contaminated territories during the period of 1993–1997.

The level of malignant neoplasms incidence increases constantly among the residents of radiation contaminated territories. The thyroid gland cancer incidence increased 2.5 times among the residents living in radionuclide contaminated territories in 1990–1998.

The health condition worsened in all groups of primary affected people. In comparison with the control population, the frequency of acute forms of diseases converting into relapsing and chronic ones increased; the duration, complicated course, synchronization and invalidization increased. A high frequency in combined diseases was noted. Diseases of the nervous system and sensory organs, circulatory system, respiratory organs, digestive organs, musculoskeletal system, endocrine system, and urogenital system affected people most of all.

Chapter 8
RISK LEVELS UNDER DIFFERENT CONDITIONS OF RADIATION EXPOSURE

Risk is a possible danger of harmful action of environmental factors, including ionizing exposure of the human organism.

Somatic and genetic effects are distinguished. The somatic effects are connected only with the irradiated organism and genetic ones (irradiation action on the germinal cells) can be pronounced in further generations.

Harmful effects of irradiation can be stochastic, i.e. accidental (such as the induction of cancer) and non-stochastic (such as cataracts and other induction reactions.)

Stochastic effects have a probable character and appear after long-term observation of big population groups, numbering tens and hundreds or thousands of humans.

The dependence of somatic effects on the exposure dose is shown in table 14.

Under the action of ionizing irradiation, the time of death from malignant tumors may fluctuate significantly depending upon the dose, its power, and types of irradiation. Skin cancer develops later (on average after 26 years) in people affected under professional action, than in patients, affected in a single dose and repeatedly in radiotherapy (on average after 13–14 years)

The basal-cell carcinomas develop after 7–56 years in patients affected by roentgenoepilation concerning dermatomycosis, and in one woman — 64 years after radiation exposure. The latent period less than 10 years was observed only in 61% of the patients, it was 31–50 years — in 20%.

Radiation exposure can lead to the development of breast cancer. This concerns women, patients suffering from tuberculosis, ones being under long repeated radiological investigations, especially in artificial pneumothorax, survived atomic explosion, exposed in childhood for different causes.

The average latent period for the development of breast tumor after a single exposure in women in Hiroshima and Nagasaki was approximately 18 years. It is known that breast cancer can develop 25–55 years later (average 33 years later) after irradiation concerning apropos acne or hirsutism. The average time from exposure to the development of leukemia was 11.75, 11.5, 9.0 and 7 years correspondingly in people with an average dose of 132, 285, 520 and 1426 sGy.

Malignant tumors of the thyroid gland develop 5–35 years after therapeutic exposure in childhood concerning different diseases (increasing of the thymus, hypertrophy of the tonsils and adenoids, cervical lymphadenitis, mastoiditis, sinusitis, keloidical scars, etc.).

Numerous cases of the appearance of malignant tumors in humans after the use of a thorotrast for diagnostic remedies (tumors of the liver, kidneys, leukemia, brain tumor, osteosarcoma, etc.) are described. The average latent period of tumor appearance is 30 years.

The average latent period for neoplasms under chronic influence of low doses of radiation is approximately 50 years, i.e. cancerogenic action of ionizing radiation not always has time to be realized completely in the forthcoming life, since the latent period can exceed the expected forthcoming life expectancy at definite levels of action.

Genetic effects of irradiation are distributed stochastic and are shown only in the next generation. Therefore, they cannot be detected in the given individuals. They appear in the irradiated population on the basis of statistical analysis. The most part of genetic effects is shown only in the case when the changed gene conjugates to a gene having the same disorder. Such an incidental combination of two mutated partners can occur or cannot.

Harmful dominant mutations appear at the first generation and, as a rule, do not pass to the next generation. Recessive genetic effects of irradiation — point mutations do not appear at the first generation. The probability of their appearence is prolonged after exposure on an endless line of next generations.

The data on the death rate in children, born in people who survived the atomic bombing in Hiroshima and Nagasaki, is evidence that the dose, which doubles the frequency of mutation, seemingly is not below 1 Gy for both sexes. Consequently, the increasing number of the genetically caused diseases per 0.01 Gy is not higher than 1% of the corresponding natural frequency.

Table 14. **The dependence of somatic effects on the irradiation dose**

Types of irradiation	Dose, Gy	Reaction
Single or short-term (within 4 days) gamma-radiation	0.5–1.0	Insignificant convertible changes
	1.0–2.5	Light form of radiation sickness
	2.5–4.0	Radiation sickness of the moderate degree of severity
	4.5	Without treatment the death rate 50%
	4.0–10.0	With active treatment, survival is possible
Contact β-irradiation of skin parts with contaminated products	8.0–10.0	Light reddening of the skin
	10.0–15.0	Edema and reddening of the skin, with dry peeling
	15.0–25.0	Appearance of vesicles against a background of edema and reddening
	25.0–50.0	Ulcer disorder of the skin
Internal β-irradiation of the GIT by the entering of mixes of fission products with air, water and food	4.5–12.0	Light radiation disorders
	12.0–25.0	Moderate degree disorders
	25.0–40.0	Severe disorders
	More than 40.0	Extremely severe disorders with fatal outcome

The induction risk of any serious inherited genetic anomalies in the first generation is estimated as 10–70 cases per 1 million live births, which forms 0.01–0.07% of the spontaneous frequency of cases of hereditary anomalies at present.

The types of changes and sensitivity to induction of these effects significantly change depending upon the stage of intrauterine embryo development at the moment of irradiation and on the fact, whether there is irradiation before implantation of the oosperm in the wall of the uterus, or during the basic phase of organogenesis when organs and tissues of the body are differentiated in an embryo, or during the subsequent development of the fetus. Irradiation of the fertilized egg before implantation into the uterus can lead to embryo death and disorder of implantation. However, those embryos which survive after exposure and settle develop normally.

The possible frequency of cases of intellectual retardation (nanocephalia) for irradiation doses of 0.5 Gy with high power is estimated as 0.1. The increase in quantity of nanocephalia and mental retardation is marked among children affected in Nagasaki during intrauterine development (3–17 weeks of pregnancy). In Hiroshima where during the explosion of the atomic bomb, the neutron component was significantly higher, comparable numbers of such cases were observed at lower doses. But, with irradiation of the embryos during radiological procedures (doses of some tens of milliGy) any significant deviations from the norm were not discovered.

In irradiation during the next stages of the fetus development, the possibility of death cases and the development of anomalies decrease: insignificant development defects are observed more frequently. The sizes and body mass at birth, as a rule, is less in comparison with the control group. Japanese children, affected during intrauterine development by radiation exposure as a result of the atomic bomb explosions at Hiroshima and Nagasaki (irradiation dose — 0.5 Gy), at the age of 17 had obvious signs of decrease in body mass. High doses of irradiation in the period of fetus development (last 33 weeks of pregnancy) can cause growth disorders and an increase in the mortality rate. The frequency of malformations (for example, nanocephalia) at this stage is less than irradiation at the stage of organogenesis, though under diagnostic irradiation during the forth and fifth months of pregnancy the development of heterochromia (unequal coloring of the iris of the eye) is observed.

There is a definite interrelationship between congenital malformations in people and tumors. There are many examples of the combination of hereditary tumors and congenital malformations. A predisposition to the skin cancer is observed in xeroderma pigmentous. Patients with cytogenetic congenital malformations often have leucosis with obscure cellular immune insufficiency, lymphoma with congenital malformation of the urinary tract — nephroblastoma.

Chapter 9
THE PROBLEM OF IONIZING RADIATION LOW DOSES

The range of ionizing radiation doses, that can be estimated low, are the doses, which exceed the natural radiation background 5–10 times, on the one hand, and approximately 100 times less than $LT_{50/30}$ on the other hand. So as for a man, the low doses are 4–5 rad (0.04–0.05 Gy) under single irradiation. However, the doses up to 1 Gy are consodered to be low by the authors of publications in scientific literature. The world literature analysis which was carried out by M. T. Rudnev (1996) indicates that the following phenomena are possible in a dose range up to 1 Gy:

1. An increase in the quantity of chromosomal aberration in the lymphocytes of the blood, the stimulation of the immune reaction and frequency of the autoimmune appearances of thyroid pathology, an increase in the insulin content in the blood plasma and thyroxin concentration, an increase in the contents of free radicals, catecholamine excretion and its metabolism products — vinylamine acids, disorders of lipid metabolism and an increase in lymphocyte quantity.
2. The absence of basic hematological indices, content of replaceable and non-replaceable amino acids, the total cholesterol and urea.
3. System reactions on the indices of workability (the total amount of work, maximal power, duration of work) oppression of the bioelectrical and retractile activity of the muscular-skeletal apparatus.
4. A decrease in the short-term memory and an increase in the stereotypical pattern in behavior, decrease in the stability of the higher nervous activity to the influence of stress factors.

Some peculiarities in the morbidity structure and functional condition of the cardiovascular and nervous systems are revealed under chronic influence of ionizing radiation low doses in professional conditions. The dependence of the genetic state, haemodynamic indices and the time approach of dark adaptation upon the absorbed dose are established. A significant decrease in the capacity of T-lymphocytes to blasttransformation that characterizes the changes in cellular immunity is marked in absorbed doses of 20–70 sGy. The reverse dependence between cytogenetic and immunological changes in lymphocytes is established. With an increase in the length of service, an inclination to the anxiety condition appears and is observed in some people asthenisation. During psychological examination, the tendency to anxiety condition is discovered in most of the workers.

The population is most widely exposed to low doses irradiation during radiological examinations. The cytogenetic method allows to detect changes when doses of local irradiation do not exceed 0.5–2.0 sGy.

When a small quantity of radionuclides enters an organism, the defense-compensation processes, realized on molecular, cellular, system and organism levels, can provide normal vital activity.

A slow development of the processes with wide individual variants is characteristic for low doses. Organism's reactions can be divided into 4 phases: absence of defeat; significant functional disorders; strain; structural changes with disorders of the compensatory-regenerative processes and possible subsequent transition into tumor growth. An increase in life expectancy due to the influence of small radiation loads can result from nonspecific stimulation of the defense-adaptive reactions of an organism. This does not exclude the possibility of the development of various forms of late effects and, in some cases, promotes its appearance because time is prolonged, which is necessary for the realization of the pathology.

The biological effect of low doses of radiation has stochastic character. The disorders that appear in an organism are nonspecific and can occur as a result of the action of other factor not connected with radiation. Quantitative laws can be received only from big populations, examined for a long period of time.

For correct interpretation of the obtained data, it is necessary to keep the following principles:

1) it is necessary to have simultaneous dynamic examinations of the control groups;

2) it is necessary to compare the dynamic shifts with the preliminary examination results;

3) it is necessary to conduct statistical processing of the materials and to state the significance of the distinctions of frequency from

the deviations in different terms of examination within the basic and control groups.

For understanding the problem of low doses the estimation of background irradiation influence on a person of a great value. The absence of deviations in the state of health of people, the pregnancy course, and the indices of birth rate and newborn mortality rate in areas with increased levels of natural ionizing radiation (India, Brazil) are established.

Recently additional exposure of residents of regions with a "normal" natural background of radiation (2–3 mSv/year) up to the total dose 10 mSv/year (under the condition of real relative benefit of such increase: habitation building, productivity growth, energy reception, etc.) is considered permissible. In the regions with higher levels of natural radiation background, the value of premised additional irradiation must be reduced, reaching the zero value under the natural radiation background of 20–25 mSv/year, typical for some populated areas of the planet.

It is experimentally established the growth retardation in the conditions of low background chamber (ten times reduction in the natural background) in conditions of lowered natural background of ionizing radiation. The introduction of uranium salts into the low background chambers, restoring the natural level of irradiation (by preserving all the other conditions of the experiment), removed the observed effect.

Chapter 10
THE COMBINED ACTION OF RADIATION AND NON-RADIATION FACTORS

The combined action of radiation and non-radiation factors appears to be significant modification effects. The additive and super-additive effect is revealed by the additional action of microwave-irradiation, increased temperature. The results are inconsistent in relation to the combined ionizing radiation action of vibration. Alongside the super-additive effects concerning the development of conditioned reflexes, the radio-protective action of vibration in the conditions of post-vibration depression of oxidizing processes is marked. An increase in the lethality of experimental animals under the influence of lowered temperature is leveled after the preliminary acclimatization.

An increase in radio-stability under the influence of acceleration, laser radiation, high mountains and a weak alternating magnate field has been experimentally proven.

The possibility of summation and potentiation of the combined action of ionizing radiation and toxic chemical substances (nitrates, heavy metal salts, ethanol, tobacco smoke, pesticides, ammonia, benzene, mercury bichloride, etc.) is established.

The organism's reaction on ionizing radiation action changes under the influence of functional loads (pathophysiological conditions, traumas, diseases).

External gamma irradiation can change the radionuclide metabolism (higher accumulation in the thyroid gland of iodine-131, inhibition of the excretion of radioactive bromine). The incorporation of radionuclides (iodine-131, plutonium-239) promotes a change in the course of radiation sickness. An increase in additivity in relation to the development of malignant tumors is discovered under the combined action of external gamma irradiation and radionuclides (alkaline lands, rare lands, plutonium-239).

There are data on the changes of metabolism and biological action of radionuclide mixtures in comparison with those ones for isolated nuclides.

Chapter 11 METABOLISM, BIOLOGICAL ACTION OF RADIOACTIVE SUBSTANCES

11.1. METABOLISM OF RADIOACTIVE SUBSTANCES

Radioactive substances can enter an organism in three ways: with food and water into the gastrointestinal tract, through the lungs and through the skin. The most important and dangerous is the inhalation of radionuclides. This promotes a huge respiratory surface of the alveoli; its size is approximately 100 m^2 (50 times as much than the surface of the skin).

The fate of radionuclides that were detonated in the respiratory ways is connected with the sizes of the radioactive particles, their physical and chemical properties and the transportability in the organism. Good soluble substances, most frequently, are quickly (10 min) reabsorbed in the blood vessels, and then, in the metabolism process, they are deposited in some organs and systems of the organism and excreted. Insoluble or poorly soluble substances, which settle in the upper respiratory ways, are taken away together with mucus, after that, with great probability they enter the digestive tract, where they are reabsorbed by the intestinal wall. Some particles settle in the alveolar part of lung tissue or captured by lymphocytes and taken away, or migrate to the lymph nodes, where they stay for months or years. During the inhalation of non-transportable and short-living radionuclides, the respiratory organs become critical from the radiation load.

The second significant way — the entering of radionuclides by food and water. Nutritional substances, with background concentration of natural radioactive substances, can be polluted by unnatural radionuclides, which enter agricultural plants, organism of animals and food products from the environment through the biological food chain.

The most part of radioactive substances pass transiently and are excreted from the intestines. When radionuclides (radioactive substances) enter the digestive tract, irradiation of the intestines occurs, the short running alpha or beta particles irradiate only its wall while gamma quantum reach other internal organs, located in the abdomen and thorax. So, in the case of radioactive substances entering an organism through food and water, when some parts of the intestines absorb significant parts of energy, the gastrointestinal tract becomes a critical organ for radiation load.

The human organ is critical if:

a) it receives the greatest dose or acquires the greatest quantity of radionuclides;

b) it plays the most important role in the normal functioning of the whole organism;

c) it possesses the greatest radiosensitivity, i.e. damaged by the smallest irradiation dose.

Radionuclides, like other substances, in the composition of liquid and gaseous compounds penetrate through the skin, quickly enough, sometimes in significant quantities. So, the speed of penetration into a human's organism of tritium oxide steam and gaseous iodine through the unbroken skin can be compared with the speed of penetration of these substances through the respiratory ways. The quantity of plutonium, that penetrates into an organism due to pollution the skin with its water-soluble compounds, is not less than when entering through the stomach.

The permeability of the skin abruptly increases under the influence of a number of chemically active substances, for example, substances degreasing solvents, especially when there is damage to the outer layers of the epidermis, which play a leading role in the barrier function of the skin.

Radiating disorders of the inner organs by radionuclides, which penetrate through the skin, do not differ by character from the observed ones when radioactive substances enter through the gastrointestinal tract and the lungs.

The ways of introduction are significant in the initial period of the radionuclide effect. Then, in all cases there is a more or less complete reabsorption in the blood and deposit in the corresponding organs.

The quantity of radionuclides, which enter an organism, depends upon their properties and chemical nature. Some elements (Ca, Sr, Ba, Ra, Y, Zr, Pu-citrate), have significant osteotropical, others (Ce, La, Pm, Am, Cm) — selectively accumulate in the liver, the others — in muscles (K, Sr, Rb), the others are in comparatively regular intervals distributed with a tendency to accumulation in the reticuloendothelial tissue of the spleen, bone marrow, adrenal glands and lymph nodes (NB, Ru, Tc, Po).

The distribution of elements within the limits of some groups of a periodical system has much in common. The elements of the first basic group (Li, Na, K, Rb, Cr) are completely reabsorbed from the intestines, selectively distributed in the organs, and rather quickly excreted with urine. The elements of the second group (Ca, Sr, Ba, Ra) are reabsorbed well from the intestines, selectively deposited in the organs and are excreted with feces in some quantity more than with urine. The elements of the third basic and forth collateral groups, including light latitudes, actinides and transuranic, practically are not absorbed from the intestines, are selectively deposited in the liver and to a smaller measure — in the skeleton, excreted exclusively with feces. The elements of the fifth and sixth basic groups of the periodical system, except for polonium, are comparatively well absorbed from the intestines and are excreted almost exclusively (up to 70–80%) with urine, within the first days due to the fact that they are discovered in organs in a comparatively small quantity.

A precise dependence exists between the basic physical-chemical properties of elements or their compounds and the type of distribution. The elements, forming in water soluble compounds of basic character, belong to the types of distribution depending upon the valency to “uniform” (Li, Na, K, Rb, Cs) or “skeletal” (Be, Ca, Cs, Ba, Ra). Trivalent and tetravalent cations form in water practically insoluble hydroxides of basic character, undergoing in neutral environment of an organism hydrolysis with the formation of radiocolloids, with rare exceptions (yttrium, heavy lanthanides), distributed by the “liver” type. The pentavalent, hexavalent, and septavalent ions, forming hydroxide amphoteric or acid character, possess “uniform” (Cl, F, Br, J, Nb, Tc, Po) or “liver” (Sb, As, S, Se, U) types of distribution.

The particles of small sizes are captured mainly by the skeleton, the bone marrow; the particles of larger sizes are englobed by reticuloendothelial cells of the liver and spleen.

11.2. THE BIOLOGICAL ACTION OF RADIOACTIVE SUBSTANCES

One of the most important factors, significantly indicating the specificity of radiation sickness at all stages of disorder, is the type of radio-element distributed. During damage by diffusely distributed radionuclides (^{137}Cs,^{106}Ru,^{95}Nb,^{210}Po), opposite form "skeletal" and "liver", there is a small distinction between acute, subacute and chronic effective doses, a strong decrease in the mass of the spleen and testes, a significant depression of lymphoid haemopoiesis, primary occurrence of tumors in soft tissue (adenoma of the mammary glands, lung cancer, breast cancer, cancer of the small intestines, sarcoma of the duodenal and cecum, and kidney tumors).

A sharp increase in the mass of the spleen — as the result of ectopic haemopoiesis, a relatively stronger depression of bone marrow myeloid haemopoiesis, the absence of acute atrophy of testes, primary occurrence of bone tumors, are observed during damage by the "skeletal" radiators (^{89}Sr, ^{90}Sr, ^{140}Ba, ^{226}Ra, ^{90}Y, ^{91}Y, ^{239}Pu) in contrast to the "uniform". During damage by radionuclides, selectively depositing in the liver (^{144}Ce, ^{140}La, ^{147}Pm), it is specific enough the occurrence of ulcer-necrotic changes in the tunica mucosa of the small and large intestines with selective localization of necrosis in the proximal parts of the duodenal, pyloric parts of the stomach, cardial parts of the esophagus, absent during damage by the "skeletal" and "uniform" radiators, the occurrence of cirrhoses, liver tumors and osteosarcomas.

Besides of the character of distribution, the effective period of half excretion, the size which depends upon speed of radioactive decay and excretion of radioelements from an organism, renders a very significant influence on the course and outcome of radiation sickness.

When damaged by irradiators with short effective period of half excretion (^{90}Y, ^{160}La, ^{95}Nb, ^{137}Cs, ^{140}Ba, ^{106}Ru, ^{210}Po), there is enough small distinction between acute, subacute and chronic effective doses, the peripheral blood normalizes quietly and completely, osteosarcomas (^{90}Y, ^{140}La) and cirrhosis of the liver (^{140}La) occur relatively less often and later, ectopic lienal haemopoiesis (^{90}Y, ^{140}Ba) quickly stops, caused by an early normalization of bone marrow haemopoiesis. When damaged by irradiators with large effective periods of half excretion (^{89}Sr, ^{90}Sr, ^{226}Ra, ^{144}Ce, ^{147}Pm, ^{239}Pu) a big distinction between acute, subacute and chronic effective doses is observed. The normalization of white blood occurs very slowly, ectopic lienal haemopoiesis (^{89}Sr, ^{90}Sr) is kept long-term, cirrhosis of the liver (^{144}Ce, ^{239}Pu) and osteosarcomas occur frequently and rather quickly.

When damaged by good reabsorbed irradiators, the clinical picture of the disease does not depend upon the form of injection, in the case of the poor reabsorbed irradiators, it is determined by the form of injection of the substance and characterized by the prevalence of the local processes, dependent upon the localization of the irradiators, the common and local radioactivity of an organism. In oral introduction, the poor reabsorbing irradiators (^{144}Ce, ^{90}Y, ^{91}Y, ^{140} La) in the acute phase, diffusive disorders of the small and large intestines, such as acute necrotic-ulcer coloenteritis, accompanied with pronounced reaction processes such as intensive leukocytic infiltration of the stroma of the intestines, distinct phagocytal reactions, early regeneration of the epithelium and the development of abrupt pronounced leukocytosis after short-term leukopenia, accompanied with hyperplasia of the myeloid tissue of the bone marrow develop. In contrast to good reabsorbing irradiators (^{89}Sr, ^{90}Sr, ^{140}Ba, ^{137}Cs) the malignancy action of poorly reabsorbing radionuclides (^{106}Bu, ^{144}Ce, ^{147}Pm) is determined by the way of introduction: in intravenous introduction, as a rule, osteosarcomas occur, in peroral — carcinomas and sarcomas of the intestines, with introduction through the respiratory system — lung cancer and sarcoma of the lungs and bronchial tubes, with hypodermic introduction — lung cancer and sarcoma of the lungs and bronchial tubes.

The form, course, and outcome of radiation sickness depend not only upon the properties of the etiological factor — irradiator. Both different terms of death of experimental animals from the same dose (that is very distinctly shown at damage by irradiators with short-term half effective periods of excretion and with peroral introduction of poorly reabsorbing irradiators) and the occurrence of corresponding pathological processes (cirrhosis of the liver, bone and soft tissue tumors, leukemia) in only a part of the experimental animals are evidence of the role of individual reactivity of an organism. Osteosarcomas and other tumors occur earlier in young animals, more often they are multicentric and metastasize more than in older ones.

Some cases are known of the high selectivity of distribution. So, isotopes of iodine accumulate exclusively in the thyroid gland. Evidently organotropic radionuclides are more dangerous than diffusive ones; their concentration in tissues and, consequently, the tissue dose in equal conditions are always bigger in magnitude.

Except for the described macrodistribution of radionuclides in an organism, it is necessary to take into account their microdistribution in various organs and tissues. Osteotropic elements such as strontium and barium accumulate mainly in the growing parts of tubular bones — metaphysis and epiphysis, being distributed non-uniformly and forming so-called "hot spots" was proved by the autoradiographic method.

Such pathological processes as cirrhosis of the liver, sclerosis foci in the lungs and changes in the bone tissue, including the formation of osteosarcomas are a result of large non-homogenous microdistribution of radionuclides in tissues.

When large quantities of radioactive substances enter an organism, which most often occurs in extraordinary conditions, acute radiation disorders, the features of which are determined by specific features of incorporated radionuclides, develop. For example, under an incorporation of radioactive phosphorus or sodium isotopes, differentiated by relatively short period of half-life, uniform distribution and enough severe irradiation, a typical ARS occurs, which does not differentiate from the development by common exposure. In introduction of organotropic radionuclides into an organism, different variants of radiation disorders of an organism arise with primary appearances in tissues, where the dose load is maximal and becomes critical in this case.

A significant feature of the disorders during internal irradiation is that radionuclides of heavy elements present a special danger in such cases. Possessing a high relative biological efficiency (RBE), these irradiators, despite the small penetration capacity, cause heavy disorders of the pneumatic ways and intestines (epithelium, which losses all of their reserved energy). Another feature of the biological effects of incorporated radionuclides (irradiations) is determined by the fact that in contrast to external irradiation where the organism plays a passive role, in internal one — the organism plays an active role in the formation of tissue doses because of the presence of transport and metabolic processes, causing an accumulation and excretion of radionuclides from certain organs and tissues.

Sclerotic changes arise first of all in critical organs during deposition of radionuclides. Under conditions of local irradiation, their appearance is determined by the exposure zone and level of dose, during total exposure — by the dose levels.

The significance of the type of radionuclide distribution for the clinical displays of intoxication are revealed by comparing the incidents connected with the introduction of regular intervals of radionuclide distributions — tritium and osteotropic radionuclides — radium.

The following case caused by tritium is used as an example.

Patient K., 37 years old, seriously broke safety precautions while working with tritium, hid this fact from the administration, did not visit a physician and a day later took a vacation. The next day, the patient's general state of health had worsened a little, weakness appeared, fatigue, and his appetite worsened. After three weeks, pains in the oral cavity appeared during chewing, pressure in the back, frequent urinations, dark urine color. On the skin of the thorax, abdomen and forearms haemorrhagic eruptions appeared. The temperature increased to 39°C, difficulty in swallowing because of sharp pains in the oral cavity appeared. The same day the patient for the first time saw a physician and was hospitalized.

After entering the clinic, the state of the patient was severe, temperature was 38.1°C; he was a little slow, adynamic. Skin surfaces had a grayish shade. Multiple haemorrhagic rashes were on the skin of the thorax, abdomen, forearms, and shins, on the internal surfaces of the hips and shoulders — vast haemorrhages. A putrefactive odor came from the mouth. The mucous of the tongue, alveoli, internal surface of cheeks, lips are abruptly hyperemic, friable, swollen, covered with a dirty-gray film and small ulcers, which are sensitive to the touch and easily bleed. Pulse — 110 beats per minute, rhythmical, of satisfactory filling and tension. Arterial pressure — 150/100 mm Hg. Outlines of the heart are in normal ranges; on the apex cordi the tones are muffled. On all parts of the lungs — vesicular respiration. The abdomen was soft, painless during palpation. The liver and spleen were not increased. The Pasternasky's symptom was negative on both sides.

The day after the patient entered the hospital the peripheral blood was: Hb 90%, erythrocytes — 4 153 000, color index — 1.09, leukocytes — 200, eosinocyte — 8%, relating to stab neutrophile — 1%, lymphocytes — 75%, monocytes — 10%, plasmatic cells — 1%, unrecognized cells — 5%, anisocytosis +, polychromatophilia +, ESR — 50 mm/h. Examination from the sternal puncture revealed devastation of the bone marrow. Urine was dark brown, specific mass 1030, protein — 0.66%, epithelial cells — single in the visual field, leukocytes 0–2 in the visual field, erythrocytes — fresh and alkaline covered the whole visual field.

The patient's status remained serious during first 5 days of staying at the hospital. The body temperature increased up to 38–39.1°C, vast bleedings in the place of injection were observed in the evenings. In the peripheral blood, acute leukopenia (the quantity of leukocytes 150–400) and neutropenia (the quantity of neutrophils 3–7/mm^3), thrombocytopenia were kept, the erythrocyte contents increased to 2,500,000 and haemoglobin — up to 60%, ESR remained accelerated to 48 mm/hr. Signs of regeneration were marked in the bone marrow puncture along with a sharp decrease in the total quantity of remaining cells.

The patient's status was satisfactory, his weight had steadily increased since the 10th day. In the peripheral blood the quantity of leukocytes increased with a simultaneous increase in the quantity of neutrophils and a moderate shift to the left in the leukocyte formula, the indices of red blood improved, the quantity of thrombocytes repaired very slowly. All of the regeneration of the red and white haemopoiesis growth was represented in the myelogram, with a total quantity of cells being 50,000 in 1 mm^3.

It was possible to talk about clinical recovery by the 72nd day after the beginning of acute signs of the disease. Six months after the beginning of the disease, the victim returned to work under the conditions of excluding contact with ionizing radiation.

The next observation is given as an example of characteristic clinical displays, developing during the introduction of a large quantity of soluble radium compounds into the organism.

Patient Z., 23 years old, with suicidal intentions took 2.03 mcC of radium bromide orally. All the measures for acceleration of excretion were done only 24 h later, because the victim simultaneously took a large dose of luminal and within 20 h was in a deep sleep stage. The quantity of radium in the organism, on the basis of radiometric methods, was determined to be 150 mcC (on the terminal period of observation), almost with no decrease in comparison to the starting radionuclide quantity. The patient's health condition was satisfactory at the second day after the suicidal attempt. The satisfactory status of the patient was kept for 3.5–4 years, which allowed him to continue working, studying and even take part in expeditions.

Temporary pains and swollenness in the area of the left calcaneal bone, treated as periostitis, however without corresponding changes on the X-ray film were marked on the 11th month from the beginning.

Periostitis worsened by the end of the 3rd year, in expedition conditions. After an unsuccessful extraction of cavity-filled tooth, further a flaccid current of sequestrated osteomyelitis of the maxilla developed. Sequestrotomy and extraction of the tooth, endured by the patient, were quite satisfactory; his state of health improved a little.

The patient had distinct signs of ostenisation and circulatory dystonia of the hypotonic type with characteristic clinical displays appeared only by the 4th–5th year. The patient lost weight little by little. Intensive pains in the left part of the mandible, disturbing eating and sleeping, sometimes local swelling of the mucous membrane with excretion of bloody fluid appeared at the beginning of 5th year. The pains spread on the way of the trigeminal nerve and went to the left ear. Simultaneously, he was disturbed by intensive pains in the sternum and less intensive in the right half of the pelvis. Radiological investigations discovered foci of destruction in the calcaneal area, sternum, jaws, and also, rarefied bone structures in other parts of the skeleton.

Further, the general condition of the patient continued to worsen. The pain in the mandible and foot were not eliminated with drugs and deprived the patient of sleep. He was forced to leave work and studies; he was continuously in the hospital. Soon deformation of the sternum with protrusion of its body and manubrium, suspicion to osteosarcoma occurred. The diagnosis of osteosarcoma of the sternum was confirmed by X-rays after 2 months of clinical suspicion. The general condition of the patient continued to worsen, coughing and pains in the chest appeared. Symptoms of left-sided exudating pleurisy and mediastinitis, which gave the basis to suppose spreading of a tumor in the pleural cavity, appeared. Repeated pumping out of the fibrous-haemorrhagic liquid only temporarily facilitated the general status of the patient. Cachexia increased. Anemia sharply progressed and ESR increased. The patient died from increased cardio-pulmonary insufficiency.

Pathoanatomical diagnosis: chronic radiation sickness because of exposure of radium, pancytopenia, disintegration of the osteosarcoma of the sternum, spreading into the tissue of the anterior mediastinum, osteosarcoma of the right cristae of the iliac bone, left-sided fibrin-haemorrhagic pleurisy; cachexia.

People exposed to irradiation due to radium entering the body in quantities which exceed the permissible limit 10 times live for a long time and their health is satisfactory. They cope with a range of common diseases and banal surgical interventions, frequency of which is common too. But tumors of bone tissue are more frequent among the death causes.

The basic effects arising due to the incorporation of radium are sarcoma of the bones, carcinoma of the paranasal sinuses and air cells of the procesus mastoideus.

The evolution of leucosis is observed while radioactive substances enter an organism, especially the ones that are deposited in the bone tissue.

The cases of leucosis development are known when the patients were introduces radioactive phosphorus because of diseases of the haemopoietic organs, or they were treated with the usage of radioactive iodine because of tumors of the thyroid gland. The symptoms of the disease appeared in 3–10 years after the treatment course.

^{131}I is capable to induce tumors of the thyroid gland, hypophysis, adrenal glands and other organs in vast dose diapason. Radioactive I is capable of induce adenoma and cancer of the thyroid gland in absorbed by the gland doses of 2 to 15 Gy. Cancer of the thyroid gland was discovered in 7 women among 243 people (women and men) affected on the Marshal Islands during 22 years of observation. The total dose of external gamma irradiation was in the range of 1.72 Gy and a total dose on the thyroid gland — 16–20 Gy. The quantity of tumors per a dose unit was higher in women exposed at the age of 15–18, and in babies and children. The average latent period becomes higher with an increase in the age at the moment of exposure.

There is a report about the development of lung cancer, cancer of the rectum, urinary bladder and basalioma cases in groups of 65 people, working with luminescent radioactive paint.

Tritium oxide (by experimental data) possesses a high leucosagenic effect. The RBE index of tritium oxide in comparison with roentgen irradiation by the leucosogenic effect parameters was estimated by various authors as 1.4:4.

The atrophic and hypoplastic status of the mucosa of the GIT with a clinical picture of chronic hypo- and antacid gastritis, revealed in people living after the atomic bombing of Hiroshima and Nagasaki for 1–9 years and more.

So, the estimation of possible biological dependence of radioactive substances which entered an organism is based, first of all, on the data about the ways of its entrance, distribution, excretion from an organism and the dynamics of the absorbed doses formation in the basic organs of the deposition.

Owing to high radiosensitivity of gonads, embryonic, fetal and early postnatal period of development, it is necessary to consider the possibility of radioactive damage irrespective of the type of radionuclide distribution.

The following laws were experimentally established.

The character of structural and functional changes of the testes after injection of effective quantities of long-living radionuclides (^{90}Sr,^{239}Pu,^{241}Am,^{237}Np) was essentially the same as under the action of external gamma-irradiation.

Despite the fact that the entered radionuclides cause the same type of disorders as after an external irradiation, the disorders from radionuclides are more expressive.

The disorders in the testes are caused by all the radioactive substances irregardless of the type of distribution in an organism, which is significant in magnitude and time of display of the effect. So, the percent of aberrant mitosis in the spermatogenic epithelium of animals, gradually increases reaching a maximum absorbed dose of 370 sGy in absorbed dose of 3 sGy from ^{137}Cs. When introducing ^{90}Sr, the cytogenetic effect appeared only when the absorbed dose in the bone tissue was 770 sGy. Perhaps, a greater expression of the effect of ^{137}Cs introducing, distributing evenly in an organism, occurs due to direct action of radiation on the testes. In case of ^{90}S locating in the bone tissue the influence on the gonads is indirect.

The morphological changes of the ovaries by radioactive substances are mostly analogical to the disorders appearing under external irradiation. These disorders are concluded in the evolution of dystrophic changes and death of follicles in various stages of maturity. The changes are revealed first in the epithelium and in the ovicell follicle. The nucleus and protoplasm of the ovicell of mature follicles are most sensitive to irradiation; the nucleus, as a rule, is wrinkled and fragmented, the protoplasm is homogenous and hyperchromatic. The changes in the ovaries after the action of various physical-chemical properties of radioactive substances are the same type.

It is important, that the character of revealed changes depended upon the time after radionuclide introduction in all of the studied radioactive substances. So, karyorrhexis, discomplication and swelling of the cells of the follicular epithelium, lysis of the ovicells were revealed in the early terms after the introduction of subacute quantities of fission products of uranium. Growth of connective tissue of the non-secretory part of the ovary was revealed in later terms. The degree of depression of ovogenesis, time of occurrence of significant structural changes in the ovaries depended upon the quantity of introduced radionuclides, absorbed doses in the basic organs of deposition, and to a smaller degree — upon the absorbed doses in the ovaries. The functional disorders of the ovaries arise earlier than any shifts in the blood system and histological changes in the ovaries.

The mechanism of observed changes, seemingly, is connected not only with the direct action of ionizing irradiation on the gonads, but also with the detected influence on other endocrine glands, resulting in total dyshormonal disorders.

11.3. THE LAWS OF RADIONUCLIDES TRANSITION THROUGH THE PLACENTA

The possibility of penetration through the placenta was proven in experimental conditions for almost all of the studied radionuclides.

But the difference in the possibility of placental transition for various radionuclides is 100 times higher in the quantitative relation. The degree of radionuclide transitions to the posterity through the placenta depends on the contact character between the mother's blood and the fetus's blood, determined by the histologic structure of the placenta and the physical and chemical properties of radionuclides.

The quantity of radionuclides which pass through the placenta in the fetus depends upon a number of physiological conditions and the positions of the elements in Mendeleyev's table. A significant increase in the transition through the placenta within late terms of pregnancy is typical for all of the studied radionuclides. By introducing radionuclides before conception, there is an inverse relation between the time interval of elements introduction before birth and the quantity of radionuclides that transited to the fetus. An inverse relation between the mass number of the radionuclide and its part which passes to the fetus is marked for the I, II, and VIII groups of elements.

The danger of radionuclides entering to pregnant women is determined not only by their quantity, which passes through the placenta. There is a significant delay of radionuclides with a large mass number in the placenta.

The concentration of radionuclides in embryonic tissue is higher than in the mother's.

The influence of radionuclides on the embryonic development is determined by the stage of embryogenesis at the moment of introduction of radionuclides into the mother's organism. So, the introduction of thyrocardiac quantities of ^{131}I at the early terms of pregnancy corresponds with the periods of preimplantation and placentation of embryos results in high antinatal death, sharp depression of the total evolution of the surviving fetus in connection with the depression of growth and differentiation of various tissues, which to a certain degree is caused by athyroid condition of the mother's organism. At the late terms of pregnancy, corresponding with the fetus period, such influence is not accompanied by intrauterine death of the fetus, but direct damaging action of the radionuclide on the cytoplasmatic and nuclear structures of cells of various organs of the fetus, which mostly affects the thyroid gland, kidneys and liver, takes place.

11.4. THE INTRODUCTION OF RADIONUCLIDES FROM A MOTHER'S ORGANISM WITH MILK

It is shown in experimental conditions that radionuclides, which are poorly reabsorbed from the gastrointestinal tract, do not appear in milk or are found in insignificant quantities.

The introduction of radionuclides from the mother's organism in milk and the high reabsorption of radionuclides form the gastrointestinal tract of young people can lead to significant deposition of radionuclides in posterity.

The greatest quantity of radionuclides transported with milk to the posterity, was discovered in those cases when a radionuclide enters the mother's organism during lactation, less — during pregnancy and even less — before conception. The specified law seemingly depends upon the decrease of concentration in time of radionuclides in the mother's blood and upon the weak mobilization of radionuclides, connected in the deposition organs.

An inverse relation between the size of introduction with the mother's milk and their mass number was discovered for the radionuclides of the II group.

Those radionuclides that are reabsorbed in adults from the gastrointestinal tract in a small amount (^{239} Pb) can be passed through milk too. It is proved that transportation of these radionuclides to posterity was 66 times less than ^{47}Ca under the same conditions.

Radionuclides are more mobile if they are introduced into the posterity's organism with milk, than during pregnancy.

So, representatives of the III group (^{91}Y and ^{144}Ce) are excreted through milk 10 times as much than through the placenta. Seemingly, only iron passes through milk in a less quantity than through the placenta, which can be explained by the active role of the placenta in the transport of iron from the mother's organism to the fetus.

The dynamics of change in the concentration of activity sharply differs in a young and adult organism, which is caused by two parallel processes: high levels of metabolism in a growing organism and "dilution" of activity due to skeleton growth.

For approximate judgment of the possible affecting action of radionuclides, which enter the posterity through the mother's milk, it is necessary to take into account the difference in absorption of radionuclides by the basic deposition organs of children. The absorption of radioactive iodine by the thyroid gland in newborns is twice as high than in adults. The average dose per body, received by a child, is 22 times, the average dose on the thyroid gland — is more than 25 times higher than for a standard person (due to the difference in body mass and radionuclide metabolism). The absorbed dose in the thyroid gland for children at ages up to 1 year was 0.32–0.1 Gy for 37 kiloBk of ^{131}I, and only 0.013 Gy — for the standard person.

Chapter 12
CLINICAL (RADIATION AND NON-RADIATION) METHODS OF EXAMINATION

During examination of the residents of contaminated with radionuclides zones, it is necessary to take into account the complaints of the patients and the time of their occurrence. It is necessary to establish the probable causal relation with ionizing irradiation (II), then examine the patient thoroughly (especially the skin and visible mucous membranes), perform percussion and auscultation of the organs of the chest, palpate the abdominal cavity and examine the rectum with a finger. Palpation of the breast and genital organs is conducted in women.

According to the complaints and exposed clinical data, the volume of laboratory investigation (hematological, biochemical, immunology, etc.) is determined and the plan of patient investigation with radiation and non-radiation methods is constituted.

The estimation of the condition of the *respiratory organs* can be done with the method of electron microscopy of forceps biopsy of the bronchi, which was used during examination and treatment in clinics for participants of liquidation of the consequences of the Chernobyl NPP accident who suffer from chronic bronchitis and bronchial asthma. Significant vascular, intravascular and extra-vascular changes were discovered in a majority of the examined people in 3 to 6 years after the disaster in the microcirculatory system of the mucous membrane propria of the bronchi that is evidence of disorders of the microhaemodynamics and microcirculation in an organ.

Differences in the character of disorder of the microvessels were revealed both in different observations and in topographically near zones of the investigated tissue. In one case the vessels were sharply constricted almost to slit-like forms, and in the other case — dilated vessels. Frequently, the capillary lumen is damaged by erythrocyte aggregates.

Early diagnosis of the *liver* pathology and the necessity of an objective estimation of its functional condition in case of non-expressed clinical symptoms are of primary value in people exposed to radiation during the Chernobyl accident.

The definition in blood serum of L-serine dehydrase activity and L-trionindegidratasa — enzymes, which are mainly located in the cytoplasm of hepatocytes was used as tests, adding to the complex of routine biochemical investigations. Hyperactivity of enzymes in blood serum testifies to the presence of cytolytic syndrome. The high sensitivity of these indices allows to recommend them for estimation of the liver functional condition in people affected by radiation. An increase in the uridinediphosphate derivatives metabolism speed which testifies to the liver connective tissue metabolism intensification is considered as a precaution of future liver cirrhosis after the *incorporation* of hepatotropic radionuclides.

Early changes in the basic organs irradiated by ^{237}Np (liver, kidneys) are possible to be detected in investigation of biological oxidation processes and fermental systems, metabolism of nucleinic acid, lipids and mineral substances.

During an examination of the haemogenesis system in people affected by irradiation as a result of the Chernobyl accident, the quantity and quality changes in the elements of peripheral blood and bone marrow can be revealed. According to the myelogram data, an increase in the contents of plasmatic cells, reticular cells, lymphocytes against a background of a moderate decrease in quantity of cells of the bone marrow is marked. Hypersegmentation and hyposegmentation of the granulocytes nuclei, toxic granularity of neutrophils, processing and villosity of the cytoplasm of lymphocytes of peripheral blood and bone marrow undergo no changes.

An increase in the quantity of old vacuolated, degenerated forms of thrombocytes is revealed. The adhesive-aggregative capacity of thrombocytes increased too.

Studying the paramagnetic centers of blood reveals changes in the functioning of major metalloprotein of the blood — ferrum-transferase and Cu- ceruloplasmin, resulting in disorders of ferrum transport to the bone marrow.

During the morpho-functional examination of blood cells in people, affected by radiation as a result of the Chernobyl accident, various disorders of the lymphocyte morpho-structures (atypical forms, fringing of the cytoplasm, reeder's form and pyknosis of the nuclei) are discovered. Various nuclear anomalies, toxic granularity in neutrophils are revealed in a majority. Morpho-metrical examinations revealed a significant decrease in the sizes of neutrophils.

Disorders in the enzyme-chemical organization of neutrophils — decrease in the activity of peroxidase, increase in the activity of acid phosphatase, the presence of non-specific esterase, increase in the contents of glycogen, are established. These changes are combined with a 5–6-fold decrease in their antimicrobic function in the liquidators, which specifies deep disorders in the system of natural protection. A significant decrease in the electrical potential of erythrocytes is registered in liquidators.

As time passes after the moment of radiation exposure, a part of the anemic conditions among the total sum of hematological affects increases while the frequency of leucopenia decreases. The revealed hematological effects develop against a background of a large quantity of metabolic disorders, moreover in the course of time, the frequency of revealed disorders and the quantity of their indices increase.

Stable indices of disorders of the metabolism of collagen and glycoaminoglycane, indicative of destructive processes in the connective-tissue matrix, followed by processes of bone marrow haemopoiesis are discovered in most of the examined people having hematological disorders.

Residents of the controlled regions statistically more frequently complain of *pain in the hip and knee joints* and such clinical syndromes as *osteochondrosis* of the neck-thorax part of the spine, vegeto-irritation syndrome of vertebrogenal cardialgia, humeroscapular parasynovitis. Porosity of the bone tissue by the data of echosteometry and the absorbed densimetry are significantly less than in control. The degree of aging in the basic group (3rd and 4th zones of radioactive contamination) is 6.5 years more than for the standard population.

Changes in the immune status are revealed in remote terms after the disaster. Changes in the quality character in blood cells are detected, especially in the forms, which are responsible for the quality of immunity cells. There is a tendency for a decrease in the peripheral blood of absolute quantity of practically all forms of leucocytes. It concerns mostly the immunocompetent forms — lymphocytes, monocytes, neutrophils. There is a decrease in both the relative and absolute contents of eosinocytes in a majority of the examined girls.

Features of hormonal disorders are revealed in people working within a 30 km zone. Among the signs, which determine the condition of disadaptation, a decrease in noradrenaline excretion with urine, and in a part of the examined — dopamin, is marked. There is an assumption that the function of the hypothalamus is highly sensitive to irradiation.

The *disadaptation syndrome* in the exposed in low doses workers of the 30 km zone of the Chernobyl NPP has a metabolic, regulatory and psychological peculiarities, characteristic for the obesity processes. There is a reason to assume that hormonal shifts provide the organism's adaptation, simultaneously being the factor, catalyzing processes of mental and physical aging.

Stable hypercorticoidism on a beta-endorphine level decreasing background, a longtime tension in the simpatico-adrenal system with predominance of mediator link activity in comparison with the normal one; disorders of the intrasystem mechanism of reverse connection in the hypophysis-suprarenal system (ratio of ACTH level to cortisol) were discovered.

The dynamic *investigations of cytogenetic indices of the blood* by the chromosomal aberration test in victims of the Chernobyl accident testify that blood cells with radiation markers-dicentric — often without accompanying pair fragments are registered in the late period after the disaster. The support of the pool of aberrated lymphocytes with the greatest probability is caused by the bone marrow cells production, which DNA code has radiation damages induced by primary exposure after the disaster. The frequency of chromosome aberration can increase with time.

From a wide spectrum of biochemical indices it was possible to distinguish three groups of the most vulnerable parameters, the disorders of which have a close interrelationship with the development of non-stochastic pathological effects of radiation influence. The following is detected in a wide range of dose diapason (0.25–1.0 Gy and more):

1. Dislipoproteinemia of the atherogenous type.
2. Hypercholesterinemia.
3. Disorders of free-radical processes.

Essential changes of the middle size molecules content in the blood, an increase in alkaline phosphatase activity, ALT, ASLT, sharp oxidization of free radical lipid were marked during late terms of the Chernobyl NPP disaster. Correlation between an increase in the alkaline phosphatase content in blood serum and the osteosarcoma appearence were experimentally established.

It is possible to reveal *postradiation encephalopathy* with the help of the following diagnostic criteria:

— verification of radiation sickness;

— fast progression type of nervous-psychological disorders;

— the endophorm psycho-organic syndrome;

— the microfocal neurological symptomatic mainly of the diencephalo-truncus cerebri level;

— progressing vegetative insufficiency;

— flat or disorganized type of EEG with paroxysmal activity, inter-hemispherical asymmetry and domination of the β- and γ-diapason spectral capacity;

— deformation, asymmetry and changes in the amplitude-terminal parameters of the caused brain potentials;

— disorders in the regulation of cerebral circulation with the absence of stable changes;

— absence of psychological pathology of the other genesis.

Researches of cerebral haemodynamics in people, affected by ionizing radiation, allow the revealing of a number of parameters, characterizing brain circulation. The latent pyramidal insufficiency with cerebrovascular pathologies in people who took part in the liquidation of the Chernobyl NPP accident, reveal with the help of clinical symptoms pathological synkinesis (involuntary additional concurring movements, arising as an answer to voluntary ones).

The complex clinical neuro-physiological investigation of the functional condition of the nervous system in people who took part in the liquidation of the Chernobyl NPP accident revealed a decrease in the functional activity of the sympathetic part of the nervous system.

It is established that *pregnancy* in the inhabitants of the controlled after the disaster is accompanied by an increase in the procoagulator and thrombocytic links in the system of haemostasis, an arise of intravascular blood coagulation, leading to microcirculation disorders. Such disorders of haemostasis balance in pregnant women living in radioactively contaminated territories can cause an increase in the frequency of bleedings during delivery.

A decrease in the total lipids content, cholesterol, phospholipids in blood serum with an increase in triglyceride levels is marked in *children* residing at radiation controlled territories.

Peripheral neurovascular syndrome, phenomena of secondary angiospasms, and symptoms of “thermoamputation” of fingers and feet are revealed with the help of a *thermography* in people affected by ionizing radiation as a result of the Chernobyl NPP disaster.

Essential deviations in the state of health of people affected by ionizing radiation action are detected with the help of instrumental methods of diagnosis (Table 15).

The results of cerebral haemodynamical investigations with the help of RTG and ultrasonic dopplerosonometry of people affected by ionizing radiation as a result of the Chernobyl NPP disaster testify that against a background of relatively undamaged blood speed in the main vessels of the neck a range of parameters, which characterize brain circulation, can be revealed: significantly high per cent of revealing REG-curves of distonic-hypertonic types, decrease in the pulse blood flow, and in the tone of the arterial brain vessels, increase in the brain vessels resistance. Expressed intrahemispheric asymmetry in the amplitude of rheographic waves, decrease in the factor of reliability of the system of brain circulation were revealed. Changes in the reflect formation of cerebral distonic-hypertensive syndrome, the basis of which could be disorders in the tone regulation of small and middle caliber brain, are revealed. Changes in brain circulation appear to be connected with external irradiation, working within a 30-km zone, and working conditions. The analysis of the received data is evidence of a necessity of including people working in conditions of increased radiation contamination in the group of increased risk of cerebrovascular pathologies development,

Table 15. **Experience of non-radiation instrumental diagnosis methods usage**

Method	Results of investigation
Children	
Thermography	Duly diagnosis of malignant neoplasms
People undergoing the influence of ionizing irradiation	
Thermography	Symptom of "thermoamputation" of hands and feet Change in the proximal-distal interrelationships Revealing of secondary angiospasm
REG, ultrasonic dopplero-sonometry	Change in a number of parameters, characterizing brain circulation
Triboluminescence of the expiring air condensate (TLEAC)	An increase in cancerogenic risk is revealed

conducting corrections in the revealed disorders and preventive measures.

Alongside with clinic laboratory investigations, one of the most perspective methods at the first stage of hematological screening is the *method of contactless thermography*. The introduction of thermography methods in work practice of assizes brigades while conducting prophylactic medical examination of children residing in controlled territories enables the possibility to determine the condition of lymph nodules in all the groups of the body; allows topographical diagnosis of the damaged foci and simultaneously diagnose malignant formations. Results from the conducted investigations revealed a difference in the temperature emission from lymph nodule projections of various geneses. Asymmetry of the temperature on the forearms, legs, shins, proximal-distal ratio changes were frequently marked in these patients. The indicated signs confirmed the presence of peripheral neurovascular syndrome in patients, phenomena of secondary angiospasms and correlated with complaints and objective clinical symptomatology.

Thus, thermography is enough objective method for estimating the condition of vegetative providing of vascular tone regulation at all the levels of the VNS and it can be used widely for diagnosis of vegetative disorders in people affected by the influence of ionizing radiation as a result of the Chernobyl NPP disaster.

Triboluminescence of expiring air condensation (TLEAC) is an indicator of cancerogenic risk among people, being present under conditions of dangerous ecological factors after the Chernobyl NPP disaster. The most probable fact of cancerogenic risk was discovered in a hard control zone with a density of contaminated territories being ^{137}Cs 1–80 Cu/km^2. There is a significant correlation connection between TLEAC and exposure dose of the thyroid gland with ^{131}I.

While examining people *incorporated with radionuclides* of various depositions, the recommended methods of investigation are presented in table 16.

The searches for diagnostic tests for revealing malignant tumors have been conducted for many years. All attempts to find some specified universal test failed. However, the usage of common but sensitive clinical chemistry tests, in particular immunological and isoenzymatic ones have been very helpful in the diagnosis of tumorous processes. So, the Regan's enzyme and its thermolabile variants should be regarded as alarming biochemical signs and patients must

Table 16. **Methods recommended for examining people incorporated by radioactive substances**

Radio-nuclide	Critical organs	Recommended methods of examination
^{239}Pu	Liver, skeleton	Determining the level of albumins, gamma-globulins, protein-connected hexoses, hexosamines, sialine acids, lactate-dehydrogenase, bone alkaline phosphatase, oxyproline
^{210}Po	Liver	Observing the liver functional condition
^{235}U	Kidneys	Determining the concentration of residual nitrogen, urea, potassium, alkaline phosphatase, lactate-dehydrogenase in blood serum
^{131}I	Thyroid gland	Determining the concentration of protein-bound and butyl-extracted iodine, direct detection of the hormones of the thyroid gland with the help of radio-immune methods
^{137}Cs	Muscles, parenchymatous organs	Determining serum enzymes that have muscular origin (AST, creatine kinase, LDH and its isoenzymes), level of creatine and creatinin excretion
^{90}Sr	Bones	Estimating the functional condition of bone tissue, determine phosphorus and calcium in blood serum

undergo oncological examination. The frequency of alpha-fetoprotein (AFP) appearance make up 65–90% in tumors, but AFP is not seen in cholangiocellular cancers, angio- and reticulosarcomas of the liver. A great expressiveness of LDH_5, LDH_4, or LDH_3 is observed in malignant tumors of different localizations against a background of a slight increase in the total activity of serum LDH. However, the changes in isoenzyme contents or LDH total activity are absent in 1/3 of the cases of malignant tumors.

The analysis of the changes in the organism of people affected by ionizing radiation, allowed Ukrainian scientists O. M. Kovalenko to develop risk criteria of non-stochastic and stochastic consequences of irradiation:

— stable increase in the level of antioxidant system (AOS);
— accumulation of lipid peroxidation products (LPO) ;
— stable disorders in the vitamin and microelement balance;
— functional inferiority of the haemopoietic system with quanti-

tative-qualitative disorders in the content of blood cells, which have stable or frequent relapsing character;

— structural and functional disorders in blood metalloprotein;

— stable or relapsing changes in the cellular and humoral links of the immune system;

— presence of vegetovascular dystonia (disfunction) syndrome, like the appearance of diencephalolimbic-reticular complex pathology;

— stable changes in an individual, cognitive disorders and disorders of the emotional-will sphere (stable psychopathological conditions), occurring after radiation influence;

— long (for some years) regulative changes in hormonal homeostasis (hypercorticoidism, hyperinosemia, hypotestosteronemia, hyperestrogenemia, hypogonadotropinemia, hyperangiotensinemia, hyperprolactinemia, etc.);

— decrease in physical work ability, dystonic character of reaction to physical loads and decrease in aerobic maintenance;

— decrease in the tolerance of glucose, dyslipoproteinemia, hyperglobulinemia and other subclinical (latent) appearances of disordered metabolism;

— subatrophic and atrophic changes in the mucous of the respiratory ways, erosive and ulcer changes in mucous of the stomach and intestines as a result of entering various irradiators and its local action;

— stable changes in the automicroflora (dysbacteriosis) of the intestines, mouth, skin as indications to a decrease of non-specific resistance and local immunity in an organism;

— stable or reversible (frequently relapsing) hyperbilirubinemia, hyperenzymemia and functional insufficiency of liver polygonal cells, which have no connection with the viral, toxic and autoimmune liver damage;

— high levels of absorbed dose by the thyroid gland, chronic thyroiditis as a condition of hypothyroidism development;

— cataractogenic doses in total gamma-irradiation (more than 2Gy) and applicational action of beta-irradiations on eyes.

According to O. M. Kovalenko the criteria of development of stochastic consequences may be the foolowing:

— high level of stable chromosomal aberrations or its accumulation with time, the appearance of clones of aberrated cells in the bone marrow and blood;

— the chronic myelodisplastic syndrome;

— the chronic immune depression and the autoimmune syndrome;
— presence of metaplasia of integumentary epithelium of the bronchi mucosa and the mucous of the gastrointestinal tract;
— consequences of irradiation burns on the skin and underlying tissues;
— increased levels of cancer-embryonic antigens, which are revealed in the dynamics;
— stable increase in polyamine concentrations (putrescin and spermidine);
— stable hypersomatotropinemia;
— stable hypocholesterinemia.

Chapter13
MEDICAL PROTECTION, PRINCIPLES OF PROPHYLAXIS AND TREATMENT OF RADIATION AFFECTIONS

A so-called medical protection should be conducted in case when radiation of people in doses higher than the permissible limits is inevitable.

13.1. PHARMACOCHEMICAL PROTECTION FROM RADIATION DURING ITS EXTERNAL INFLUENCE

Unfortunately, physical protection can be not always conducted completely. For example, physical protection can not be carried out even during X-ray therapy of malignant neoplasms. Therefore besides of physical protection or alongside with it, it is necessary to find means and methods directed at the increase of stability of an organism to radiation.

Weakening of damaging action of ionizing radiation can be obtained in the conditions of oxygen starvation or acute oxygen insufficiency of cells and tissues at the irradiation moment; an increase in oxygen content intensifies this action.

The protective effect of oxygen starvation is shown irregardless of the fact, what causes the oxygen deficiency in cells at the exposure moment: decrease in oxygen quantity, squeezing the blood vessels in the irradiated section during radiation, depression of the respiratory center (for example, morphine), blocking of haemoglobin by carbon monoxide or any other methemoglobin former, blocking or weakening tissue breathing.

The following processes help increase radioresistency of an organism in hypoxia conditions:

— increase of the power of the mitochondrial system, oxygen utilization in tissue, including haemopoietic;

— reorganization of metabolism due to an increase in anaerobic processes;

— decrease of the energetic expenses when the organism can manage a smaller quantity of oxygen, because a number of physiological functions are established on a lower level;

— increase of the haemopoietic base.

The basis of the radioprotectors protection mechanism may involve the following processes:

— competition for strong oxidizers and free radicals, which are formed as a result of radiolysis of water;

— increase of endogen thiole compounds in tissues;

— formation of mixed disulfides and a temporary reverse in their connection;

— formation of temporary reverse connections with sensitive groups of vitally important enzymes or other protein molecules, which provide protection from the damaging action at the moment of exposure;

— formation of strong compounds with heavy metals, providing accelerated current of chain reaction of oxidation;

— migration of surplus of energy from the macromolecules to the radioprotectors;

— inhibition of the chain oxidation reactions with branched links, which connect active radicals (forming in an organism at the exposure moment), causing an interruption of the reaction;

— absorption of secondary ultraviolet irradiation, stimulating the macromolecules, such as nucleinic acid;

— increase in stability and mobility of the organism's protection mechanisms;

— prevention of disorder of interaction of excitation and inhibitory processes in the CNS;

— metabolism depression;

— detoxification or acceleration of toxic products excretion from an irradiated organism, etc.

13.2. ANTIRADIATION MEASURES

Antiradiation measures differ by the mechanisms of antiradiation influence, the time used and the sphere used.

I class. *Radioprotectors* (radioprotective preparations) are synthetic or biological chemical compounds (cysteine, glutathione, serotonin), which should be injected into the organism immediately or 10–15 min before acute lethal irradiation.

The most effective radioprotectors belong to two groups of chemical compounds: *mercaptoalkylamine* (cysteine, cystaminum, cystaphos, gammaphos, etc.) and *indolyalkylamine* (triptamine, serotonin, mescaline, etc), in which tiol groups are absent.

II class. The methods of treatment for radiation sickness are directed at the struggle with certain damages:

1) *bone marrow* — transplantation of bone marrow, embryonic tissue, haemotransfusion, blood components and blood substitutes, injection of haemopoiesis stimulators, etc;

2) *intestinal, autoinfection* — antibiotics of wide profile,

3) *haemorrhagic* — transfusion of thrombocyte mass, antihaemorrhagic means;

4) *toxemia* — haemosorption, enterosorption, plasmapheresis, etc.

According to data of Ukrainian scientists A. E. Ramashko, L. P. Kindselsky, M. N. Kovalenko, and A. I. Avramenko, the primary specialized medical measures for people suffering from acute radiation sickness due to the Chernobyl accident are directed at the excretion of incorporated radionuclides and decomposition products of tissues from the affected organism. Intensive disintoxication therapy with washing the stomach, intestines, forced diuresis, haemosorption and enterosorption, stable ion prescription are used. Simultaneously by indications active symptomatic therapy was conducted, protein and water-electrolyte metabolism well corrected. Special treatment was based on anti-infection principles and supporting therapy, consisting in a patient isolation, intestinal decontamination, antibiotics and substantial transfusions of blood cell components. Transplantation of the allogenic bone marrow or human embryonic liver cells was applied in case of irreversible myelodepression prognosis. The accepted scheme of acute radiation sickness therapy was individualized depending upon the clinical picture, determining the syndrome (or syndromes) in the dynamics of the height of the disease, the condition of the local radiation damages and the arising of complications.

Various combinations of preparations with radioprotive, antioxidant, adaptogenic, membrane-protective, haemostimulating, immunomodulating, hepatotropic, nootropic, sedative and other actions (O. M. Kovalenko) were prescribed at the hospital stage of rendering aid to people suffering from acute radiation sickness.

Supporting therapy, directed at the prevention of aggravations and relapses (drug treatment, massage, physiotherapy, exercise therapy, and reflexotherapy) was used at the ambulant stage.

A complex of natural-climatic factors and drug-free methods of treatment directed at the increase of protective force and non-specific resistency of an organism are used at the sanatorium stage.

III class of antiradiation preparations are used under the conditions of low intensity irradiation, they are capable of increasing the common non-significant resistance and radioresistency of an organism, eliminate the initial radiation disorders arising at the level of biological membranes, cellular organelle, vascular-tissue barriers, systems of homeostasis regulations, etc. Preparations of biological origin and synthetic preparations with antioxidants (AO) and antiradical action (AO — vitamins from groups A, C, E, K, P, carotenoids, AO-enzymes, especially super-oxiddismutasa, catalase, vegetable phenolic compounds, synthetic AO, ional, butylated hydroxyanisole, ethoxyquinn, etc), adaptogens (ginseng, eleuterococc, schizandra chinensis, gold root, licorice, achibocea, etc.) as well as some immunomodulators belong to this class of antiradiation measures.

The use of these preparations must be course-like, instead of constant, to prevent adaptive reorganization of an organism, which can bring the helpful effect of this preparation to naught.

Tens of plants containing adaptogens grow wild and are cultivated in Ukraine. Proper adaptogen properties of *Potetialla erecta (L) Rarusch* were found among the examined in the laboratory of experimental pharmacology of the Experimental Radiology Institute of Medicinal Herbs and Fruits.

Potetialla erecta (L) Rarusch in the form of radicis tincture protects effectively early changes that are observed in an organism in the case of long influence of low levels of gamma irradiation. The chemical contents of *Potetialla erecta (L) Rarusch* (tannins, saponin, organic acids and others) neutralize free radials, peroxide and hydrogen peroxide of lipids and other dangerous products formed in tissues during irradiation.

Some metabolites of the organism — sodium succinate, sodium malat, sodium lactate, histidile, sodium gamma-hydroxybutyrate, etc. — belong to adaptogens.

IV class — special class of antiradiation measures consisting of enterosorbents, which use is directed at the bonding and excretion of radionuclides from the organism.

Unfortunately, there are no sorbents, which would interact only with radioactive atoms and wouldn't with their stable analogues, i.e. the sorbent together with radionuclides always take useful electrolytes, metabolites, microelements, vitamins, etc. from the organism.

Therefore sorbents should be applied only in case of acute influence of a significant quantity of radionuclides. In conditions of stable entering of low concentration of radionuclides the use of sorbents is inexpedient and even dangerous.

None the less, enterosorbents are more promising as measures of overcoming endogen intoxication, which arises as the appearance of serious diseases of the liver, kidneys, etc.

13.3. RADIOPROTECTIVE NUTRITION

The entering of artificial radioactive substances into the environment is accompanied by the inclusion of their certain quantity in the migration process, accumulation in food products and then directly into the human organism. This problem has special urgency and acuity after the Chernobyl NPP disaster.

The human health is influenced by not only the structure of food rations, but also the contents of contaminants in them — foreign substances in today's social-ecological situation.

The insufficient use of basic food substances (proteins, vitamins, polyunsaturated fatty acids, mineral acids) promotes the occurrence of so-called deficiency diseases, decrease in an organism's resistability. In conditions of higher radiation influence optimal maintenance of a person with high-grade proteins — sources of irreplaceable amino acids — have giant significance. The latter regulates the anti-intoxication function of the liver, takes part in haemopoiesis, increases immunity, promotes high-grade assimilation of vitamins and other substances.

Proteins are the carriers of sulfhydryl groups — effective in-activators (competitors), which are oxidized with active radicals easier than with biological radicals such as in beef, pork, poultry, rabbit, eggs, fish, milk and milk products. Vegetable proteins, which are contained in haricot beans, peas, soybeans, green peas, buckwheat, oatmeal, grain products from coarse ground grain, have important significance. The specific gravity of vegetable proteins must be 60% for children and adolescents and 50% — for adults of their general quantity. The specific gravity of fats must be no more than 30% for children and people of old age, for adults 33% from the common energetic ration value.

Polyunsaturated fatty acids in a complex with other (lipotropic) substances (sulfur-containing amino acids, vitamins, and phospholipids) significantly influence basic metabolism. Their insufficient contents with increased radiation loads reduce the intoxication function of the liver and help accumulate metabolites in the organism's tissues.

The providing of an organism with carbohydrates, first of all food fibers and pectin substances is of great value. The presence of original carboxyl groups of hyaluronic acid in pectin substances causes their ability to bind metal ions in the digestive tract.

Vitamins are irreplaceable food substances for the organism; they should be received in the form of polyvitamin preparations like "Undevit", "Revit", "Pentavit", etc. Vitamin P was one of the first vitamins to be used as a radioprotector. Its biological action in conditions of ionizing radiation is protection of vascular walls, first of all of the capillaries.

A sufficient contents of Mg, K, Ca salts in a diet promote a decrease in accumulation of radioactive Cs and Sr in an organism. The enrichment of an organism with optimal Se quantity possessing antioxidant properties as well as easy assimilated iron participating in haemopoiesis has important significance. The specified elements are contained in food products of animal and vegetable origin.

A diet of an adult should include no less than 400 g of vegetables, 500 g of potatoes, 300–400 g of fruits and berries, 500 g of milk and milk products, 50–70 g of cheese, 200–350 g of meat and fish, 30 g of vegetable oil, 60 g of grains and beans, 25–30 g of butter, 1 egg, 20 g of sugar, and 300–400 g of bread.

Children must have per day in average 300–400 g of vegetables, 100–150 g of fruits and berries, including juice with pulp (110–150 g), 100–200 g of meat and meat products, 40–50 g of fish and fish products, 10–25 g of vegetable oil, 30–60 g of grains, 0.5–1 egg and 90–350 g of bread. It is recommended to give children lard 15–25 g, which contains biologically active arachidonic acid. Half of the bread eaten by children must be rye.

It is necessary to remember that the contents of radioactive substances significantly decreases during culinary processing of products (Table 17).

It is recommended to use secondary broths for feeding: meat and bones washed with cold water, cooked for 10 min, this broth is poured off, and then the meat and bones are washed with cold water and cooked. Fish is prepared in the same way.

13.4 PRINCIPLES OF PROPHYLAXIS AND TREATMENT OF LATE EFFECTS OF RADIATION DAMAGES

Protective methods that prevent the organism's death from acute radiation sickness, as a rule, do not eliminate the occurrence of the late effects of ionizing radiation action.

Proceeding from the concept that in the evolution of premature aging and the diseases connected with it reactions of the active form of oxygen and pereoxidation of lipids, have a significant importance, it appears logical to use antioxidants for the purpose of prophylaxis of premature aging.

Table 17. **Influence of culinary and technological processing of food on radionuclide contents**

Product	Type of processing	Decrease in radioactivity of the product, %	
		^{137}Cs	^{90}Sr
Potato with the peel	Boiling in fresh water	3	3
Peeled potato	Peeling the potato	0–40	30–40
	Boiling in fresh water	30–45	21
	Boiling in salt water	50	30
Beef	Boiling	70	50
Fish	Boiling	60	–
Milk	Preparing cottage cheese	79	73
	Preparing baked butter	100	100
Mushrooms	Washing under fresh running water	18–32	–
	Boiling twice for 10 min with the broth drained each time	97	–

The substances possessing antioxidant action are divided into two groups:

Antioxidants of biological origin are water and fat soluble. Vitamin C, citric and nicotine acids, sulfur-containing amino acids, vitamins of the P group and benzoic acids belong to the water-soluble. Vitamins of the E group (tocopherol), a majority of phospholipids, vitamins of the K group, bilirubin, biliverdin and other steroid hormones belong to fat-soluble.

Synthetic antioxidants. A number of antibiotics have high antioxidant properties.

Lipids of various organs of an organism have antioxidant activity. Antioxidant action is the universal property of tissue lipids of all organs in relation to energetic substrates.

Taking into account modern data about the etiology of atherosclerosis, regulation of the condition of the psycho-emotional sphere, restriction of emotional stresses that mobilize glucocorticoids and catecholamins play a great role in prophylaxis and treatment.

Physical activity is also of great value in atherosclerosis prophylaxis: gymnastics, physical work in the air, walks and dosed out walking, tourism. Stimulations of metabolism and the preservation of physical activity are promoted by water procedures — rubdowns, douches in the mornings with the room temperature water, warm and cool and contrast temperature showers.

Ultraviolet radiation (15 procedures per a course) gives favorable results in patients with cerebral atherosclerosis.

The treatment in South Crimea land influences atherosclerosis patients favorably. Dosed air and air-solar baths, sea baths, sleeping on the sea bank and in climate pavilions, excursions are prescribed during the warm seasons. Dosed walks at the sea shore, a day sleep at an aerarium are recommended in cold seasons.

Physical methods of treatment must be applied widely in irradiated people as preventive and complex therapy of atherosclerosis symptoms with signs of ischemia of vital organs — the heart, the brain, and the extremities. These methods help to improve the functional condition of the cortex processes and VNS processes, stimulate metabolism, mobilize potential protective forces of an organism.

13.5. ANTIMUTAGENIC PROTECTION

A complex of treatment-prophylactic measures directed at a decrease in the level of genetic loads in the population and the protection of the population gene pool was introduced as a part of the state program "Ukrainian population gene pool protection" carried out under the guidance of Ukrainian scientist I. R. Barylyak.

The actuality of the antimetagenic problem depends upon the mutagenesis and carcinogenesis mechanism, as a result a majority of antimetagens are effective not only against processes induced by mutagenesis, but also carcinogenesis.

The following compounds are antimutagenic:

1. Dismutagens, inactivating the mutagen agent.
2. Modifiers of mutagen metabolism.
3. Compounds, decreasing the DNA separation and replication mistakes.
4. Preparations with unknown mechanism of antimutagenic activity.

However, as it follows from this classification, only the substances belonging to the third group have true antimutagenic activity. The others can influence the level of mutation. However, their influence appears at various levels of toxic(pharmaco)dynamics and kinetics, i.e. affects the metabolism of a compound possessing antimutagenic activity.

Antimutagens and their metabolites of a natural origin attract ever-increasing attention last years. Vitamins, pigments, amino acids, phenols and polyphenols belong to those substances. All of these compounds are present in various concentrations in raw staff — vegetables, fruits, herbs, a majority of which people use in food.

All plants, especially fresh leafy vegetables, dog rose fruits, unripe walnuts, black currants, potatoes, pine needles, spruce, larch contain vitamin C, which is the inhibitor of endogen formation of mutagens and oppresses the formation process of mutagens and their predecessors. The antimutagen effects of ascorbic acid can be caused by its influence on the immunocompetent system, called to "clean up" the organism from the mutant changed cells.

Vitamin E (tocopherol) is contained in vegetable products, especially in vegetable oil in enough quantities. Antimutagen properties of alpha-tocopherol are substantially caused by its ability to inhibit free-radical processes.

Vitamin K accumulates in leafy vegetables, carrot roots, fruits of a pumpkin and other plants. Vitamin K decreases the frequency of spontaneous and inductive chromosome aberrations.

Folic acid, contained in yeasts, liver, and green leafy vegetables, has antimutagen properties.

Vitamin B_2 (riboflavin), yellow pigment, is contained in small quantities in green leafy vegetables and grass buds. It is a part of flavin enzymes, participating in oxidation processes.

Plants, containing carotene (provitamin A) are rich in vitamin A. Salad, spinach, sorrel, green onion, celery, cabbage leaves, tomato, sweet peppers, roots of red carrots, apricots, plums, sea-buckthorn, bibberry, dogroose fruits, lucerne, flowering red clover, and a number of other plants contain vitamin A. The antimutagen effect of vitamin A exceeds other vitamins in some cases. Vitamin A increases the titer of circulating antibodies and a number of antibody-forming and englobed cells, influences the cellular membrane and the synthesis of corticosteroids, influences the excretory function of the liver. The absence of vitamin A in food renders an inhibitory action on the mitotic activity of cells.

Retinoids belong to antimutagens of endocellular action, inhibiting cellular replication and promoting nucleophilic DNA sites.

Beta-carotene is the pro-vitamin of vitamin A — a pigment widely spread in plants. Carotene is not synthesized in the tissues of vertebrates, therefore it must enter with food. Thanks to its ability to suppress free radical processes, carotene is an effective antimutagen.

Colored substances — pigments — are included in the tissue of all organisms. Porphyrins, carotenoids, ficobilins, anthocyans, flavones, melanins, etc. belong to pigments. Porphyrins (chlorophyll, bacteriochlorophyll, haemoglobin, cytochrome, etc.) are effective antimutagens. The frequency of sister chromatid changes decrease under the influence of chlorophyll in the cultivated lymphocytes of a person.

Mutagen inhibitors, acting extracellularly and intracellularly, are a complex of phenolic compounds, contained in the plants. It is vitamin E, coffee, ferrule, ellagic acids and other phenol compounds, having easily eliminated hydrogen atom in their chemical structure and are capable of interrupting reactions of free radicals formation or form stable non-active phenoxyle groups with them.

The antimutagenic effect of natural polyphenol complexes can be connected both with the direct action of antimutagens and the automutagens or by products of their transformation, and with the activation of cellular regenerative systems. Some phenols suppress the mutagen forming process from its predecessors. The antioxidant properties of various phenols are defined by the peculiarity of their chemical structure, by the quantity and hydroxyl group position in particular.

The mix of tannery substances are contained in oak bark and chestnut, in sumac leaves, quebracho wood, bark of the willow, birch, and spruce are called tannins. A majority of unhydrated tannins belong to the flavones class. All tannins contain a big numbers of phenol OH groups and have an ability to form durable connections with proteins and some biopolymers as well as to bind bacterial toxins and toxic salts Ag, Hg, Pb in the organism, decrease spontaneous inducted mutability.

Yellow, orange and red crystals-bioflavlonoids (vitamin P) are contained in the leaves, fruits, roots, seeds of plants. Dog rose fruits, lemons, flowering buckwheat are especially rich in them. Catechins, flavonols, flavones, and coumarin belong to the flavonoid group. Flavonoids are the natural antioxidants that bring about their antimutagen properties.

Catechins are contained in leaves of tea, vine rod, cocoa beans. It is described by the genetic activity of catechins, extracted from a tea plant and epygallocatechins.

The fragrant substance — coumarin is contained in a numbers of plants (for example, in Melilotus officinalis (L) Pall.). Particularly, the giant-fennel fruits contain 1.09% of coumarin and the roots — 0.62%. Some coumarins effectively induce chromosome aberrations and/or posses increased cancerogenic activity; others render antimutagen antineoplastic effect that is connected with the presence of methyl group in the 4, 5, 6 or 7 position. 7-oxicumarius camomile flowers and in the wild pepper bark. Its antimutagenic activity is well-known.

Quercetine is a natural substance, pigment, present in vegetative tissue, belongs to the group of flavonoid. The antimutagen properties of quercetine are caused by its ability to inhibit free radical processes.

Rutin is a 3-ramnoglucoside of quercetine. Tea leaves, ruta, buckwheat are rich in it. Rutin completely inhibits the oxidation process of amibiphenil in the concentration of 10^{-5}–16^{-6} M and prevents its genotoxic action.

Fragrant substances are present in numerous valatile oils, giving them a specific odor. The characteristic antimutagen activity is inherent in some falconoids (anisaldehyde, cinamaldehyde, cinnamon aldehyde). Caffeine, influencing the reparation processes, is received from the seeds of the coffee tree, tea leaves, cola seeds etc. The antimutagen properties of caffeine were described as long as in the 60s. The modifying effect of caffeine is different at various levels of mutagenesis. Caffeine protects the chromosome apparatus from damages by mutagens at relatively low levels of mutation action, the effect of caffeine to a great degree depends on the genotype of an organism at higher levels of mutagen action.

13.6. PRINCIPLE OF ACCELERATION OF RADIONUCLIDES EXCRETION

When alkali-earth, rare-earth and heavy elements of radionuclides enter an organism, an insignificant natural excretion through the kidneys and intestines always happens. However, as a rule, 50–80% of the radionuclides that enter an organism are held in it because of the formation of insoluble in water compounds with biosubstrata.

The problem of speedy elimination of radionuclides from an organism is relatively practicable in acute cases, while the radionuclides are present in blood in a free condition. This task becomes significantly complicated in case of chronic intoxication when radionuclides are chemically bound with biosubstrata.

The measures directed at the prevention of radionuclide deposition in tissues and their accelerated elimination from an organism consist of the inclusion of radionuclides in the structure of good soluble compounds or conversion of the poorly soluble radionuclides compounds into easily soluble.

Complex formers capable of forming durable easily soluble compounds with radionuclides are used for this purpose.

The complex formers must meet the following requirements:

1) be nontoxic;

2) form durable water-soluble complexes with radionuclides;

3) they shouldn't be included in metabolism processes in an organism and undergo some chemical conversions;

4) they must not circulate for a long time in the blood and reach the deposition place of radionuclides at a single introduction.

The use of substances accelerating the excretion of radionuclides can lead to intensive exposure of the kidneys because of destruction of their complexions so that the condition of an organism can be detected by the condition of the kidneys. The organism has storage of proper natural complex formers. A great number of compounds that are metabolism products: lemon acid, bile acid, amino acids,

Table 18. **Substances used for reducing absorption and accelerating excretion of some radioactive substances from the organism (according to N. P. Maschenko and V. A. Kurashko, 1992)**

Preparation	Dose, method of intake	Substance
Adsorbents		
Adsorbar (barium sulfate with the development of adsorptive surface) or barium sulfate — roentgen-contrast substance	15 g per 200 ml of water, p.o.	Products of nuclear division, strontium, barium
Sodium or calcium alginate	15 g per 200 ml of water, p.o.	Strontium, barium
Bentonite	20 g per 200 ml of water, p.o.	Cesium
Magnesium oxide	30 g per 200 ml of water, p.o.	Products of nuclear division, molybdenum, zirconium, barium, curium
Polisurmin	4 g per 200 ml of water, p.o.	Strontium
Complex-formers		
Dekaptol	2 ml of a 10% solution, intramuscular	Cesium
Sodium or zirconium citrate	1 tbsp. of 10% solution 3 times a day	Cesium
Oxycomplexons	5–10 ml of a 5–10% solution, intravenous	Zirconium, ruthenium, niobium
Pentacinum	10 ml of a 5% solution in an isotonic solution of sodium chloride, intravenous, dropping. Aerosol (for inhalation)	Ruthenium, barium, cesium, neptunium, plutonium, curium
Calcium-tetacin	40 ml of a 5% solution in an isotonic solution of sodium chloride, intravenous, dropping	Cesium
Ferrocin	1 g per 10 ml of water, p.o.	Cesium
Phosphycin	10 ml of a 10% solution in an isotonic solution of sodium chloride, intravenous	Neptunium

purin, pirimidin, riboflavin, etc. belong to the natural complex formers.

The accumulation of radioactive elements in an organism can be decreased successfully by blocking the reticuloendothelial system, which is responsible for the delay and accumulation of radionuclides, with preparations of iron.

The intake of stable iodine like potassium iodide (KI) or iodate (KIO_3) blocks the accumulation of radioactive iodine in the thyroid gland.

The iodine absorption by the thyroid gland is normalized approximately in one week after a single intake of the preparation. In a long intake of iodine radioisotopes in an organism, an effective blockade of the thyroid gland can be supported by repeated doses of iodine preparations.

The maximum effect of iodine prophylaxis is marked in case of preliminary (before the iodine radionuclides entering an organism) intake of stable iodine or immediately after the entering. The intake of stable iodine after 6 h decreases the exposure dose of the thyroid gland approximately 2 times, the decreasing dose will be insignificant in 24 h.

When radionuclides enter an organism to decrease the dose of internal exposure, measures for decreasing the absorption, reduction of time of their stay in the digestive system and the upper respiratory ways as well as acceleration of their elimination from the organism are conducted. The nasopharynx, the oral cavitiy and the stomach are washed out, complexons inhalation or the intake of absorbents (depending upon the features of radionuclides and their ways of intake) with subsequent application of expectorates, emetics, laxatives and diuretics, cleansing enema are conducted for this purpose. A list of adsorbents and complexons, which can be used to decrease the reabsorption of radionuclides and accelerate their elimination from the organism are given in table 18.

Chapter 14
PROPHYLACTIC MEDICAL EXAMINATION OF PEOPLE AFFECTED BY THE ACTION OF IONIZING IRRADIATION

The purpose of prophylactic medical examinations is to conduct treatment-prophylactic, social-sanitation and rehabilitation actions directed at the decrease of mobility and disability, increase of workability.

14.1. PRINCIPLES OF CLINICAL OBSERVATION OF PEOPLE WORKING WITH IONIZING IRRADIATION SOURCES

Clinical observation of people working with sources of ionizing irradiation includes primary and periodical checkup.

The following tasks are solved during a primary checkup:

— to receive the initial data of the workers' health condition, which is necessary for solving questions about the character and cause of possible subsequent deviations from the norm;

— non-admission to work for people, which contact with ionizing sources can cause health disorders or aggravate and worsen the present disease course.

The purposes of periodical checkup are the following:

— early recognition and prophylaxis of the common somatic diseases including those ones which prevent from working with sources of ionizing irradiation;

— clinical estimation of the common condition of work of different professional groups, necessary for substantiated systems of treatment-prophylactic measures and the organization of clinical observation and rational employment;

— timely detection of initial deviations of professional character, choice and providing necessary prophylactic events, which protect their progress.

Periodical checkups of people working with sources of ionizing irradiation include obligatory examinations of peripheral blood analyses in the following volume: definition of the quantity of leukocytes, thrombocytes and erythrocytes in 1 liter of blood, haemoglobin (g/l), calculation of the quantity of reticulocytes, leukocyte formulas as well as ESR definition.

The above-mentioned volume of peripheral blood examination taking into account modern levels of doses at production (commonly, less than 15 mSv) is not enough to reveal radiation effects and has only common medical value. More information on the action of very low doses is given by the appearance of "group shifts" which are found in comparison with a corresponding control group.

The frequency of checkups depends upon concrete work conditions. The functional conditions of the critical organs are the most completely examined. The medical conclusion is made according to the results of the checkup. It gives a picture of health condition and a possible dependence of the revealed changes on the action of ionizing irradiation and other work conditions.

14.2. NATIONAL REGISTRY OF UKRAINE

The National Registry of Ukraine (NRU) represents a system of revealing, gathering, examining, keeping (at magnate carriers), automatic processing and analysis of the information about the health condition, dose load, medical security of people affected by radiation exposure due to the Chernobyl NPP (CNPP) disaster, for processing the system of measures directed at the preservation of health and providing of scientific and sociological investigations. The purpose of the NRU is the preservation of health of the Chernobyl accident survivors by way of developing organizational-medical and social measures.

The tasks of the NRU are the following:

— creation of the longtime registry system for the people living in Ukraine;

— personal observation and estimation of the health condition of people belonging to the NRU account by the results of the purpose prophylactic medical examination;

— providing a prolong control over the survivors' health;

— revealing the trustworthy causal relations between health indices and risk factors of radiation and non-radiation origin;

— gathering, long storage of information on the health condition of the population affected by the CNPP accident taking into account the social-hygiene, social and social-psychological factors, personal and common dose load of internal and external irradiation;

— estimation and prognosis of the health condition of the affected population, medical-demographical, epidemiological and social-psychological situation;

— providing a long-term control over the health condition of the affected people, epidemiological changes;

— development of prophylactic events, directed at the decrease in negative consequences of the CNPP accident on the basis of the NRU data;

— informational support of special scientific investigations of clinical, epidemiological, medical-biological and sociological character.

The population, subjected to observation during their whole life is conditionally divided into groups of registration:

1. People who participated in the CNPP accident clearing up.
2. People who were evacuated from the zone of radiation influence or who independently left the contaminated zone during the evacuation period since 26.04.86.
3. People who are living or lived at the indicated territories.
4. Children who were born from people of the 1–3 groups of registration, not depending on their parents' present residency.

5 categories of victims are distinguished depending on the conditions and exposure dose (Table 19). People of each category are examined in complete volume during prophylactic medical examination in the establishments indicated in table 19.

The following categories of people affected after the CNPP disaster were distinguished to determine privileges and compensations:

1. The CNPP accident cleaning up participants, which lost partly or completely the work ability as a result of the CNPP accident, people with radiation syndrome, as well as people which have a disease connected with the consequences of the CNPP accident — 1st category.
2. The CNPP accident cleaning up participants which worked at the alienation zone in 1986–1987 as well as those injured because of the CNPP accident and evacuated from the alienation zone — 2nd category.

3. The CNPP accident cleaning up participants which worked at the alienation zone in 1988–1990, as well as people affected after the CAPP disaster, who constantly worked, work or live at the territories of unconditional (obligatory) and guaranteed voluntary migration — 3rd category.

4. People who constantly work and live at the territories of intensified radio-ecological control — 4th category.

Groups of prophylactic medical examination registration are replenished as a result of the work of advisory councils, which establish the causal relation between the disease and works on the Chernobyl NPP accident consequences cleaning up.

The establishment of the causal relation of diseases and disability with the works on the Chernobyl NPP accident consequences cleaning up and their professional character is carried out by the central advisory council on the basis of the USCRM and regional advisory councils in the regional centers.

The regional interdepartmental advisory councils function according to the following instructions:

1. When there is not enough information about the patient, the council gives an inquiry about the necessity of additional information to organs of public health at the place of observation of the health condition of inquiring people.

2. In case of the absence of dosimetric documentation and data on the professional route, doses of internal and external exposure during the working period at accident consequences cleaning up, they make an inquiry to the service providing radiation control at accident cleaning up participants and its consequences.

3. Documents of people who were and are participants of the accident and its consequences cleaning up, as well as those who got sick with the purpose to establish the relation of the diseases with the action of II and other dangerous factors are considered.

4. The documents received no later than 10 days before the session are considered at the session of the council.

5. The session of the council is held as the letters, documents come, but no less than once a quarter.

6. The council considers the next documents:

— the letter or application of people, petition of trade-union or other public organizations, materials of directive organs, petitioning of the organs of public health, writings from the case record or from the out-patient card, conclusions from the observation places or the patient's treatment about the health before and after their partici-

Table 19. **Categories of prophylactic medical examination of the Chernobyl NPP survivors**

Category observed	Characteristics of the examined people	Exposure dose, sGy	The establishments for prophylactic medical examination
1	People who had radiation sickness and who have radiation sickness or who received radiation damage, as well as people who have a disease that is directly connected with radiation damage and injuries as a result of the of the CNPP accident cleaning up		Specialized establishments, Scientific Research Institute of Medical Radiology of the Academy of Medical Science of Ukraine
2	The CNPP accident cleaning up participants evacuated from the radiation zone, as well as people, who received an exposure dose: — adults — pregnant women (at the moment of the accident) and children born in them — newborns, children, teenagers	 25 and more 5 and more 5 and more	Specialized establishments
3	All the rest CNPP accident cleaning up participants irregardless of the radiation dose: — adults — pregnant women (at the moment of the accident) and children born in them — newborns, children, teenagers	 10–25 1–5 1–5	They are observed at their local clinics; they are given consultation at specialized clinics if necessary
4	All the rest evacuated from the action zone irregardless of the radiation dose People, living at the controlled territories and who has received radiation dose	 5–10	They are observed at their local clinics. They are given consultation at specialized clinics if necessary

	All pregnant women and children born in them living in the controlled territories irregardless of the radiation dose Children born in a father who received a radiation dose of more than 25 sGy before conception		
5	All the rest people living at controlled territory who received a radiation dose, and children born in parents of the 1–3 groups	Up to 5	They are observed at their local clinics. They are given consultation at specialized clinics if necessary

* Irradiation of the whole body surface within the first year of the accident at the account of the internal and external irradiation

pation in the Chernobyl NPP accident consequences cleaning up, certified by the medical-prophylactic establishment with a seal stamp, and the results from the clinical blood analysis and other laboratorial investigation;

— a copy of medical documents about the results from the check up before to assign to a job in the accident's zone and after returning;

— data on the frequency and length of the diseases with temporary disablement (before and after the accident);

— data on the level of internal and external exposure, character and place of work for the accident consequences cleaning up.

7. The council has a right to ask for the original medical documents and enlist medical workers which participated in the observation and treatment of the patients.

8. If necessary, the patient is called to the council meeting and is hospitalized in the SCRM clinic or the other professional specialized establishment.

9. If necessary to consider a question at the council meeting, the patient is given a medical certificate.

The establishment of ionizing irradiation influence on residents presents often a difficult task even with the use of modern diagnostic methods. It is explained, first of all, by the fact that irradiation does not cause any specific (pathognomonic) deviations, characteristic for factor only.

Last years the idea of overestimation of the low radiation levels factor in the development of pathological processes is considered while disregarding other non-radiation influences of the environment.

The reason is the fact that, when studing questions of the ionizing irradiation action, the characteristics of the ionizing action is represented in the quantitive expression but the estimation of the other factors has preferentially qualitative character.

The physician examining the affected residents not always has data about the health condition in the period before exposure.

Some chronic inflammatory processes having often a latent course, cause leuco- and neutropenia as well as astenization, complicating the differential diagnosis with radiation injuries of the same systems.

In these conditions information about the individual radiation affections is especially important.

14.3. ADJACENT SPECIALIZED REGISTERS

While working with Chernobyl registers, the necessity of access to various and detailed information of medical and dosimetric character arises. This information is mostly accumulated and stored in other specialized registers, related to adjacent knowledge branches.

The following specialized registers have been created in Ukraine:

1. The local iodic dosimetric register of Ukraine.
2. The register “Cancer of the thyroid gland”.
3. The register “Haemoblastosis”.
4. The oncological register.
5. The register “Children”.

Alongside with the register “Children” on the basis of the Institute of Epidemiology and Prophylaxis of Radiation Injuries of SCRM of the AMS of Ukraine, specialized sub-registers for deeper scientific researches of the children’s population with an increased radiation risk (radiation doses of the thyroid gland more than 2.0 Gy) are created.

14.4. PRINCIPLES OF PURPOSE PROPHYLACTIC MEDICAL EXAMINATIONS OF PERSONS EXPOSED TO RADIATION AFTER CHERNOBYL NPP ACCIDENT

Purpose prophylactic medical examination is a complex method of medical-prophylactic measures, providing dynamic observation for people exposed to radiation after the Chernobyl NPP accident in order to reveale and prevent diseases associated with multifactor influences of the Chernobyl accident consequences, including radiation; monitoring of the common incidence, disability and mortality rate during the active working period.

Providing of purpose prophylactic medical examination stipulates solving of the following basic tasks:

— estimation of personal and collective health of the clinically examined people both by way of individual medical checkups, and by means of analysis of integrated indices of the health condition by taking into account sex, age, professional and other features;

— differential active dynamical observation of the healthy people, patients having risk factors and sick persons;

Table 20. **Obligatory volume of examination of the adult population, subjected to the National Register of Ukraine**

Affected categories	Specialists that conduct the observation	Volume of instrumental and laboratory diagnostic examination
I II III	Therapist, hematologist, endocrinologist, ophthalmologist, neuropathologist, surgeon-oncologist, otolaryngologist, urologist, obstetrician-gynaecologist	Instrumental examinations: ultrasound, ECG Laboratory examinations: blood analysis (morphological, biochemical, immunological, hormonal, determination of the index of the coagulation system); urine analysis (general urine analysis, urine sugar)
IV	Therapist, endocrinologist, neuropathologist, surgeon-oncologist, obstetrician-gynaecologist	Instrumental examinations: ultrasound, ECG Laboratory examinations: blood analysis; urine analysis

— revealing and eliminating the reasons causing the diseases;
— development and duly providing of medical-sanitation measures, securing a healthy way of life.

The obligatory volume of a medical checkup of the adult population subjected to the National Register of Ukraine is presented in table 20. The obligatory volume of a medical checkup of children, teenagers under 15 years old subjected to the National Register of Ukraine is in table 21.

During a medical checkup special attention must be devoted to the revealing of radiation-induced diseases, radiation-induced pathological conditions; risk factors of the development of radiotropic disorders of organs and systems — endocrine, immune, haemopoietic, nervous, organs of vision.

Table 21. **Obligatory volume of examination of children, teenagers under 15 years old subjected to the National Register of Ukraine**

Affected categories	Specialists that conduct the observation	Volume of instrumental and laboratory diagnostic examination
I II III	Pediatrician, hematologist, endocrinologist, ophthalmologist, neuropathologist, surgeon-oncologist, otolaryngologist, gynaecologist	Instrumental examinations: estimation of physical development, ultrasound, ECG Laboratory examinations: blood analysis with unrolled formula (including leukocytic formula, content of thrombocytes, reticulocytes), TTH, T-3, T-4, common urine analysis, urine sugar
IV	Therapist, endocrinologist, neuropathologist, surgeon-oncologist, obstetrician-gynaecologist	Instrumental examinations: estimation of physical development, ultrasound, ECG Laboratory examinations: blood analysis; common urine analysis
V	Pediatrician, hematologist, endocrinologist, ophthalmologist, neuropathologist, surgeon-oncologist, gynaecologist	Instrumental examinations: estimation of physical development, ultrasound, ECG Laboratoryexamination: blood analysis; common urine analysis

14.5. SANITATION OF PEOPLE AFFECTED BY CHERNOBYL NPP ACCIDENT

Propagation of a healthy way of life occupies the main place in providing the rehabilitation and prophylactic measures directed at a decrease in the social risk factors. Lots of attention is devoted to the balance of food, which is selected taking into account of the presence of obesity, lipidemia, hypertension and digestive diseases. Explanatory work, reflex- and psychotherapy play a significant role in the fight with smoking and alcohol.

Physical activity is prescribed under individual programs with the purpose of hyperkinesias factor decreasing and workability increasing, normalization of body mass. The load intensity depends upon the physical condition, which is defined by the clinics data, tolerance to physical loads and general workability. The physical training program is regulated by such regimens as sparing, sparing-training and intensive-training.

Now professional reorientation of a majority of patients is conducted. However, the process of employment must be dynamical and vary according to the improvement process of the patient's condition, providing adequate work loads according to the function possibilities of the organism and the absence of ionizing irradiation at work. The number of people with an inadequate reaction type to loads has considerably decreased: the pulse cost of work decreased, the geodynamical reaction to loads became more adequate; changes on the ECG appear less often. However, the frequency of subjective causes limiting physical workability increased.

Gradual improvement of general health condition was observed in patients after acute radiation syndrome. However, the presence of a number of diseases as well as an increased risk of appearance of remote consequences from ionizing irradiation in them requests a long systematic lifelong clinical observation, conduction of rehabilitative and prophylactic measures.

Asthenic syndrome with various accompanying vegeto-vascular disorders arises most often in people affected by radiation action of the Chernobyl NPP accident. This syndrome is stable, resistant to various types of drug and drug-free therapy, accompanied by subjective, unpleasant sensations for the patient and often serves as the reason of hospitalization and transfer to an invalid group. Treatment of the asthenic syndrome must be complex and include the drug correction, psychotherapy in its complete volume and diversity. Tranquilizers (phenosepam, rudotelum, seduxenum, relanium, nozepam, etc.) in a combination with adaptogens such as the eleuterococc type, and nootrops, pyroxene for vegeto-vascular crisis with simultaneous reception of complex vitamins, fruit juices, phytopreparations are useful for asthenic syndrome. Psychotherapy in different variants, autogenic training, massage and self-massage are of especial value in the treatment of asthenic syndrome. Treatment of the accompanying diseases is necessary, which significantly increases the effect of the therapy carried out on the occasion of asthenic syndrome. The dosed work is also useful.

The investigations conducted in the Chernobyl accident consequences participants as well as in people living at hard radiation control zones prove that hypoxia action normalizes the intensity of free radical processes, increases the power of the antioxidant system, and significantly increases the activity of key enzymes of the respiratory cycle.

The clinical experience testifies that a combination of principles of chronotherapy and chronopharmacology and the use of antioxidants (some tranquilizers, nootrops, flavonoids, carotenoids, vitamins, amino acids, microelements) by patients with blood circulation diseases, residing at the contaminated territories, significantly increases the efficiency of the treatment and decreases a possibility of complications development.

At present the treatment of autoimmune chronic thyroiditis belongs to difficult problems and come mainly to the use of thyroid preparations and prednisolone. The appointed measures are inefficient in some cases, and sometimes their application is impossible because of side effects.

As a result of long observation of people with cerebral-vascular disorders affected by ionizing radiation due to the CNPP accident, a system of differential medical-rehabilitation measures was developed (system provides three stages: polyclinic, hospital, sanatorium treatment). The revealing of patients, their examinations, dispensary observation, the treatment course are provided in the policlinic conditions. The patients are transferred to hospital treatment in appearance of the decompensation stage in the condition of the cerebral circulation. Vasoactive, vegetotropic means in combination with antiparoxysmal, adaptive measures, hypertensive, general reinforcing and other preparations (depending upon the leading clinical syndrome: liquor-hypertension, asthenic, paroxysmal conditions) are applied as basic therapy.

After the hospital treatment, rehabilitation and sanitation are provided in the conditions of a sanatorium, mainly of a local climate zone. The basic accent during sanitation at the sanatorium is stressed on non-medicamentous methods (climate, psycho-, herbal medicine, dietary food, physical training, massage, acupuncture, information-wave therapy, bioadaptive regulation).

Methods of Health Improvement in Sanatoriums-Preventoriums Developed by the Employees of the Odessa State Medical University under the Leadership of Professor V. V. Kenz

Damp rubdowns at decreasing temperatures 33–30–25°C, hydrokynesotherapy or swimming in a swimming pool, circular showers of different temperatures, pearl or carbon dioxide baths are recommended under asthenic conditions.

Hydrokynesotherapy in a pool, 4-chamber galvanic baths, hydrosulphuric baths of low concentration are useful for people with vegeto-vascular disorders.

Physiotherapeutic measures of an activating or an inhibiting type depending upon the initial background can be used with the purpose of normalization of gastrointestinal tract functions.

Sanitation of the Chernobyl zone children in sanatoriums with the use of a number of new products (fruit-vegetable puree and drinks on the basis of pumpkin and vegetable marrow, tomato juice from orange tomatoes, preserves from mussels, colewort liver, oil, waffles, chocolate and dragee with food albumin, dogrose concentrates, birch-citric juices with sweeteners, etc.) significantly increased the concentration of haemoglobin and erythrocytes in the blood; improved providing with proteins, calcium, phosphorus, ascorbic acid, thymine, riboflavium and other vitamins. Oxidation-rehabilitation processes and microflora of the intestines were normalized.

The contents of erythrocytes with pathological and degenerative changes in the form of the surface in the blood of children, affected after the Chernobyl accident, statistically significantly decreased due to a complex sanitation of the children in the sanatorium.

Besides of the general contraindications to sanatorium-dispensaries through the state of health for people residing in zones with increased radiation, it is necessary to take into account the following additions:

— presence of lymphoadenopathy;

— euthyroidic increase of the thyroid gland of the 3rd degree, and for being in contrast climate conditions in the summer — 2nd degree too; 1st and 2nd degrees — with the presence of nodular formations;

— repeatedly revealed changes in the blood picture (increase of more than $8.5 \cdot 10^9$/l and a decrease of less than $3.0 \cdot 10^9$/l of leukocytes, agranulocytosis, monocytosis, marked thrombocytopenia);

— for being during the warm months in contrast climate and climate-geographical zones;

— immunodeficiency conditions with hypoblastic disorders of haemopoiesis for being in contrast climate and climate-geographical zones (southern regions, high mountains).

CONCLUSION

Facts and clinical observations of ionizing irradiation action on the living organism have been gathered and analyzed for more than 100 years by the efforts of a number of scientists.

The variety of conditions of irradiation (types of irradiations, people contact forms with sources of irradiation, quantitative characteristics of radiation factors, time intervals after the exposure, various radiosensitivity of organs, tissues and ontogenesis periods) significantly modified the action effect of ionizing radiation.

The basic laws of ionizing irradiation influence on cells are established. The most diversified radiation cellular reactions (delay in mitosis, induction of chromosomal aberrations, and degree of DNA synthesis depression) are expressed in various degrees and depend upon the stage of its life circle.

It is proved that the radiosensitivity of tissue is proportional to the proliferative activity and inversely proportional to the degree of cellular differentiation. Radioresistant low-renovated tissues appeared to be functionally defective.

The structural and functional changes can be observed in all organs; moreover the disorders in them depend upon the radiation dose and time after irradiation.

The biological effect of external exposure has some dependence upon the dose, its power, divisibility of irradiation, type of ionizing irradiation, etc. The lighter the particles and their energy, the greater their penetrating ability. Beta- and alpha-particles that poorly penetrate through the skin are absorbed by the epidermis, causing disorders limited to the place of their action, whereas the flow of gamma-quantums, protons and electrons penetrate through a person's whole body. The higher the specific ionization, the greater the biological efficiency of irradiation. The ultimate radiobiological effect depends upon the quantity of energy absorbed by tissues: the larger the absorbed dose, the faster the desired effect.

The genetic effects are conditionally divided into three groups: hereditary disorders, physiological inferiority and increasing cancer risk. The dependence of the dose — effect for any type of genetic effect has no threshold, because the mechanism of genetic changes is molecular.

Pathological effects due to the exposure *in utero* can be observed in any period of pregnancy. Although these effects are various, there is no period in which an embryo would not suffer from an irradiation dose of more than 0.5 Gy. The reaction of a growing organism to the influence of ionizing irradiation differs from an adult one by a complex of symptoms, their time of display and dose, causing the corresponding effects.

The remote effects arise in people 10–20 and more years after the radiation exposure. The remote effects include: shortening of life expectancy, occurrence of additional cases of leucosis, malignant tumors and cataracts (in comparison with the average level of disease), nephrosclerosis, disorders of the balance in the function of the endocrine glands, decrease in fertility, sterility, embryo development disorders.

The biological effect of low dose irradiation has a stochastic character. The disorders arising in an organism are non-specific and can appear as a result of the influence of other factors, which are not connected with irradiation. The quantitative laws can be received only for large populations, investigated during long terms while observing the following principles:

1. The presence of data of simultaneous dynamic examination of the control groups.
2. Comparison of shifts dynamics with the results of the preliminary examinations.
3. Statistical processing of materials with the establishment of significant differences of frequency of separate shifts in the various terms between the basic and control groups.

The combined action of radiation and non-radiation facts is intensively studied, the obtained facts are inconsistent. The further accumulation of facts, their quantity estimation, their analysis and construction of a working hypothesis about the mechanisms of additive and superadditive effects are necessary. Under the influence of functional loads, pathophysiological conditions, traumas, and diseases, the organism's reaction to the influence of ionizing irradiation changes.

The metabolism and biological action of radioactive substances depends upon their physical and chemical properties, ways of intake, radionuclide tropism, quantity intake, and the dose absorbed in the basic organs of deposition.

The search of radioprotective, antimutagen, accelerated elimination of radioactive substances is carried out intensively.

The basic groups of people in need of primary help are the Chernobyl NPP accident consequences cleaning up participants, especially in doses more than 25 sGy, children irradiated intrauterine, victims with hematological disorders as well as with developed invalid-making pathologies.

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