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RADIATION SAFETY

Textbook

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The sources of ionizing radiations, technical equipments of control of radiation situation, are considered, short description of radiation-dangerous objects is given, requirements over of normative documents are brought on providing of radiation safety. The special attention is spared to organization of radiation defense of population in the conditions of normal situation and at a radiation accident. It is intended for students, studying discipline "Radiation safety"

The textbook may be to the useful bachelors, master's degrees and graduate students that pass preparation after speciality of Technology of defence of environment, and teachers and research workers, approaching them professional base to the international requirements and facilitating perception of English-language literature.

Розглянуті джерела іонізуючого випромінювання, технічні засоби контролю радіаційної ситуації, наведений короткий опис радіаційно-небезпечних об'єктів, вимоги до відповідних нормативних документів. Особлива увага приділена організації радіаційного захисту населення в звичайних умовах і у випадку радіаційної аварії. Підручник призначений для студентів 1-го курсу магістратури за спеціальністю 183.“Технології захисту навколишнього середовища ”

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CONTENT

INTRODUCTION

One of major terms of life and labor of man there is safety of her vital functions. Radiation safety is science and practice of maintenance of health of man in the conditions of work with the different sources of ionizing radiation. The sources of ionizing radiation (IRS) found wide application in different industries of industry, energy, science and medicine. About 10 thousand enterprises, establishments and establishments, are counted in Ukraine, where various ionizing sources are used, including more than 30 thousand radio nuclei devices. Work with radio nuclides and sources of ionizing radiation is potentially dangerous, because in case of accident influence of radio nuclides and other sources of ionizing radiation a man can not feel by means of the organs, but discovers only by means of the special devices. Thus, the increasing of reliability and safety during work with IRS is related to regulation and quality implementation of corresponding instructions and rules.

A radio contammant that can be caused by a radiation accident remains on great while, and decontamination has limit possibilities. Thus, the important element of strategy of modern radiation safety, that purchased the special value after an accident on Chernobyl' NPP, is establishment of barriers of motion of radio nuclides for to the food chains.

Radiation safety of population is the important element of national safety and implies the state of security of present and future generations from noci-influence of radiation. Any useful application of sources of ionizing radiation in industry, science, medicine, agriculture must be safe.

CHAPTER 1. THE GENERAL CHARACTERISTIC OF IONIZING RADIATION

Radioactivity is defined as spontaneous nuclear change as a result of which a new nucleus or element is formed. The change is accompanied by the emission of particles and/or electromagnetic radiation. Radioactivity is a characteristic of unstable isotopes (atoms of the same element but with differing numbers of neutrons in their nuclei) that enter to more stable state by a process of radioactive decay, also known as disintegration.

The number of radioactive isotopes they possess distinguishes the various elements. The particles and the electromagnetic radiation that are emitted because of radioactive decay are called radioactive radiation.

Radioactive radiation is characterized by its ability to cause ionization (emission of an electron from the atom) when it traverses any medium.

Ionization is the process by which the radiation loses energy, and is the process responsible for the damage caused by radioactive radiation.

Radioactivity is not a new phenomenon. Our planet, from the moment of its creation, continuously exposed to radioactive radiation from a variety of sources: cosmic radiation, radiation caused by the decay of radioactive isotopes (such as uranium) in the ground and in the oceans, and even from radioactive isotopes occurring naturally in our own bodies (such as an isotope of potassium).

1.1 The types of ionizing radiation

Radionuclides are both natural (relatively small) and artificial origin. The last (for all elements of the Mendeleev table) physicists have already received more than 2000. Dozens of types of such active nuclei are generated during the operation of nuclear research or power reactors.

An atomic nucleus consists of nucleons – protons and neutrons that can grow into each other. The charge of nucleus is determined by the number of protons of Z and corresponds to the sequence number in the table of Mendeleyev. Mass number A is equal to the incurrence of nucleons – protons (Z) and neutrons (N): A = Z + N. For denotation of atomic nucleus use the symbol of element that an atom belongs to. For example, $^{235}_{92}U$ is a nucleus of uranium-235, in that 235 nucleons from that 92 are protons, because an element uranium has 92th number in the Periodic system D.I. Mendeleyev.

Nuclides with an identical number of protons named *isotopes*. They differentiate the mass number of A. All isotopes belong to one chemical element. The number of radioactive isotopes they possess distinguishes the various elements. Thus, for example, hydrogen has 3 isotopes in all, of which only one is radioactive, while lead has 32 isotopes, of which just 3 are non-radioactive (stable). Isotopes have different degrees of stability. Below is a table 1.1 of the isotopes of hydrogen.

Table 1.1

Sign of isotop	Name of isotope	Number of protons	Number of neutron	Atomic weight	Stable isotope	Radioactive isotope
^1H (H)	hydrogen	1	0	1	x	
^2H (D)	deuterium	1	1	2	x	
^3H (T)	tritium	1	2	3		x

Nuclides with an identical mass number A named *isobars* that belong to the different chemical elements.

Radionuclides, having an identical mass number A and an identical amount of protons of Z, but being in the different power state and respectively different half-life T, are *isomers* (*nuclear isobars*).

Radioactivity is ability of atomic nucleus spontaneously to grow into other nucleus with emitting of different types of radioactive radiations and elementary particles.

An ionizing (radioactive) radiation is a stream of particles and quanta of electromagnetic radiation passing of that through a substance results in ionizing and excitation of atoms and molecules of environment. A radiation is a method atoms give surplus of energy that.

Radioactive radiation is characterized by its ability to cause ionization (emission of an electron from the atom) when it traverses any medium. Ionization is the process by which the radiation loses energy, and is the process responsible for the damage caused by radioactive radiation.

Radioactivity of isotopes existing in the wild, name natural, and activity of the isotopes got as a result of different nuclear reactions - artificial.

In the process of radioactive decay, various forms of radioactive radiation occur. Ionizing radiations (IR) subdivided into electromagnetic and corpuscular. Basic types of radioactive radiation : alpha, beta, is a neutron (group of corpuscular radiations), x-rayed and gamut-radiation (hertzian waves are over short-wave to the range).

The types of cooperation IR with a substance:

1. ionising and excitation of atoms;
2. dispersion (resilient and непружне) is on electrons;
3. dispersion (resilient and непружне) is on kernels;
4. absorption of particles kernels;
5. breaking of nucleons is out of kernels;
6. annihilation of particle and anti-particle;

7. formation of pairs, et.set.

For the charged particles the most considerable mechanisms of cooperation are ionising and excitation of atoms. Ionizing ability of radioactive radiation depends on his type, energy, and also substance that is ionized. Can be appraised after the specific ionising, that is measured by the amount of ions of this substance that appears on length in 1см. Than anymore is a size of the specific ionising, the energy of radiation is quicker spent and the a less way will pass a radiation in a substance to the complete lossElectromagnetic IR is gamma-quanta, x-rayed radiation. Corpuscular IR are all other types of radiations: beta- particles, protons, alpha-particles of and other.

The main types of Ionizing radiation detailed below.

Alpha radiation – helium nuclei, which are produced by radioactive decay of elements heavier than lead or formed in nuclear reactions.

$$^{A}_{z}X \rightarrow {}^{A-4}_{z-2}Y + {}^{4}_{2}He^{++},$$

where X is a chemical symbol of element that disintegrates (parent nucleus). У– chemical symbol of product nucleus.

Disintegration of isotope of radium that flows with formation to radon can exemplify:

$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He^{++}$$

Alpha decay is accompanied by a radiation daughter's kernel γ – rays.

Speeds with that α - particles take off from a kernel that disintegrated, very large ($\sim 10^7$ m/sec) arrive at; kinetic energy - a few MeV. Thus, their ionizing ability is enormous. and as on every act of ionising certain energy (for example, midair on formation of one pair of ions spent on the average 35eV) is spent, then them penetrating ability is insignificant: run-length makes a few centimetres (3 - 10cm) midair, in liquid and hard environments - order of 10^{-3}cm. A flow of α - particles fully stays by ordinary sheet of paper, practically does not penetrate through the superficial layer of epidermis of skin. Reliable defence is also a clothing of man. As α--radiation has the most ionizing, and the least penetrating ability, external irradiation by a stream of α- particles isn’t practically dangerous, but penetration into an organism with respirable air, by a meal, water or through an open wound is extraordinarily dangerous.

Beta radiation – these are electrons ($\beta^{=}$) or positrons (β^{+}), which are formed during the beta decay of various elements from the lightest (neutron) to the heaviest.

Most of the materials used in biological and medical research emit $\beta^{=}$ radiation:

$$^{A}_{z}X \rightarrow {}_{z+1}^{A}Y + {}_{-1}^{0}e + \tilde{\nu},$$

where $\tilde{\nu}$ is a symbol of antineutrino.
For example:

$$ {}_{15}^{32}P \rightarrow {}_{16}^{32}S + {}_{-1}^{0}e + \tilde{\nu} . $$

In medical diagnostics we use materials that emit positrons because β^+-radiation will always be accompany with gamma radiation.

$$ {}_{z}^{A}X \rightarrow {}_{z-1}^{A}Y + {}_{1}^{0}e + \nu , $$

where ν is a symbol of neutrino.

$$ {}_{z}^{A}X \rightarrow {}_{z-1}^{A}Y + {}_{1}^{0}e + \nu ; $$

$$ {}_{9}^{18}F \rightarrow {}_{8}^{18}Y + {}_{+1}^{0}e + \nu + \gamma . $$

Passing of β - radiation (electrons and positrons) through a substance substantially differs from passing of α - particles. Basic mechanisms losses of energy by electrons and positrons - ionization and radiation. A radiation one is an electromagnetic radiation that arises up at braking charged particles. Power of this radiation is proportional fourth degrees of acceleration, and as an acceleration is inversely proportional to mass, then this power is inversely proportional fourth degrees of mass and will matter only for the easy charged particles, id est electrons and positrons.

The charge of β-particles is less, and speed more than at альфа-частинок, then they have less ionization, and greater penetrating ability, than α are particles. Run-length of β-particles of high energy equals in mid air to 20m, water and living fabrics - to 3cm, metal - to 1cm. In practice β-particles is almost fully taken in by window and motor-car glasses and metallic screens in a few millimetres thick. A clothing takes in to 50% of β-particles. At the external irradiation of organism on a depth near 1mm penetrates only 20-25% of β-particles. Therefore, external β- radiation presents a serious threat only at the hit of radionuclidess directly on a skin (especially on eyes) or inward to the organism. At the internal irradiation of man, beta-radiation is extra hazardous.

Electromagnetic radiation has a wide spectrum of energies and different sources: gamma-radiation of atomic nuclei and braking radiation of accelerated electrons, X-rays, radio waves.

Gamma-radiations are short-wave electromagnetic radiations with length of 10^{-10} - 10^{-13}m, that is produced by the nuclei of atoms at radioactive transformations (β- and (rarer) α- disintegration). It is the flow of γ - quanta that move with velocity of light. Mechanisms of cooperation of γ - quanta with a substance mainly three: photoeffect, effect of Compton and birth electronic - positron pair in the coulomb field of nucleus. The first two effects are the result of cooperation - quanta with the electrons of substance. But the mechanisms of this cooperation are different: in first case this absolutely unelastic collision, and an effect of Compton is qvasielastic cooperation γ - quantum with an electron.

As a result of absence of charge far operating coulomb cooperation is not inherent to the γ -quanta. Collision γ - quanta with electrons and nuklei of substance take place comparatively rarely. However, at a collision, as a rule, γ - quanta are taken in or disperse large-angle, i.e. practically leave from a bunch. Ionizing ability is a radiation substantially less than, than in β- or α- particles, however it has most penetrating ability. Layer of the half-note weakening - a radiation in water folds 23cm, to steel - near 3cm, to the concrete - 10 cm, tree - 30cm. Because of large penetrating ability - a radiation is the найважнішим factor of defeat at an external radioactive irradiation.

The body of man they pass through. The complete protecting from these radiations, providing is difficult. In practice weakening of intensity of gamma-radiations different substances is characterized by the size of layer of the half-note weakening (layer of substance, at passing of that intensity of radiation diminishes in two times). In practical activity for defense screens with large atomic mass (lead, tungsten) or more cheap materials (steel, cast-iron), and stationary screens, are used from a concrete. High penetrating ability of gamma-radiations does them identically dangerous both at the internal and at external location of radiant.

Another form of radiation known as X radiation (commonly called X rays) has properties identical to those of gamma-radiation. The difference in names has mainly historical reasons.

The x-rayed radiations are a type of electromagnetic radiations that can present a danger for a man. However in medicine, as a rule, is used by more subzero energy and briefly, and they found a wide use in diagnostics of different diseases.

Other forms of radioactive radiation, such as neutron radiation (n) and proton radiation (p), are used for research in physics and atomic engineering.

Neutrons are the particles radiated only by technical (artificial) sources.

Neutrons it is accepted to classify after energies. For every area of energies characteristic certain types of reactions. From the theory of nuclear reactions it is known that the section of cooperation of neutrons with nucleus on the average sharply grows on the law of "1/v" at reduction to energy of neutron.

After this property neutrons are divided into two large groups - slow and rapid neutrons. A border between these two groups is not clearly certain and is in area of ~ 1000eV. Neutrons take part in all types of cooperation. By basic processes, that result in dispersion, absorption, diffusions and т. other of neutrons in a substance are processes of cooperation of neutrons with the kernels of atoms. Absence of electric charge allows to them to penetrate through the electronic shells of atoms and freely to approach nucleus. Unique property of neutrons of small energies to cause various nuclear reactions, including division of nucleus is predefined these. Under act of neutrons, there are elements of Na, K, C, N, P transform into radionuclide, which are gamma-radiators. Sources of neutrons are atomic reactors on thermal neutron.

Because the neutrons do not have a charge, and their mass is much larger than the masses of electrons, they have a large penetrating power and lose their energy practically only when they collide with atomic nuclei. In this case, the elastic and inelastic scattering of neutrons by nuclei can be possible.

Neutron radiation is dangerous because of its high penetrating ability and the ability to cause in the living organisms the indicated radioactivity. Depending on the energy, they distinguish between ultra short, fast, intermediate, slow and thermal neutrons.

For protecting from neutrons are used screens from a beryllium, graphite and materials, containing hydrogen (paraffin and water). From the combined action of neutrons and gamma-radiations screens from heavy and easy materials (lead-water, lead-polyethylene, iron-water of and other of pair of combinations) are used in practice.

Cosmic radiation comes to Earth from outer space. It consists mainly of protons and helium nuclei. The heavier items are less than 1%. Penetrating deep into the atmosphere, cosmic radiation interacts with the nuclei that form part of the atmosphere, and forms streams of secondary particles (mesons, gamma quantum and neutrons).

1.2 Kinetics of Radioactive Decay

The amount of radioactive substance in course of time diminishes because of its decay. Radioactive decay is a statistical phenomenon. We can know how many nuclei disintegrate per unit of time, but not which nuclei will do so.

Speed of radionuclide’s decay determined by the degree of instability of their nuclei. For every radioactive substance, speed of decay of nuclei of its atoms is permanent, unchanging and characteristic only for this isotope. All radionuclides disintegrate in the same order and submit to the law of radioactive decay. Essence of law consists in that the same part of available nuclei of atoms of radioisotope disintegrates for time unit.

Separate radioactive nuclei disintegrate independent of each other. It is therefore possible to consider that amount of nuclei of dN, that disintegrate for the small interval of time of dt, proportional to both the number of present nuclei of N and interval of time dt:

$$dN = -\lambda N dt, \qquad (1.1)$$

λ is a *constant of decay* – physical constant, that is the rate of decay of the material is fixed, cannot be changed, and is unaffected by other factors such as: pressure, temperature, etc.

When we solve the above equation, we get

$$N = N_0 e^{-\lambda t}, \tag{1.2}$$

where N_0 is the initial number of radioactive nuclei (at time t = 0), N is an amount of atoms that did not disintegrate to the moment of time of t. A formula (1.2) expresses *the law of radioactive decay*. This law is very simple: the amount of nuclei that did not disintegrate decreases after exponent.

It is possible to estimate *mean time of life* of nucleus:

$$\tau = \int_0^\infty t e^{-\lambda t} dt = 1/\lambda, \tag{1.3}$$

Mean time of life of nucleus equals the interval of time, for that the initial amount of nuclei diminishes at "e" times, i.e. approximately in three times.

More often apply other characteristic – time in which half the radioactive nuclei will decay. This value $T_{1/2}$ is called the period half-disintegration or *half-life*. For $t = T_{1/2}$

$$\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}}.$$

Then

$$T_{1/2} = \frac{\ln 2}{\lambda} \tag{1.4}$$

Period half-disintegration for well-known in this time radioactive nuclei is in the large range of values from small fractions of a second to million years. For example, ^{12}B have a half-period $T_{1./2} = 1.8 \cdot 10^{-2}$ sec, and for ^{187}Re $T_{1/2}$ = 3000 milliards of years.

Note. In the same way is defined biological half-life ($T_{1/2\ b}$): the time taken by half the quantity of radioactive material that has penetrated a living body to clear away. (This value is not a physical constant. The biological half-life depends on various biological parameters that change from person to person and, for the same radioactive material, between various chemical compounds.)

When radioactive material penetrates the body, then on the one hand it continues to decay according to its physical half-life, and on the other hand, it is cleared out of the body according to the biological half-life. Also is defined the effective half-life ($T_{1/2\ eff}$), a combination of the physical and the biological half-lives. When we speak of the dangers of radioactive materials that are liable to penetrate the body, the effective half-life is the value that interests us. Thus, for example, the physical half-life of tritium is about 12.5 years, while its biological half-life is about 12 days. However, that when the type of half-life is not specifically stated, reference is always to the physical half-life.

Activity of radioactive preparation is name the number of acts of disintegration that takes place in preparation for time unit. If for time dt decay dN nucleus, then activity equals the product of constant of decay on the amount of present in preparation nuclei that did not disintegrate.

$$A = -\frac{dN}{dt} = \lambda N \, . \qquad (1.5)$$

In the International System of units (SI), unit of activity is 1becquerel (Bq). 1Bq= 1decay/s. Assumed application of off-system units: decay/min and curie (Ci). Unit of activity curie is determined as activity of such preparation in that there are $3{,}700 \cdot 10^{10}$ acts of decay for a second.

In practice activity can be examined as superficial, volume and specific.

Specific activity a of radioactive preparation is determined by the amount of acts of disintegration for one second on unit of mass of radioactive substance:

$$a = A/m, \quad \text{Bq/kg} \; ;$$

$$. \quad a = \frac{\ln 2 \cdot N_A}{M \cdot T_{1/2}} \, ,$$

where M is a molar mass; N_A - Avogadro’s number.

Specific activity is used for determination of degree of contamination of solid mater4ials.

By *volume activity* (activity of source of IR is in unit of volume) is used for determination of degree of contamination of air, liquid.

$$q = A/V.$$

System units - Bq/m^3 , Bq/*l*. an off-system - Ci/m^3 , Ci/*l*.

Superficial activity is activity of source of IR on unit of area (closeness of contamination). This index is used for determination of degree of contamination of some locality. Unit of closeness of contamination is Бк/м^2. Because at radiation accidents contamination considerable territories are exposed to, then larger off-system unit is more often used – Ci/km^2.

$$1\text{Ci/km}^2 = 3{,}7 \cdot 10^4 \text{Bq/ m}^2 = 37\text{kBq/ m}^2.$$

Locality is considered unpolluted at activity to 1Ci/km^2.

1.3 The system of dosimetric quantities and the main radiation-hygienic parameters are regulated by quantities, dose limits and permissible levels

The degree of exposure to ionizing radiation in any environment depends on the radiation energy and is estimated by the dose of ionizing radiation.

Irradiation is the effect on a person or any object of ionizing radiation.

External exposure - exposure of a human body or any living object to sources of are such an amount of ionizing radiation that forms about 2 billion pairs of ions in 1 cm3 of dry air under normal conditions.ionizing radiation that are outside it.

Internal irradiation - irradiation of the human body or any living object, individual organs and tissues from sources of ionizing radiation, are located inside the object.

In radiation protection, radioecology and radiobiology, five main types of doses of ionizing radiation are distinguished: exposure, absorbed, equivalent, effective and collective.

1**. *Exposure dose of photon radiation*** is a relation of total charge of all ions of one sign (*dQ*), formed in air, when all electrons and positrons that is disengaged by photons in the elementary volume of air, fully stopped in it, to mass of air *dm* in this volume:

$$D_{\exp} = dQ / dm \quad . \tag{2.1}$$

Unit of display dose in CI is coulomb on a kilogram (C/kg). Off-system unit of display dose is roentgen (R).

Roentgen (X-Ray) - an amount of ionizing radiation that forms about 2 billion pairs of ions in 1 cm^3 of dry air under normal conditions.

The exposure dose can be used to determine the potential of ionizing radiation.

2. ***The absorbed dose D*** is a relation of average energy (*dE*) that is passed to the ionizing radiations to the substance in an elementary volume, to mass of *dm* substance in this volume:

$$D = dE / dm . \tag{2.2}$$

The absorbed dose of indirectly ionizing radiation is estimated using the concept kerma (***k****inetic* ***e****nergy* ***r****eleased per unit mass).*

Kerma (K) is the ratio of the total primary kinetic energy of all charged ionizing particles formed under the action of indirectly ionizing radiation in an elementary volume of a substance to the mass of a substance in this volume:

$$K = dE_k / dm, \quad (2.3)$$

$dE_{k\,I}$ - the sum of the initial kinetic energies of all charged ionizing particles are released as a result of the action of indirectly ionizing radiation in a substance with mass *dm*.

It is most often used to measure the absorbed dose in air and is called the air kerma.

The SI unit of absorbed dose is Gray (Gy). One gray is equal to an absorbed dose of 1 joule/kilogram (100 rads).

Rad is the special unit of absorbed dose. 1rad is equal to an absorbed dose of 100 ergs/gram or 0.01 joule/kilogram (0.01 gray). 1rad = 0,01 joule/kg = 0,01Gy = 1cGy (centigray).

3. *An equivalent dose.* The dose that a person receives depends on the type of radiation, energy, flux density and duration of exposure. However, the absorbed dose of ionizing radiation does not take into account the fact that the effect on a biological object of the same dose of different types of radiation is not the same. To consider this effect, the concept of an equivalent dose was introduced.

An equivalent dose ($H_{T,R}$) in an organ or tissue is a quantity that is determined as a product of absorbed dose ($D_{T,R}$) from a radiation as R, averaged on a separate organ or tissue (T) and radiation quality factor (w_R):

$$H_{T,R} = D_{T,R} \cdot w_R, \quad (2.4)$$

It is customary to compare the biological effects of various types of radiation with the effects caused by X-rays or weakly energetic gamma radiation.

A radiation weighting factor w_R (the previous name is a *coefficient of quality*) is a coefficient that takes into account relative biological efficiency of different types of ionizing radiation, id est. them power harmfulness comparatively with the effects caused x-rayed or by a low power gamma-radiation. Value of radiation weighting factor w_R for the different types of radiation, and also the absorbed doses, the action of that is equivalent to unit of the dose got from γ-rays.

Table 1.1 Value of radiation weighting factor w_R for the different types of radiation

Type of radiation	Factor w_R	Absorbed dose
X-, gamma, or beta radiation	1	1
Alpha particles, multiple-charged particles, fission fragments and heavy particles of	20	0.05

unknown charge		
Neutrons of unknown energy	10	0.1
High-energy protons	10	0.1

At the action of a few different types of radiation under different weight coefficients an equivalent dose is determined as a sum of equivalent doses of these types of radiation:

$$H_{T,R} = \sum_{R} D_{T,R} \cdot w_R \qquad (2.4)$$

Unit of equivalent dose in the SI-system is sievert (Sv). Sievert is energy of any type of the ionizing radiation, absorbed by 1kg of biological tissue at that a biological effect is identical to absorbed dose of 1Gy control x-rayed or gamma-radiation.

Off-system unit of equivalent dose is rem. The dose equivalent in rems is equal to the absorbed dose in rad multiplied by the quality factor (1rem=0.01Sv).

4. ***An effective dose (E)*** is used as a measure of risk of origin of remote consequences of irradiation of man, the degree of influence of ionizing radiation determines on the body of man taking into account the differences of action of different types of ionizing radiation on tissues and organs.

An effective equivalent dose (E) is a sum of products of equivalent doses of H_T in separate organs and tissues on corresponding tissue weight factors w_T:

$$E = H_T w_T \ . \qquad (2.5)$$

A tissue weighting factor of w_T is a coefficient that is used exceptionally for the calculation of effective dose and represents relative probability of stochastic effects in tissue (organ). Sum all weighting factors on all organs equals unit: w_T=1. (table 1.2).

Table 1.2 Value of tissue weighting factors (wT), used in NRSU- 97

Organ or Tissue	w_T	w_T
Gonads	0.20	0.20
Marrow (red), colon, lungs, stomach	0.12	0.48
Skin, surface of bone	0.05	0.25
"Other organs" (thyroid, cerebrum, standard of extrathoracic area, thin bowel, kidneys, muscles, pancreas, spleen, timus and uterus)	0.01	0.02
Together *		1.00

*For the estimation of the external dose got all body (it is added to the internal dose), the weighting coefficient w_T = 1.0 is used.

An effective dose, as well as equivalent dose, is measured in sievert

Every organ and every tissue have a different value in the life-support of organism.

A critical organ is an organ or tissue, part of body or all body, the irradiation of that inflicts most harm to the organism. Like critical (vitally important) elements can be distinguished in every separate cage. There are three methods of selection of critical organs:

- after the most radio sensitivity in the certain system of organism;
- after the most absorbed dose of radiation;
- after the selective accumulation of increase concentrations of certain radionuclide.

An effective dose represents the general effect of irradiation - harm for all organism at the irradiation of separate organs and tissues.

The use of concept of effective dose is assumed at the values of equivalent doses below than threshold of origin of deterministic effects (0.1Sv at a sharp irradiation or chronic for a year).

For taking into account of changes of stream of ionizing radiation use ***the power of dose*** – relation of dose of radiation (absorbed, display, equivalent, effective) for some interval of time to the size of this interval:

$$D^* = dD/dt \text{ (Gy/sec)}; \qquad D^*_{\exp} = D_{\exp}/dt \text{ (R/sec)};$$

$$H^* = dH/dt \text{ (Sv/sec)}; \qquad E^* = dE/dt \text{ (Sv/sec)}.$$

Power of dose it follows to examine only for the short intervals of time (for a second, for a minute, in an hour).

5. ***The collective effective (equivalent) dose.*** When calculating the consequences of an accident, it is extremely important to determine the magnitude of the collective radiation dose that the population has collected - all those who were directly or indirectly affected by the radiation.

Collective effective (equivalent) dose it is the sum of individual effective (equivalent) radiation doses of a certain group of the population for a certain period of time, or the sum of the products of the average group effective doses by the number of persons in the corresponding groups that form the collective for which it is calculated

$$S = E_i \cdot N_i \;, \qquad (2.6)$$

where E_i – the average effective (equivalent) dose to a subgroup of the population i;

N_i - the number of persons in the subgroup.

The unit of measurement is man-sievert (man-Sv). The off-system unit is man-rem. 1 person-Sv = 100 person-rem.

In the event of the Chernobyl disaster, the collective dose reached millions of man-rem.

The ratio between units of the dose of ionizing radiation is presented in the table of Appendix 1.

1.4 Features of action of radiation on a man

An environment takes the energy radiated by radionuclidess. Radioactive particles, possessing enormous energy, at passing through any substance run into atoms and molecules of this substance and result in their destruction, ionising, to formation of reactionary capable particles - fragments of molecules: ions and free radicals.

As a result of affecting of ionizing radiations organism of man there can be difficult physical, chemical and biological processes in fabrics. Depending on the size of eaten up the dose of radiation and from individual possibilities of organism the changes caused in living fabric can be convertible and irreversible. Принебольших doses the invaded tissue restores the functional activity. Large doses at the protracted influence can cause the irreversible defeats of separate organs or all organisms.

The biological operating of radiation on a living organism is the result of the following after each other a few stages:

- absorption of energy of radiation by cages and fabrics of organism;
- education of free radicals and oxidants;
- violation of biochemical processes; ·
- violation of physiological processes.

Primary radiation-chemical changes two mechanisms are the basis of:

a) a direct action is the direct co-operating of ionizing radiations with critical molecules that grow into free радикалы;

b) indirect action - when a molecule directly does not take in energy from an ionizing radiation, and gets her from other molecules, as the organized matter on 70-80% consists of water, then greater part of energy of radiation is taken in exactly by the molecules of water, and then the products of радиолиза of water operate on biomolecules.

Waters got in the process of радиолиза free radicals, possessing high chemical activity, enter into chemical reactions with the molecules of albumen, enzymes and other structural elements of biological fabric, that causes the change of biochemical processes in an organism. Exchange processes are violated as a result, activity of the enzymic systems is repressed, the height of fabrics is slowed and ceases, there are new compounds not enorganic, are toxins. It results in violation of vital functions of separate functions or systems of organism overall.

Any type of ionizing radiation causes biological changes in an organism both at an external and at internal irradiation (fig. 1.1). [2]

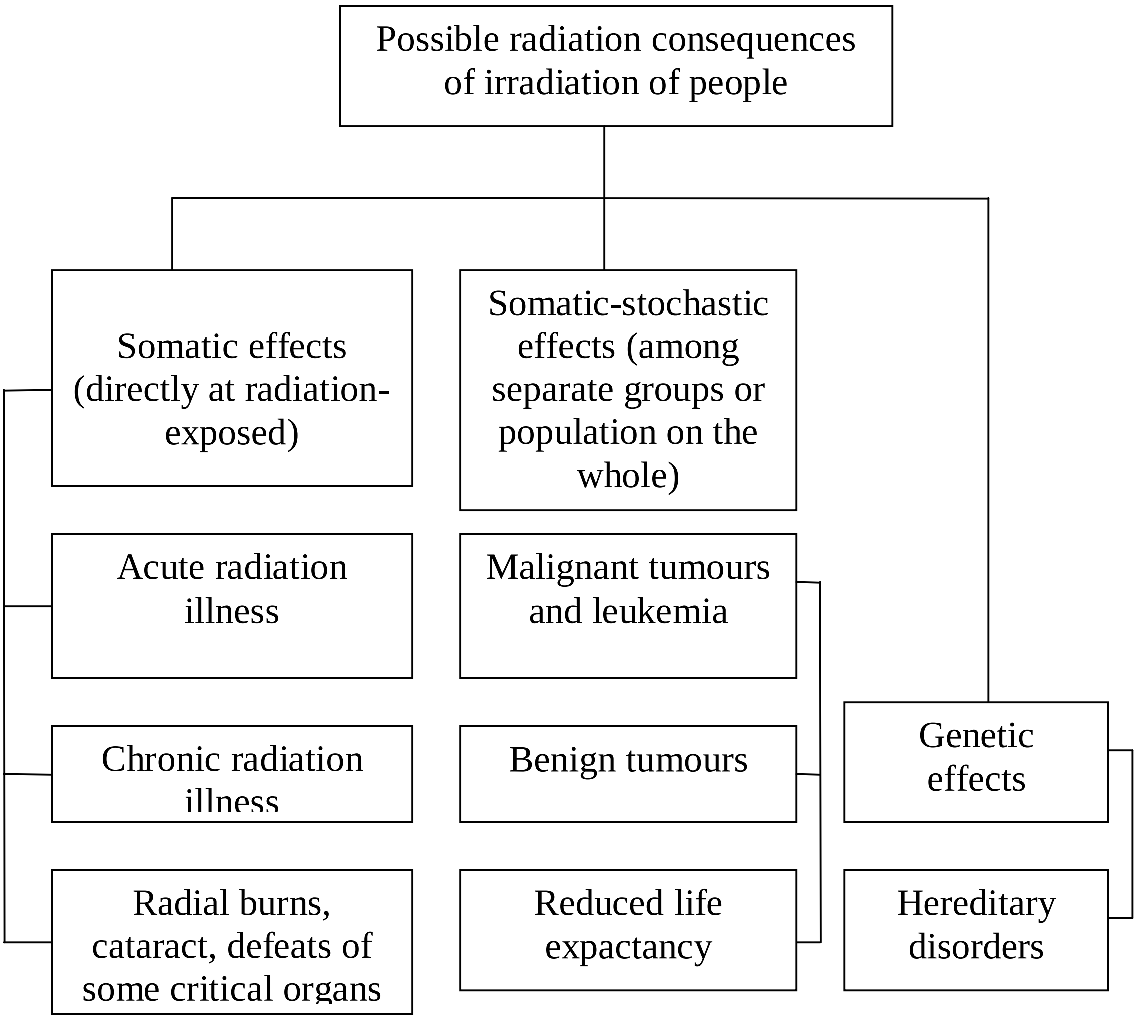

Fig. 1.1 Classification of possible consequences of irradiation

Notes: 1. *Somatic effects* are pathological violations arising up in the organism at exceeding of certain dose threshold.
2. *Somatic-stochastic effects* - pathological violations arising up in орга- низме radiation-exposed do not have a dose limit and carry probabilistic character.
3. *Genetic effects* - pathological violations arising up in the bioblasts of radiation-exposed do not have a dose limit and carry probabilistic character.

Basic features of action of ionizing radiation:

- high efficiency of absorbed energy, as a result a few of this energy can cause deep biological changes in an organism; ·
- presence of the hidden appearance of action of ionizing radiation duration of that grows short at an irradiation in large doses; ·
- accumulation of action of small doses; ·
- affecting of radiation not only this living organism but also on his posterity;

- different sensitiveness to the irradiation of different organs of living organism; · a non-permanent irradiation in a large dose causes deeper consequences, than frequent, in a sum constituents the same dose.

The irradiation of organism is distinguished as sharp and prolonged, single and multiple. Under sharp understand a brief irradiation at high power of dose (0,1Gy/min. and higher). Under prolonged is an irradiation at subzero power of dose (cGy/ hour and below). Both sharp and prolonged irradiations can be single and frequent (by a shot). For a single irradiation accept the irradiation got during a 1-4 twenty-four (regardless of multipleness of the got doses) hours. In addition, a chronic irradiation that is examined as a variety of frequent irradiation is known, but what be going on very protractedly and in small doses.

From data of some researches [2], the reference indexes of radiation safety of people can make: ·

- quarter dose – 30mSv (3 rem; 3,4 R); ·
- annual - 50 mSv (5б rem; 5,7 R); ·
- emergency - 100 mSv (10 rem; 11,4 R); ·
- catastrophic - 250 mSv (25 rem; 28,4 R); ·
- critical - 1Sv (100 rem; 113,6 R); ·
- semilethal - 4 Sv (400 rem; 454,5 R); ·
- lethal - 7 Sv (700 rem; 795,4 R);

The biological effect of ionizing radiation depends on a total dose, time of influence, type of radiation and sizes of the exposed to rays surface. In addition, the consequences of influence of radiation on a man are determined by the row of other factors : heredity, character and quality of life (socio-economic prosperity, availability and quality of medical service, presence of pernicious habits etc.), by the state of habitat.

A role of each of these factors in development of diseases can be different. The degree of danger of defeat depends also and from speed of leadingout of radionuclidess from an organism. Quickly circulating in an organism substances (water, natrium, chlorine) do not stay too long on great while and substances, not formative connections entering in the complement of fabrics (argon, xenon, krypton of and other). Some substances badly hatch from an organism and accumulate in him. Thus one of them (ruthenium, niobium of and other) are evenly distributed in an organism, other сосредотачиваются in certain organs: in livers - thorium, lanthanum, actinium; in bone fabric is strontium, uranium, radium.

One of methods of reduction of influence of radiation on the organism of man is a reception of antioxidants. Antioxidants are the biochemical substances, included in preparations, foodstuffs, that help an organism to render harmless free radicals until they will have time to prang a living cage. A human organism is able to produce own antioxidants, but only in a limit amount. Many natural antioxidants are contained in foodstuffs and, getting in an organism, protect cages from destruction. Among them most activity is possessed by a beta-carotene (vitamin of A), vitamin of C, vitamin of E and selenium. For creation of own antioxidants an organism needs sufficient amount of zinc, copper and manganese, that in foodstuffs comparatively small. These substances can be found in bioactive additions composition of that must sneak up specialists.

In the zone of accident on the objects of nuclear energy enhanceable maintenance of radioactive iodine and caesium reveals first of all. A basic element that is actively taken by a thyroid is an iodine. This element makes basis of hormones of thyroid. The hormones of thyroid execute vitally important tasks: influence on a carbohydrate, albuminous and fatty exchange, on a height and psychical development. The lack of this microelement can cause negative consequences. By reason of 65% cases of diseases of thyroid for the persons of ripe years and 95% children have the insufficient entering of iodine feed. If the level of radioactive iodine rises in an atmosphere, then the perch of ordinary iodine in an organism is taken by a radioactive iodine.

At the deficit of stable isotopes of iodine, calcium, potassium and other elements radio-nuclidess - their "twins", or antagonists of vitally important chemical elements accumulate in an organism. So, at the insufficient receipt of calcium an organism is taken in from an environment by the enhanceable amount of strontium and other chemical elements, alike on a structure on a calcium, for example, lead. Reverse dependence is obvious, getting the sufficient for vital functions amount of potassium, a man will less than master radioactive cesium - 137 - "twin" of antagonist of potassium. The man, exposed to influence of radiation, suffers from the deficit of major microelements of - калия, magnesium, iodine of and others.

Natural sources of potassium are dairies, meat, cacaos leguminous, potato, tomatoes, apricots, prunes, brown bread, bananas. There is a concept "Banana equivalent", that is used for description of radioactive source by comparing to activity of potassium - 40, contained among other isotopes калияв banana. A middle banana contains an approximately 0,42g of potassium. Radioisotopes in bananas have activity on the kilogram of weight 130Bq /kg, or approximately 19 Bq in a 150g banana. An equivalent dose in 365 bananas (one banana in a day) makes 3,6mrem, or 36μSv. Common maintenance of potassium in the organism of man makes an about 2,5g on the kilogram of body weight, or 175g (by activity 4-5 thousand Bq) for a man weighing 70 kg the Natural sources of iodine: oarweed, cod-liver oil, saltwater fish, persimmon, feijoa, nuts, gooseberry. Recommendable daily allowance norms of consumption of iodine : 90mcg - for children to 6; 120 - for children from 7 to12, 150 - for the persons of ripe years; 200 - for teenagers, expectant and feeding mothers. Thus, use in the ration of feed various rich products allows to bring down the risk of absorption the organism of man of radioactive elements.

1.5 Sources of radiation contamination of environment

The sources of radiation are divided into natural and artificial (created by a man).

Natural sources of ionizing radiation are:

- a space radiation;
- natural sources.

A space radiation plays an important role outside an earthly atmosphere, but as a result of comparatively subzero energy small influences on the dose of irradiation near a terrene. Intensity of space radiation depends on sunny activity, geographical location of object and height above a sea level.

The Space radiation consists of protons (90%), α- particles, neutrons, kernels of atoms of different elements and other particles

Natural sources. More than 60 natural radionuclides being in the biosphere of Earth it is possible to divide into three groups.

The first group is natural radioactive rows of long-living radionuclides, which enter in the complement of Earth since her formation. In a radioactive row every next nuclide arises up in the α- or β-decay of previous.

The second group – radio nuclides that is not included in radioactive rows. 11 long-living radio nuclides (^{40}K, ^{87}Rb, ^{40}Ca, ^{120}Te, ^{138}La, 1^{47}Sm) that have period's half-disintegration from 10^7 to 10^{15} years belong to this group.

The third group – cosmogony radio nuclides that continuously arise up in a biosphere as a result of nuclear reactions under act of space radiations. Cosmogony radio nuclides appear mainly in an atmosphere as a result of co-operating of protons and neutrons with the nuclei of nitrogen, oxygen and argon, and farther get on an earth surface with atmospheric precipitations. To them belong ^{3}H, ^{14}C, ^{7}Be, ^{22}Na, ^{28}Mg, ^{32}P, ^{35}S, ^{39}Ar,... – 14 radionuclides at all. Noticeable payment in the dose of irradiation is brought in ^{3}H, ^{14}C, ^{7}Be, ^{22}Na. Thus ^{3}H and ^{14}C are the sources of internal irradiation, and the basic sources of external irradiation are ^{7}Be, ^{22}Na and ^{24}Na.

Close to 70-75% doses of irradiation of population of Ukraine from all sources of natural radio-activity is on a radon. A radon accumulates into apartments, leaking through foundation and sex from soil or, rarer, freeing oneself from building materials. Reason is the Ukrainian shield - tectonic structure that passes from a north southward almost in the meddle of Ukraine and occupies close 30% of all territory. A shield consists of granites and other crystalline breeds that are characterized an increase radio-activity.

Natural radio-activity of plants, feed-stuff and food products is conditioned mainly radioactive K-40, that is mastered by a living organism together with the stable isotope of potassium, by a necessity for the normal vital functions of organism. Small part of dose is on tritium and carbon-14, that appear in atmospheric air under act of ultra-rays.

Slates have an increase radio-activity, phosphorits. Therefore phosphoric (and also nitric and potassium) mineral fertilizers often are the transmitters of radio contamination of soils and subsoil waters. High radio-activity is had calcium-silicate slag, phosphogypsum, domain slag, coal slag.

Anomalies of natural background. There are places on a planet, where the levels of radiation background increase as a result of considerable beds of radioactive minerals. Anomalous districts in Ukraine – Hmelnik, Mironivka, Yellow Water, and also Dnipropetrovsk, Kirovohrad and Mykolaiv areas, where mineries are from the booty of uranium. In these places the levels of natural background in ten and hundreds more than on other territory one times.

1. ***Artificial sources of ionizing radiation.*** Because of human activity in the external environment, artificial radionuclides and radiation sources appeared. Natural radionuclides, which are extracted from the earth's interior, together with coal, gas, oil, mineral fertilizers, building materials, began to flow into the natural environment. These include geothermal power plants that generate an average emission of about $4 \cdot 10^{14}$ Bq of the isotope Rn-222 per 1GW of electricity produced; phosphorus fertilizers containing Ra-226 and U-238 (up to 70 Bq/kg in Kola apatite and 400Bq/kg in phosphorus); coal, burned in residential buildings and power plants, contains natural radionuclides K-40, U-232 and U-238 in equilibrium with their decay products. Over the past few decades, people have created several thousand radionuclides and began to use them in scientific research, in technology, for medical purposes, and others. This leads to an increase in the dose of radiation received by both individuals and the general population.

The practical use the man of artificial sources of ionizing radiation (IR) created the real terms of additional over a base-line irradiation. As a result of economic activity of man over 1500 artificial radio-nuclei appeared in an environment and the amount of proof (unradioactive) nuclides equals 260. On this time in Ukraine there are about 8 thousand enterprises and organizations that use the about 100 thousand sources of IR.

To the basic artificial sources of radioactive pollutants take:

- application of radio-nuclei in a national economy (in different industries of industry and agriculture) and way of life;
- uranium and radio-chemistry industry, enterprises of nuclear energy;
- nuclear explosions at nuclear tests;
- application of PH in medicine.

The use of IR and RS in medicine for diagnostics and radiotherapy is the basic source of artificial irradiation of people, that exceeds influence all other artificial sources. These doses are created at the x-rayed diagnostics of people, diagnostics of the state of separate organs (lungs, liver, kidneys, thyroid and other) by means of radioactive preparations that is entered inward to the organism, and also radiation therapy, with the use of radioactive sources.

In developed countries, every thousand people account for 300 to 900 such surveys per year, not counting massive fluorography and x-ray examination of teeth. Collective effective equivalent doses are 20man-Sv per 1 million residents in Australia and 150man-Sv – in the USA. The average effective equivalent dose, obtained from all sources of radiation in medicine, in industrialized countries is 1mSv per year per inhabitant, that is, approximately half of the average dose from natural sources.

In modern terms at presence of high natural radiation background, at operating technological processes, at the use of radioactive preparations in medical aims every habitant of Ukraine annually gets an effective equivalent dose on the average 4,75mZv (space radiation - 0,5mZv, natural sources - 2,25mZv, artificial sources - 0,2mZv, medical sources - 1,8mZv).

A separate danger is presented by nuclear and accident tests on nuclear reactors.

The radiological consequences of testing nuclear weapons are determined by the number of tests, the total energy output and the activity of fragments division, types of explosions (air, land, underwater, surface, underground) and geophysical factors of the environment during the test period (district, meteorological conditions, migration of radionuclides, etc.). Testing nuclear weapons, which was particularly intensive in the period 1954-1958 and 1961-1962, has become one of the main causes of increasing the earth's radiation background and, as a result, a global increase in the doses of external internal radiation of the population [3].

In the US, the USSR, France, Great Britain and China, a total of at least 2060 tests of atomic and thermonuclear charges in the atmosphere, under water and in the bowels of the Earth, of which they are directly in the atmosphere of 501 trials. Atmospheric tests in the USSR were completed in 1962; underground explosions at the Semipalatinsk Test Site - in 1989, on the North Landfill - in 1990, France and China continued to test nuclear weapons until recently. According to estimates, in the second half of the 20th century, due to nuclear testing, $1.81 \cdot 10^{21}$Bq of nuclear fission products came into the environment, of which 99.84% was attributed to atmospheric testing. The spread of radionuclides has become planetary scale.

2. Nuclear fission products (NFP) represent a complex mixture of more than 200 radioactive isotopes of 36 elements (from zinc to gadolinium). Most of the activity is short-lived radionuclides. Therefore, after 7, 49 and 343 days after the explosion, the activity of NFP decreases accordingly, at 10, 100 and

1000 times, in comparison with the activity one hour after the explosion. In addition, the radioactive contamination is due to radionuclides of the induced activity (^{3}H, ^{14}C, ^{28}Al, ^{24}Na, ^{56}Mn, ^{59}Fe, ^{60}Co, etc.) and an inseparable part of uranium and plutonium. Especially large role has the induced activity in thermonuclear explosions [3].

At nuclear explosions in the atmosphere, a significant part of precipitation (at ground explosions of up to 50%) falls near the test area. Part of the radioactive substances is delayed in the lower part of the atmosphere and under the influence of wind moves over long distances, remaining at about the same latitude. While in the air for about a month, radioactive substances during this movement gradually fall on the Earth. Most of the radionuclides are thrown into the stratosphere (at a height of 10-15km), where their global scattering and largely decay occurs. Unsuspended radionuclides fall down all over the Earth.

CHAPTER 2. OBJECTS OF NUCLEAR ENERGY. RADIATION ACCIDENTS AND THEIR CONSEQUENCES

2.1. Nuclear energy: negative and positive consequences for the environment. Environmental risks of the nuclear fuel cycle.

The source of radiation, which is surrounded by the most intense controversy, is the nuclear power plant.

Nuclear energy is a sustainable technology. According to this principle, the following factors must be taken into account when assessing the sustainability of energy production:

1. availability and efficiency of fuel;
2. land use;
3. environmental impact of waste disposal;
4. the possibility of repeated energy cycle;
5. availability and competitiveness, including environmental and social costs;
6. climate change.

Compared to other ways of energy production, nuclear energy has a number of advantages:

1. The primary and critical component of nuclear fuel is uranium, which has no other beneficial application, except in nuclear energy. Ukraine has its own uranium deposits. There are also uranium deposits in many politically stable countries. Seawater also contains a huge amount of uranium. According to experts, its world's remaining resources are adequate for several millennia.

2. NPP requires the smallest area in contrast with other power plants.

3.4. The amounts of waste from nuclear energy is quite small in comparison with thermal power waste, most of which is sprayed into the air and is recognized today as the key component of greenhouse gases. Today only nuclear and hydropower are significant sources of carbonless and economic energy production that do not affect global warming processes.

5. The fuel exploitation processes produce long-lived radionuclides: americium (Am), curium (Cm), neptunium (Np), technetium-99, and iodine-129. (To date, technologies have been developed and tested thanks to which long-lived radionuclides (with a half-life of tens and hundred thousand years) are removed from spent nuclear fuel for undergoing transmutation in fast reactors. In that case, a closed nuclear fuel cycle is environmentally acceptable, since it requires to monitor the safety of high-level waste to be disposed (including strontium-90 and cesium-137) for only 100-200 years. After the fuel activity ceased, this waste is subject to disposal, following the principle of radiation-migration equivalence (according to this principle, the quantity of radionuclides together with waste deeply stored underground is the same as in the mined natural uranium).

6. The economic evaluation of any energy production technology should be related to the full external and social costs, in particular, the environmental effects for the fuel cycle, the impact on society (including employment, health, etc.) in local, regional, and global measurements. External costs in nuclear power cover the potential costs in the event of major accidents, which is unlikely. Considering only operating and financial costs, the cheapest are nuclear energy and gas. Taking into account also external costs, nuclear energy becomes the most profitable.

Nuclear power drawbacks

The main factors of the technogenic impact of NPP operation on environmental objects:

- negative impact on people in technological systems;
- runoff of surface and ground waters containing chemical and radioactive components;
- changes in the nature of land use and exchange processes in the immediate vicinity of the NPP;
- changes in the microclimatic characteristics of adjacent areas due to the appearance of heat sources (cooling towers, reservoirs, coolers) during the operation of a nuclear power plant.
- releases of radioactive and toxic substances - constant (which are under the control of the NPP personnel) and explosive (emergency) (see Fig.2.1).

Nuclear energy generates significantly less waste than other energy

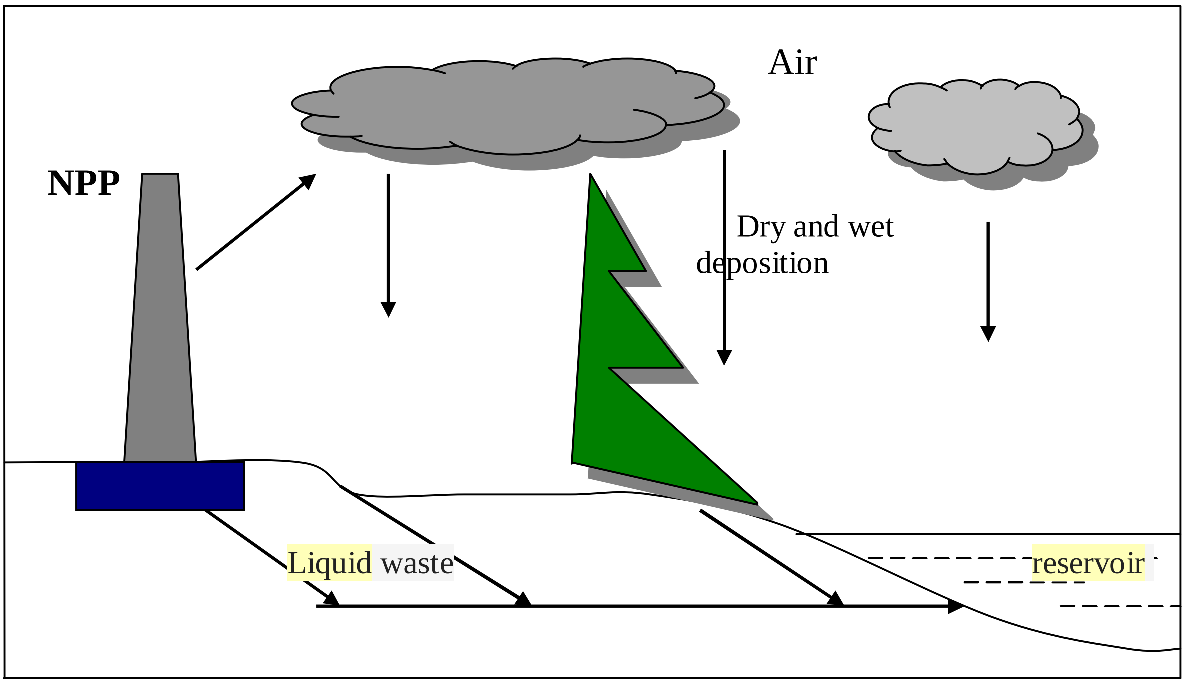

Fig.2.1. Air, surface and underground migrations of radionuclides in environment

generating technologies, but waste does exist. The safety of disposal of a large amount of radioactive waste (RW) for tens and hundreds of thousands of years is questionable due to the reliability of such long-term physical and geological forecasts.

So, The advantage of nuclear power is that it requires significantly less quantities of raw materials and land than heat stations, does not pollute the atmosphere with smoke and soot. The danger lies in the possibility of catastrophic reactor accidents, as well as in the unresolved problem of utilization of radioactive waste and leakage into the environment of a small amount of radioactivity [3]

Nuclear reactors

By the end of 1984, 345 nuclear power reactors were operating in 26 countries. Their capacity was 220GW or 13% of the total power of all power sources. By 1994, the world had 432 nuclear reactors; their total capacity was 340GW.

Most nuclear power plants in the world use thermal neutron reactors operating in a single loop or double-loop circuit, each of which has its own advantages and disadvantages. By their design, the reactors are divided into light water or pressurized-water reactors (LWR and PWR) and boiling water reactor - a high-power one (BWR). The liquid metal cooled fast breeder reactor (LMFBR) of a three-loop heat removal system is also being commissioned.

The migration routes of harmful substances are shown in Fig. 3.1.

All currently operating Ukrainian power units use LWR reactors. They require enriched uranium, making non-nuclear countries dependent on nuclear fuel suppliers. Therefore, some states (in particular Romania) are building heavy water reactors (HWR), which use fuel from natural unenriched uranium. The burnup of fuel in HWR is 4-6 times less than in LWR, and this increases the volume of spent nuclear fuel (SNF) and necessitates more spacious storage facilities.

In addition, the existing SNF reprocessing technologies provide for the removal of plutonium from it, and the creation of their own enrichment plants and facilities for SNF reprocessing in non-nuclear countries gives them the opportunity to produce weapons-grade uranium and plutonium on the basis of completely legal channels of nuclear energy. Another disadvantage of LWRs is that they use 235U as fuel, the reserves of which in the fields explored to date will only last for 50-100 years.

The main negative aspect of NPP operation is the danger of accidents and fires on them, which, as experience shows, lead to serious negative consequences. Thus, one of the urgent problems of NPP operation is to ensure nuclear, radiation and fire safety of the station in all modes, including emergency, which is achieved both by technical measures and by taking into account human factors.

2.2 Radiation accidents and their consequences

Basic information about radiation accidents

In the process of working nuclear reactors, they accumulate a huge amount of nuclear fission products and Transuranium elements [3].

In the conditions of normal operation of NPPs, radionuclide emissions into the environment are insignificant and consist mainly of iodine radionuclides and inert radioactive gases (He, Cr), whose half-life periods (with the exception of the isotope 85kg) generally do not exceed several days. These nuclides are formed in the course of the distribution of uranium and can penetrate through the micro cracks in the shells of the telescopes (fuel elements containing uranium). The entire dose of radiation, which is possible due to emissions at the nuclear power plant and caused by short-lived isotopes (iodine, IWG), is received during the year after the release, 98% - within 5 years. Almost the entire dose falls on people living near the nuclear power plant [3].

Half a century of experience in operating nuclear power plants has shown that in trouble-free operation they can be the most economical and environmentally friendly sources of energy. At the same time, nuclear energy poses a huge danger to the environment and people. This is evidenced by a number of major accidents, the main consequences of which are given below [4].

Dec. 12, 1952 - Ontario, Canada The first major accident at the nuclear power plant. Because of overheating and partial melting of the active zone, a huge amount of fission products came into the environment, and radioactive contaminated water was thrown straight to the ground near the Ottawa River. Because of leakage of radioactive materials from the laboratory for the production of plutonium (Liverpool, UK), they fell ill and killed 39 people.

1957 - the USSR "Kashtym" accident - The first such situation in the. At the Mayak chemical plant, a container exploded in the radioactive waste storage facility. The power of explosion was up to 100 tons in TNT equivalent. The radioactive cloud passed over the Chelyabinsk, Sverdlovsk and Tyumen regions. The area of the radioactive trace was more than 20 thousand km². From 23 locality were evacuated about 12 thousand people, The number of victims is unknown.

1957 - Great Britain. The "Wind Scale" NPP accident. 11 tons of uranium burned out, as a result of the fire. Radioactive fallout heavily contaminated areas of England and Ireland. The area of the contaminated area was 500 sq. km. 13 people died, 260 people fell ill with radiation sickness.

1961 - Soviet nuclear submarine K-19 (Hiroshima) in the North Atlantic. From overexposure, 8 people died, the rest of the crew received various doses of radiation, as a result of depressurization of the reactor.The boat was towed to the base and docked for repairs, which lasted two years. Dock workers received irradiation, and the area surrounding the dock was contaminated. In the next few years, another 20 crew members of the nuclear submarine died from radiation sickness.

1967 - Lake Karachay in the Chelyabinsk region. This lake was used to discharge liquid radioactive waste. as a result of a strong decrease in water level and bare areas the bottom of the lake carried radioactive dust, which contaminated an area of 1800 km^2

1968 - nuclear submarine K-27 in the Barents Sea.
9 people died, having received doses from 600 to 1000 rad, the rest of the crew suffered acute radiation sickness.Subsequently, the boat was sunk in the Kara Sea

1969 - underground nuclear reactor in Switzerland . a significant leakage of radiation occurred. In the same year in France, when the fuel was overloaded at a working reactor at the Sainte-Lauren NPP, the operator by mistake in the fuel channel did not load the fuel cell. For this reason, about 50 kilograms of molten fuel hit the inside of the reactor housing and there was a release of radiation into the environment. The reactor was stopped for one year.

1970 - Gorky, plant "Krasnoe Sormovo" On the under construction nuclear submarine K-320 happened unauthorized launch of the reactor, which worked at an exorbitant power for about 15 seconds The radiation level in the workshop was tens of thousands of roentgens. During liquidation the consequences of the accident, more than 800 people received various doses of radiation, of which three
died of radiation sickness.

1976 and 1977- At the Czechoslovak nuclear power station in Yalovskiy-Bogunitsa, there were just two accidents in. The first accident occurred due to fuel overload, the second - when the nuclear fuel was loaded on the first power unit. After these accidents, the power plant was closed.

1979 - the USA.NPP "Trimal Island" nuclear power plant (Pennsylvania). The largest radiation accident in the United States. 200 thousand people was evacuated from the danger zone of pollution.

1979 the USA. Three Mile Island Accident. An accident that occurred at the second power unit of the plant as a result of an undetected coolant leak in the primary circuit of the reactor plant and, accordingly, the loss of nuclear fuel cooling. During the accident, about 50% of the reactor core melted after which the power unit was never restored. The premises of the nuclear power plant were exposed to significant radioactive contamination, but the radiation consequences for the population and the environment turned out to be insignificant. The alarm is assigned level 5 on the INES scale.

1981 - a crash at the Tsugura power plant in Japan. 56 workers received various radiation doses, and another 278 employees of the nuclear power plant received an increased dose of radioactive exposure during emergency repair works. People have suffered damage to the radioactive contamination container at the Kerr-McGee power plant in the United States. However, perhaps, the most terrible accident occurred at the nuclear power plant in Chernobyl. Because of two powerful explosions on the fourth block of the nuclear power plant, part of the reactor unit and engine room collapsed.

1986 the USSR disaster at the Chernobyl nuclear power plant (Pripyat). The destruction was explosive, the reactor was completely destroyed, and a large amount of radioactive substances was released into the environment. he accident is regarded as the largest in the history of nuclear energy, both in terms of the estimated number of people killed and affected by its consequences, and in terms of economic damage. During the first three months after the accident, 31 people died, another 19 deaths from 1987 to 2004 can be attributed to its direct consequences. 134 people from among the liquidators suffered acute radiation sickness of varying degrees of severity. High doses of radiation to people, mainly from the number of emergency workers and liquidators, have served or may cause four thousand additional deaths from the long-term effects of radiation [5].

2011 - Fukushima-1 (Japan). Major accident at a nuclear power plant as a result of a strong earthquake and the ensuing tsunami. Killed 18.5 thousand people, up to 90% of whom drowned. Presumably, no one died from radiation. During the accident, radioactive cesium-137 got into the atmosphere 168 times more than during the explosion of a nuclear bomb in Hiroshima in 1945. After the accident, the level of Cesium-137 in water samples in the ocean off the coast of Fukushima exceeded the pre-accident level by 50 million times. About 300 thousand people were evacuated from the danger zone within a radius of 50 km. Work on decontamination of the contaminated area continues to this day. The exclusion zone remains within a radius of 20 km from the station. Elimination of all consequences of the accident, including the dismantling of reactors, will take 40 years. The total cost could be approximately US $ 600 billion.

2.3 Consequences of the Chernobyl disaster

A special place among all the accidents that happened is occupied by the Chernobyl disaster (April 1986). The Chernobyl disaster is the largest in the history of nuclear energy, both in terms of the number of people killed and injured, and in terms of economic damage. More than 115 thousand people were evacuated from the 30-kilometer zone of the nuclear power plant, and in subsequent years another 220 thousand people were resettled from the contaminated areas. About 5 million hectares of land have been withdrawn from agricultural use. Buried (buried with heavy equipment) hundreds of small settlements. More than 600 thousand people took part in eliminating the consequences of the accident. According to some data [6], the damaged reactor contained about 200 tons of fuel (uranium dioxide) and a large amount of graphite. After the accident, 120 tons of fuel (long-lived radionuclides) and 700 tons of radioactive reactor graphite were released into the atmosphere; the environment received 600 times more radioactive substances than after the explosion of a nuclear bomb in Hiroshima in 1945.

The main damaging factor of the accident was the radioactive contamination of the area. As studies have shown [6,7], in the first weeks the greatest danger to the population was posed by radioactive iodine (half-life of 8 days), and subsequently - isotopes of strontium and cesium with a half-life of about 30 years.

Isotopes of plutonium and americium remain in the soil for hundreds and even thousands of years, although their number is small. Most of the strontium and plutonium fell within 100 km of the nuclear power plant. Iodine and cesium have spread over a wider area. Radioactive contamination was noted even in districts of the USSR remote from Chernobyl: in Mordovia, Chuvashia, Nizhny Novgorod, Leningrad and other regions, as well as in other countries (table 2.1)

Table 2.1 The level of pollution of European territories as a result of the Chernobyl accident in 1986

Country	Territory area, km², with a level of contamination with cesium-137			
	1-5 Ci / km² > 37 kBq / km²	5–15 Ci / km²	15–40 Ci / km²	Above> 1480 kBq / km² 40 Ci / km²
Russia	46800	5700	2100	300
Ukraine	37200	3200	900	600
Belarus	29900	10200	4200	2200
Sweden	12000			

Finland	11500			
Austria	8600			
Norway	5200			
Bulgaria	4800			
Switzerland	1300			
Greece	1200			
Slovenia	300			
Italy	300			
Moldavia	60			

To assess the pollution of the earth's surface was chosen cesium-137. Cesium-137 has a long half-life and is a gamma-beta emitter, and therefore makes a significant contribution to the lifetime effective dose of external and internal irradiation of people. The highest doses of radiation were received by about 1000 people who were near the reactor (from 2 to 20 gray), in some cases they were fatal. For the liquidators and the population living near the NPP, the radiation doses were relatively small.

According to[7,8], the average radiation doses of these categories of citizens are presented in table 2.2

Table 2.2 Average cumulative doses in persons exposed to radiation from the Chernobyl accident

Person category	Number, people	Average dose, mSv
Liquidators (1986-1989)	600 000	≈ 100
Evacuated from the most contaminated territories (1986)	116 000	33
People living in the territory of "strict radiation control "(1986-2005)	270 000	50
Residents of other contaminated areas (1986-2005)	5 000 000	10–20

Note. For comparison: over the same 20 years after the Chernobyl disaster, inhabitants of some regions of the Earth with an increased natural background (Brazil, India, Iran, China and others) received 100-200 mSv.

Immediately after the Chernobyl accident, were taken emergency measures to control the radiation situation. From the first hours of monitoring the pollution of the atmosphere and the terrain, measurements at the industrial site of the nuclear power plant were carried out by the radiation-chemical protection troops. and outside it - by the forces of the USSR State Hydrometeorological Committee. Gamma-ray photography of the atmosphere and terrain of the near zone of the Chernobyl NPP was carried out from April 26 and throughout May every day. This information formed the basis for urgent decisions on the evacuation of the population, modes of residence and economic activity in contaminated areas, and the implementation of protective and decontamination measures. The map of the dose rate of gamma radiation was built according to the state of May 10, 1986. This map was used to determine the boundaries of the exclusion zone (radiation level more than 20 mR/h), evacuation zones (more than 5 mR/h) and control zones (from 3 to 5 mR/h). In the future, the boundaries of these zones were clarified and fixed by regulatory documents. Zoning of contaminated territories in Russia, Belarus and Ukraine is presented in table 2.3.

Table 2.3 Regulatory framework for the treatment of the territories of Ukraine, Belarus and Russia contaminated as a result of the Chernobyl accident

Ukraine	Belarus	Russia
Zone of enhanced radioecological control (4^{th} zone) - an area with a density of soil contamination with cesium-137 from 37 to 185 kBq/m², for strontium-90 - from 0.74 to 5.5 kBq/m², for plutonium isotopes - from 0.185 to 0.37 kBq/m², where the average annual effective dose of radiation to the population exceeds 0.5 mSv per year.	Living area with periodic radiation monitoring - an area with a density of soil contamination with cesium-137 from 37 to 185 kBq/m²; strontium-90 from 5.55 to 18.5 kBq/m² ; plutonium-238,239, 240 from 0.37 to 0.47 kBq/m² where the average annual effective dose of radiation population should not exceed to produce 1 mSv per year.	On the territory where the annual effective dose does not exceed 1 mSv per year, the usual control of radioactive contamination of the environment and agricultural production is carried out. This territory does not belong to the zone of radioactive contamination. socio-economic status - part of the territory Russian Federation outside the exclusion zone, resettlement zone and zone residence with the right to resettlement with a density of pollution

		cesium-137 in soils from 37 to 185 kBq/m², radiation monitoring zone - radiation doses from 1 to 5 mSv / year.
Zone of guaranteed voluntary resettlement (3rd zone)> 1 mSv / year. Density of soil contamination by cesium 137 from 185 to 555 kBq/m², for strontium-90 - from 5.5 to 111 kBq/m², for plutonium isotopes - from 0.37 to 3.7 kBq/m²	The zone with the right to resettlement is an area with a density of soil contamination with cesium-137 from 185 to 555 kBq/m², strontium-90 from 18.5 to 74 kBq/m², plutonium-238, 239, 240 from 0.74 to 1.85 kBq/m²	The zone of residence with the right to resettlement is part of the territory of the Russian Federation outside the exclusion zone and the zone of resettlement with density of contamination with cesium-137 from 185 to 555 kBq/m², restricted area of population - from 5 to 20 mSv / year.
Zone of unconditional (mandatory) resettlement (2nd zone) -> 5 mSv / year.The density of contamination for cesium-137 is higher than 555 kBq/m² on mineral soils and above 185 kBq/m² on organogenic soils, for strontium-90 - over 111 kBq/m² for isotopes of plutonium - over 3.7 kBq/m²	Resettlement zone - an area with a pollution density by cesium-137 above 555 kBq/m², for strontium-90 - above 111 kBq / m2, for plutonium 238, 239.240 - above 3.7 kBq/m². The zone of priority resettlement is an area with a density of contamination for cesium-137 from 1480 kBq/m², for strontium-90 - above 111 kBq/m², for plutonium 238, 239, 240 - ne 3.7 kBq/m²	Resettlement zone - part of the territory of the Russian Federation outside the zone alienation where the density of soil contamination with cesium-137 is over 555 kBq/m², strontium-90 - over 111 kBq/m², plutonium 238.239, 240 - over 3.7 kBq/m² Resettlement area - from 20 to 50 mSv year
	The zone of subsequent resettlement is an area with a density of contamination for cesium-137 from 555 to 1480 kBq/m², for strontium-90 - from 74 to 111 kBq/m², for	

	plutonium 238, 239, 240 - from 1.85 to 3.7 kBq/m²	
The exclusion zone (1st zone) is the territory from which the population was resettled in 1986	Evacuation (alienation) zone - the territory from which it was resettled in 1986 (30-km zone) and the territories from which additional resettlement was carried out in terms of strontium-90 density above 111 kBq/m², plutonium-238, 239,240, 242 - above 3, 7 kBq/m²	The exclusion zone is part of the territory of the Russian Federation, from which in 1986 and in 1987 the population was evacuated. The density of soil contamination with cesium-137 is over 1480 kBq/m². Exclusion zone> 50 mSv / year

The radiation monitoring system in a 60km radius zone around the nuclear power plant included 540 observation points on an area of 11.5 thousand km. Density maps of contamination of the area with strontium-90, plutonium-239, 240 and americium-241 were constructed based on the data of radiochemical analysis of soil samples. The main contamination is currently long-lived radionuclides: americium-241 with a half-life of 432 years, radium-226 (1620 years), plutonium-239 (24 thousand years), potassium-40 (1.3 billion years), uranium-238 (4.5 billion years). Strontium-90 (29 years old) and cesium-137 (30 years old) can give less pollution. The short-lived radionuclides (iodine-131, cobalt-60, cesium-134) have completely disintegrated.

Over time, the accident at the Chernobyl nuclear power plant is overgrown with more and more myths about the number of dead and injured, about mutant animals. A radiation and epidemiological register was created in which 638 thousand people were registered. Of these, 187 thousand are liquidators of the accident and 389 thousand are residents of the Bryansk, Kaluga, Tula and Oryol regions, which have been exposed to the greatest radioactive contamination. Radiation sickness was detected in 134 people who were at the emergency unit on the first day. Of these, 28 died within a few months after the accident, 20 died for various reasons within 20 years. Over the past years, 122 cases of leukemia have been recorded among liquidators, 37 of which can be caused by radiation. Specialists from the Institute for the Problems of Safe Development of Nuclear Energy of the Russian Academy of Sciences, as well as the WHO and the IAEA, explain this by the fact that in the first days after the accident, radioactive iodine in large quantities settled on pastures where cows grazed, and then concentrated in milk used by children. Currently, most residents of the contaminated areas of Russia, Ukraine and Belarus receive less than 1 mSv per year above the natural background. For more than 60 years, world science has studied the appearance of genetic defects (mutations) due to radiation and has not revealed such a relationship. The International Commission on Radiological Protection in 2007 lowered the value of the risks of mutations from exposure to radiation by 10 times. After the accident at the nuclear power plant, a sarcophagus was built over the destroyed reactor. The closure and conservation of the NPP reactors is expected until 2020, then the holding of the reactors until the radiation radiation is reduced to an acceptable level (approximately until 2045). Dismantling of reactors and equipment, as well as final cleaning of the site in order to remove all restrictions - until 2065.

2.4 Features of accidents at nuclear power plants

Analysis of the consequences of accidents at radiation-hazardous facilities allows improving the methods of protecting the population and the environment from radiation exposure. The IAEA developed and in 1990 adopted the International Nuclear Power Plant Event Scale (Table 2.4).

Table 2.4 International scale of events at nuclear power plants

Level accidents	Description	Criteria	Examples
1st	Minor incident	Functional deviations that are not report any risk, but point out flaws in serious security. (equipment failure, personnel errors, non-abundance of leadership)	
2nd	Moderate incident	Equipment failures or deviations from normal operation, which, although not directly affecting the safety of the plant, can lead to a significant overestimation of personnel measures	
3rd	Serious incident	Release into the environment of radioactive products in an amount not exceeding 5 times the permissible daily discharge. There is a significant overexposure of workers (about 50 mSv). No noticeable action required off site	Van del Los, Spain, 1989

4th	Crash within NPP	Release of radioactive products into the environment in quantities not exceeding the dose limits for the population during design basis accidents. Irradiation of workers at about 1 Sv, causing radiation effects	San Laurent, France, 1980
5th	Accidents with a risk to the environment	Release into the environment of such a quantity of radioactive products that leads to a slight increase in the dose limits for design basis accidents. Destruction of most of the core caused by mechanical stress or melting. In some cases, partial introduction of plans of measures to protect personnel and the public is required	Threemile Island,USA, 1979, "K"
6th	Severe accident	The release into the environment of a large amount of radioactive products accumulated in the core, as a result of which the dose limits for design basis accidents will be exceeded, and for forbidden accidents will not be exceeded. Large-scale action is required to prevent serious public health consequences	Windescale, Shellafield, Great Britain, 1957 g.
7th	Global accident	Release into the environment of a large amount of radioactive products accumulated in the core, as a result of which dose limits for beyond design basis accidents will be increased	Chernobyl, 1986; Fukushima-1, Japan,2011

The considered radiation accidents indicate that the most harmful impact on the environment can be caused by emergencies at nuclear power plants. The NPP provides for various safety systems designed to prevent accidents and limit their consequences. For example, at NPPs with VVER-type reactors there are five such safety barriers:

1) the shell of the nuclear fuel pellet, which retains most of the generated activity;

2) sealed fuel element cladding capable of withstanding the pressure of the accumulating fission products;

3) a reactor vessel made of steel with a thickness of several tens of millimeters;

4) concrete reactor shaft with interlayers of absorbing materials;

5) protective body of the station.

These barriers attenuate ionizing radiation. The exposure of the population living near the NPP does not exceed 2mSv per year, i.e. not higher than the natural background. During normal operation of a nuclear power plant, the main contribution to the radiation dose of the population (over 98%) is made by inert gases (argon, krypton, xenon) and radionuclides: iodine-131, carbon-60, cesium-137, cesium-134, as well as sodium-24 - for BN-600 reactors. Regulatory documents [9] set a quota for the total exposure of the population from radioactive gas and aerosol emissions into the atmosphere and liquid discharges into surface waters, equal to 250 mSv per year (200 and 50 mSv, respectively) at any distance from the NPP.

NPP accident - loss of control of the source of ionizing radiation caused by equipment malfunction, improper actions of plant personnel, emergencies or other reasons, which may or has led to the exposure of people above the established standards or radioactive contamination of the environment. The main causes of accidents at nuclear power plants: - loss of coolant as a result of a ruptured pipeline of the corresponding circuit; - damage to fuel rods with a rapid increase in the reactor power; - mechanical damage (as a result of an explosion) of water supply systems; - rupture of the pipeline of the working fluid circuit. The greatest danger for the personnel and population living near the NPP is an accident with the destruction of the core, in which there is a massive release of radioactive substances into the environment. For technical reasons, accidents are subdivided into design and beyond design basis. An accident, the cause of which is established by the normative and technical documentation, and safety is provided for by the NPP design, is called the design.

An accident is called beyond design basis if safety is not provided for by the design. Such accidents are mainly associated with the melting of fuel in the 49th reactor; they are localized using various engineering and technical and other measures not related to NPP safety systems. The release into the environment of a large amount of radioactive products accumulated in the core, as a result of which, in an accident at a nuclear power plant outside the sanitary protection zone, there may be only one damaging factor - radioactive contamination (contamination) of the area. The area is considered contaminated if the exposure dose rate measured at a height of 0.7–1 m from the earth's surface exceeds the natural background radiation of 0.5 R / h, and if more than this value, it is contaminated. Radioactive contamination of the area also arises from the explosion of a nuclear weapon. However, the nature of the territory pollution during an accident at a nuclear power plant has its own characteristics (Table 2.5), which must be taken into account when choosing methods and means of protecting the population.

Table 2.5 Features of radioactive contamination of the area during an accident at a nuclear power plant and a nuclear explosion

Features of the accident at a nuclear power plant	Features of radioactive contamination in a nuclear explosion
Prediction of the consequences of the accident is difficult and is indicative in nature due to the unpredictability of the accident conditions and meteorological conditions. The nuclear reaction will continue even after the destruction of the reactor, and the release of radioactive substances will continue for a long time.	The nuclear reaction occurs instantly with a minimum yield of isotopes with gamma radiation. The time for the fallout of radioactive fallout from the explosion cloud is several hours, and the changes in meteorological conditions during this time are insignificant. The contamination zone is predictable
Most of the radionuclides emitted from the reactor have long half-lives (plutonium-239, cesium-137, etc.). Contamination of the territory will continue for a long time - tens, hundreds and thousands of years.	The radionuclides dropped from the explosion cloud are mostly short-lived or medium-lived (strontium-89, 90), so the pollution will last much less time (the dose rate 7 hours after the fallout decreases 10 times, and after 2 days - 100 times).
When the reactor is destroyed, a powerful gaseous aerosol cloud is formed, consisting of radioactive gases, iodine in a finely dispersed state and small particles of other elements. This contributes to the deep penetration of radioactive particles into various materials of buildings, objects, which complicates their subsequent decontamination.	Radioactive particles are large and, being heavier than air, settle relatively quickly on the surface of the earth. Decontamination can be done in various ways, incl. mechanical.
Radionuclide’s in dust and gas-aerosol state are in the air for a long time,	Irradiation of people is mainly external.

which contributes to their entry into the human body through the respiratory system and mainly to internal radiation.	
Long-term release of radionuclides at a low altitude (on average 300 m) and frequent changes in meteorological conditions lead to uneven contamination of the area	The release of radionuclides occurs instantly at an altitude of 20-50 km. A radioactive cloud trail on the ground with predictable radiation levels forms relatively quickly.
The main way to protect the population is to hide in shelters and anti-radiation shelters. It is completely impossible to stop fine aerosols and radioactive gases with ordinary personal protective equipment.	A temporary method of protection can be the use of personal protective equipment, including the simplest, which can capture large particles of radioactive dust.

As can be seen from the table, the consequences of radioactive contamination of the terrain in an accident at a nuclear power plant can be more dangerous for the population than in the explosion of a nuclear weapon. At the same time, it should be remembered that radioactive contamination of the area is only 15% of the energy of a nuclear explosion, and the rest of the energy is spent on other damaging factors.

CHAPTER 2. NORMS AND STANDARDS OF RADIATION SAFETY

3.1 Radiation safety standards and principles

A schematic normative structure in industry of the use of ionizing radiation in Ukraine is shown on fig. 3.1. [10]

Fig. 3.1 A schematic normative structure in industry of the use of ionizing radiation.

The basic law in the nuclear legislation of Ukraine is the Law of Ukraine "On Nuclear Energy Use and Radiation Safety " of 08.02.1995 №39 / 95-VR, as amended. This law establishes the priority of human security and the environment, the rights and responsibilities of citizens in the use of nuclear energy, regulates activities related to the introduction of nuclear installations and sources of ionizing radiation, and establishes the legal basis of Ukraine's international obligations on nuclear energy.

According to the Law of Ukraine "On Nuclear Energy Use and Radiation Safety ", the categories of radiation safety and radiation protection are characterized by the following definitions:

• radiation safety - adherence to acceptable limits of radiation exposure to personnel, the population and the environment, established by norms, rules and safety standards;

• radiation protection - a set of radiation-hygienic, design and engineering, technical and organizational measures aimed at ensuring radiation safety.

Thus, radiation safety is a goal, the achievement of which is mandatory during the operation of a nuclear power plant, and radiation protection is a means of achieving this goal.

The radiation safety of personnel, the public and the environment is considered to be ensured if the basic principles of radiation safety and radiation protection requirements established by the current radiation safety standards and sanitary rules are observed.

A schematic normative structure in industry of the use of ionizing radiation is

Radiation safety principles:

1. *The principle of justification.* The principle of justification provides for the prohibition of all types of activities using sources of radioactive radiation, in which the benefits received for the person and society do not exceed the risk of the possibility of harm that can be caused by radiation.

This principle should be applied at the stage of decision-making by authorized bodies in the design of new radiation sources and objects of increased radiation safety, issuance of licenses, approval of regulatory and technical documentation for the use of radiation sources and changes in their operating conditions. In the conditions of a radiation accident, the justification principle does not apply to radiation sources and exposure conditions, but to protective measures, while the dose of warnings by these measures should be assessed as the magnitude of benefit. Measures aimed at restoring control over radiation sources must be applied without fail.

2. *The principle of optimization.* The principle of optimization provides for maintaining at the lowest possible level of both individual and collective radiation doses. In the event of a radiation accident, where higher intervention levels operate instead of dose limits, the optimization principle should be applied to protective measures, taking into account the warnings of radiation dose and interference losses.

3.*The principle of non-exceeding.* The principle of non-exceeding requires prevention of exceeding the individual dose limits and other radiation safety standards established by the current radiation safety standards. This principle must be followed by all organizations and individuals on whom the level of human exposure depends.

From these principles follows the need to comply with the accepted dose level; exclusion of any unreasonable radiation; reducing the radiation dose to the lowest possible level.

The current radiation safety standards of Ukraine [11-13]

Resolution of the Chief State Sanitary Doctor of Ukraine of December 1, 1997 N 62 "On the introduction of the State Hygienic Normative" , Radiation Safety Standards of Ukraine (RSSU – 97) "Permissible levels of strontium and cesium radionuclides in food (PL-97)".

- The radiation safety standards of Ukraine (RSSU – 97) cover a system of principles, criteria, standards and rules, the implementation of which is mandatory in the state policy to ensure anti-radiation protection of people and radiation safety.

RSSU – 97 [13] is the main state document establishing a system of radiation and hygienic regulations to ensure the accepted exposure levels for an individual and for society as a whole and are mandatory for all legal entities and individuals carrying out practical activities with sources of ionizing radiation.

The radiation safety standards of Ukraine (RSSU – 97) include a system of principles, criteria, standards and rules, the implementation of which is a mandatory norm for the state policy to ensure anti-radiation protection of humans and radiation safety. RSSU – 97 was developed in accordance with the main provisions of the Constitution and the Laws of Ukraine "On ensuring the sanitary and epidemic well-being of the population", "On the use of nuclear energy and radiation safety", "On radioactive waste management".

3.2 Dose limits and permissible levels

For each category, irradiated, dose limits and permissible levels corresponding to the main dose limits are established. Additional restrictions exist for women of reproductive age.

The radiation safety standards of Ukraine (RSSU – 97) that operates on this time are envisage setting of norms of irradiation of people in the conditions of practical activity in such cases :

- during normal exploitation of industrial sources of ionizing radiation;
- at a medical irradiation (irradiation of patients);
- at radiation accidents;
- at the irradiation of natural origin technogenic-increase sources.

All persons in relation to sources of ionizing radiation IR (SIR), concordantly RSSU – 97, divided into three categories:

- a category A (personnel) are persons that directly constantly or temporally work with SIR;
- a category of B (personnel) are persons, that directly does not work with SIR, but can get an additional irradiation in connection with placing of their workplaces in apartments and in-plant with radiation-nuclear technologies;

- a category C (population) is all population of country.

For all categories of exposed persons, the limits of annual radiation doses are set in terms of the factors of the individual annual effective dose and the equivalent annual radiation dose to individual organs (table.1.1) Additional restrictions exist for women of reproductive age.

Table. 3.1 The limits of doses ($mSv \cdot year^{-1}$)

Name of dose	Category of persons that is exposed to rays		
	A [a,b]	B [a]	C [a]
Limit of effective dose - DL_E	20 [c]	2	1
Limit of equivalent dose of external irradiation: - for the lens of the eye - for skin - for brushes and feet	 150 500 500	 15 50 50	 15 50 50

Notes:

a - distribution of dose of irradiation during a calendar year is not regulated;

b - for women 45 to and pregnant additional limitations operate (the dose of irradiation of underbody of stomach for any two months must not exceed 2mSv);

c - on the average for any 5 successive, but no more 50mSv for a separate year.

Limitation of public exposure (category C) is regulated by the basic sanitary rules (BSR-72/87) [14].

Exposure category C should not be higher than exposure category B.

As a result of radiation accidents, there may be a need for a planned, higher than the regulated level of personnel exposure. Exposure of personnel in accidents above the dose limits can be justified only by saving people, the need to prevent the development of accidents and exposure of more people, when it is not possible to take measures to exclude their exceeding. That is, in case of unforeseen situations in the following cases:

- when they cannot be eliminated without the use of technological operations associated with not exceeding the dose limits
- when they need urgent elimination;
- with the threat of a radiation accident development.

During realization of works from liquidation of RA the irradiation of emergency personnel is allowed by a dose no more 100mSv (by two annual maximally possible doses of irradiation of personnel that works with SIR). Thus works must be accompanied by radiation-dissymmetric control. Emergency personnel hatch from the zone of irradiation and heads for a realization of medical inspection at exceeding of dose of 100mSv.

In some cases, when emergency work is carried out to save lives, it is allowed to irradiate personnel with doses up to 500 mSv to any individual organ or to the whole body.

To introduce unified approaches to ensuring radiation safety at the international level with the participation of international organizations (IAEA, ICRP, Euratom, WHO), the international Basic Safety Standards for the Protection of the Population from Ionizing Radiation and the Safety of Radiation Sources - RSD (BSS) were introduced. The main goal of the document is to prevent deterministic effects of human exposure and to limit the likelihood of stochastic effects. [15].

The estimated total risk of stochastic effects for professionals is 0.0056% in 1mSv; for all people - 0.00076% in 1mSv; dose from background radiation - 2,4mSv/year.

Sanitary and radiation-hygienic provisions and recommendations contained in the documents of international organizations or other states may be applied on the territory of Ukraine only in specific cases when the combination of III, objects and conditions of exposure is not regulated by national legislation. Such application requires mandatory coordination with the Ministry of Health of Ukraine.

Occupational radiation dose limits and dose limits for the entire population introduced in Ukraine correspond to the recommended OSB. Regarding the levels of exposure in the event of radiation accidents (RA) for the population in Ukraine, strict standards have been adopted.

Levels of impact in the case of RA for OSB:

- stay indoors at a dose of 10mSv for up to two days
- iodine prophylaxis at 100 mg of the accumulated dose on the thyroid gland;
- evacuation at 50mSv to 7 days;
- temporary movement at 10-30 mSv per month;
- permanent resettlement at 1Zv during life; lifetime allowable dose for the population for 70 years - 70mSv;
- permissible level of exposure in a radiation accident -1Zv during life.

Modern dose gradation adopted for radiation-contaminated areas in Ukraine:

- unconditional resettlement - more than 5mSv/year;
- guaranteed voluntary resettlement - more than 1mSv/year;
- the increased radiological control - more than 0,5mSv/year.

Irradiation of personnel higher dose limits can be justified only at unforeseen situations, which can arise up in time of accidents and related to the life-saving, necessity to prevent development of accidents and irradiation of greater amount of people. Id est in cases:

- when accidents it is impossible to remove without the technological operations related to exceeding of limits of doses;
- at a necessity the urgent removal of emergency situation;
- at the threat of development of radiation accident.

For planning of events in relation to the improvement of radiation safety and operative control on a radiation-nuclear object, control levels are set in a sanitary-hygienic zone and zone of supervision.

Control levels are set by administration of enterprise for personnel, and also for territory on a concordance with public regulative organs. Certain values of control levels must be below than possible. Control levels also can be set both for separate radio nuclides in foodstuffs and objects of natural environment and for separate productive operations, modes of exploitation and territories, and others like that.

For a medical irradiation, id est an irradiation of man is as a result of medical inspection or treatment, the limits of doses for patients are not set, but entered the recommended maximum levels for the different categories of the radiation-exposed patients. Taking into account the features of this type of irradiation, against radiation defence of patients is base on principles of justified, optimizationand and unexceeding/

The recommended maximum levels irradiations of patients are driven to the table 3.2.

Table 3.2. The recommended maximum levels irradiations of patients.

Category of patients	Effective dose mZv·year^{-1})
Category AD	100
Category BD	20
Category CD	2
Category DD	1

Category of AD. Patients with oncologic and before cancer diseases, with innate cardiovascular pathology, and also quick Medicare patients.*

Category of BD. Patients with unoncologic diseases at researches with the aim of clarification of diagnosis or choice of tactics of treatment.

Category of CD. Persons that work with harmful factors on a production at passing of medical professional inspection, and also patients, are after radical treatment of oncologic diseases.

Category of DD. Persons that pass all types of prophylactic inspection, except for persons, subsumed ВД.

For the persons of categories of AD and BD additionally imposed restriction equivalent doses of irradiation of the most sensible to radiation organs and fabrics:

the lens of the eye – 150 mSv·year^{-1};

gonads of woman – 200 mSv·year^{-1};

gonads are a man – 400 mSv·year^{-1};

red marrow – 400 mSv·year^{-1}.

Persons that give help to the patients during realization of diagnostic and therapeutic procedures must not get the dose of irradiation more than 5mSv·year^{1}.

Types of zones radioactive pollution territory

The exclusion zone is the territory from which the population is evacuated immediately after the RA and no economic activity is carried out on it.

The unconditional resettlement zone is the area around the NPP where the density of soil contamination by long-lived cesium radionuclides is 15.0 Ki/km^2 or more, or strontium is 3.0Ki/km^2 or more, or plutonium is 0.1 Ki/km^2 or more, where calculated the effective radiation dose, taking into account the migration coefficient of radionuclides into plants, exceeds 5 mSv (0.5rem per year.

A zone of guaranteed (voluntary) resettlement is an area where the density of soil contamination with cesium radionuclides is from 5.0 to 15.0i / km^2, or strontium is from 0.15 to 3.0Ci / km2 or plutonium is from 0.01 to 0.1K. / km^2, where the effective dose of radiation, taking into account the coefficient of migration of radionuclides into plants and other factors, can exaggerate 0.5 mSv (0.05 rem) per year.

The zone of increased radioecological control is an area with a density of soil contamination by cesium radionuclides from 1.0 to 5.0Ci/km^2, or strontium from 0.02 to 0.15 Ci/km^2, or plutonium from 0.005 to 0.01 Ci/km^2, where the effective dose of irradiation taking into account the coefficient of migration of radionuclides into plants and other factors may exceed 0.5mSv (0.05 bar) per year.

An accident with the complete destruction of a reactor at a nuclear power plant (NPP) and its nuclear explosion - can occur due to a natural disaster, a plane crash at a nuclear power plant, personnel errors, ammunition explosion in wartime or sabotage.

In the area of the trace of a radioactive cloud of such an explosion, as in a ground-based nuclear explosion, zones are distinguished: extremely dangerous pollution (zone D), dangerous pollution (zone C), heavy pollution (zone B), moderate pollution (zone A) , radioactive danger M.

Radiation levels at the boundaries of the zones for one hour after the start of the accident (emission) are presented in Fig.3.2.

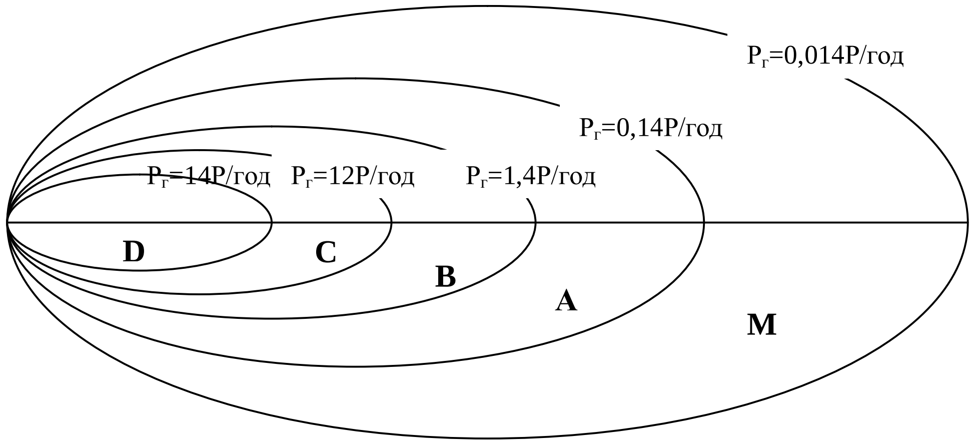

Fig.3.2 The zones for one hour after the start of the NPP - accident

Irradiation doses for the first year after the accident, corresponding to each of the zones, are given in table 3.2.

Table 3.2

The name of zone	Index of zone	Irradiation doses for the first year after the accident, rad	
		On the external border of zone	On the internal border of zone
Radioactive danger	M	5	50
Moderate pollution	A	50	500
Heavy pollution	B	500	1500
Dangerous pollution	C	1500	5000
Extremely dangerous pollution	D	5000	

The living and working conditions of the population without restrictions on the radiation factor is to obtain an additional dose due to contamination of the environment with radioactive isotopes of a dose not exceeding the exposure limits set by the State Hygienic Standards "Radiation Safety Standards of Ukraine (RSSU-97)"

3.3 Organizational support of radiation safety of the territory, object, personnel and the population

The average annual activity of radionuclide radiation sources used in Ukraine in industry and medicine is about 1 million Curie, which does not exclude, as in any production process, emergencies (ES) associated with over-exposure of people and radiation pollution of the environment.

Radiation hazardous objects

Radiation hazardous object (RHO) - an object in the event of accidents and destruction on which mass radiation damage to humans, animals and plants can occur. Radiation hazardous objects include:

- nuclear power plants;
- uranium ore mining and processing enterprises;
- enterprises for the production of nuclear fuel;
- enterprises for reprocessing of spent nuclear fuel and disposal of radioactive waste (in general, all of them can be called enterprises of the nuclear fuel cycle - NPP).
- research and design organizations with research reactors, critical assemblies and stands;
- nuclear power plants on sea and space vessels and devices;
- stationary military facilities for storage of nuclear ammunition and missile launches, as well as vehicles transporting radioactive materials;
- sources of ionizing radiation in many areas and scientific activities.

Radiation hazardous facilities also include enterprises that use small amounts of radioactive substances and products based on them, including devices, apparatus and installations, do not pose a nuclear hazard.

In Ukraine exist about 10,000 enterprises, institutions and organizations using radiation-hazardous technologies and sources of ionizing radiation in their activities. Today there are 4 nuclear power plants in Ukraine (Zaporizhzhya, Yuzhnoukrainskaya, Rivne, Khmelnytsky) (Fig.3.3), there are 2 research reactors, in 6 regions there are regional specialized enterprises for disposal and processing of radioactive waste, which are part of UkrGO "Radon". Uranium ore mining and processing is carried out in Dnipropetrovsk and Kirovohrad regions. Repositories of radioactive waste at uranium mines are overcrowded.

A large number of X-ray and radiological equipment is operated in medical and preventive institutions of Ukraine, more than 80% of which have exhausted their technical and operational resources.

Almost 75% of the territory of Ukraine suffered from 137Cs radioactive contamination, which more than doubled the pre-emergency level, due to the accident at the Chernobyl nuclear power plant. Huge volumes of radioactive waste (RAW) have been generated, which significantly exceeds the volumes accumulated as a result of other activities related to the use of nuclear energy, sources of ionizing radiation and radiation technologies. In the exclusion zone, the main economic entities in the field of radioactive waste management are the state specialized enterprises (SSEs) "Chernobyl Special Plant" and "Chernobyl NPP". Therefore, ensuring the radiation safety of the territories where RNOs exist, the facilities, personnel and the population of the adjacent territories is an urgent task, which is solved by a number of measures.

Fig.3.3 Nuclear power plants in Ukraine

Radiation safety at the facility and the surrounding area is provided by:

• quality of the radiation facility project;

• reasonable choice of area and site for the location of the radiation facility; physical protection of radiation sources;

• zoning of the territory around the most dangerous objects and inside them; - operating conditions of technological systems;

• sanitary-epidemiological assessment and licensing of activities with radiation sources;

• sanitary and epidemiological assessment of products and technologies; availability of radiation monitoring system;

• planning and implementation of measures to ensure the radiation safety of personnel and the population during the normal operation of the facility, its reconstruction and decommissioning; increase of radiation and hygienic literacy of the personnel and the population.

Radiation safety of the personnel is provided by**:**

• restrictions on admission to work with radiation sources on age, sex, health status and other indicators;

• knowledge and observance of rules of work with radiation sources[*)];

• adequacy of protective barriers, screens and distance from radiation sources, as well as limitation of time of work with radiation sources;

• creation of working conditions that meet the requirements of current norms and rules of the Republic of Belarus;

• the use of personal protective equipment;

• compliance with the established control levels;

• organization of radiation control;

• organization of a system of information on the radiation situation;

• Carrying out effective measures to protect personnel when planning increased exposure in the event of a threat and accident.

According to the current norms of radiation safety, the organizational measures ensuring radiation safety of works are:

• works are decorated with an outfit or order;

• admission to work;

• supervision during work;

• registration of breaks in work;

• registration of the end of work.

[*)] The examples of Instruction from safety rules in relation to the use of radioactive materials in an educational radiation laboratory and of Information Sheet and Regulations for Working with certain radioactive substance are driven to Appendixes 2 and 3. [16]

Radiation safety of the population is provided by:

• creation of living conditions for people who meet the requirements of current norms and rules of radiation safety;

• establishment of quotas for irradiation from different radiation sources;

• organization of radiological control;

• the effectiveness of planning and conducting measures for radiation protection in normal conditions and in the event of a radiation accident;

• organization a system of information about the radiation situation.

Sanctions for violation of the requirements of norms and rules on radiation safety in Ukraine

For violation of the requirements of norms and rules on radiation safety of Ukraine, disciplinary, administrative and criminal liability is assumed in accordance with the current legislation of Ukraine [17].

Code of Ukraine on Administrative Offenses (Administrative Code). Article 188 (18). Failure to comply with legal requirements (prescriptions) of officials of state regulatory bodies for nuclear and radiation safety.

Failure to comply with legal requirements (prescriptions) of officials of state regulatory bodies of nuclear and radiation safety to eliminate violations of nuclear and radiation safety legislation, failure to provide them with the necessary information or providing false information, creating other obstacles to fulfilling their responsibilities - entails a fine of ten to one hundred non-taxable minimum incomes of citizens.

The same actions committed repeatedly within a year after the imposition of an administrative penalty - entail the imposition of a fine of one hundred to two hundred non-taxable minimum incomes.

3.4. Management decisions and organizational measures to ensure radiation safety in accidents

General characteristics and classification of radiation accidents

The Radiation Safety Standards of Ukraine define a number of terms related to NPP accidents.

Radiation accident - any unplanned event at any facility with radiation or radiation-nuclear technology, if at the occurrence of this event two necessary and sufficient conditions are met: loss of control over the source; actual (or potential) exposure of people associated with loss of control over the source.

Nuclear radiation accident - any unplanned event at an object with nuclear radiation technology, which occurs with a simultaneous loss of control over a nuclear chain reaction and the emergence of a real or potential threat of a spontaneous chain reaction.

A communal accident is a radiation accident, the consequences of which are not limited to the premises of the facility and its industrial site, but also spread to the surrounding territories where the population lives, which may actually or potentially be exposed to radiation.

Global accident - a communal radiation accident, which affects a large part (or all) of the country and its population.

Local accident - a communal radiation accident, during which a population of up to 10 thousand people live in the accident zone.

Emergency exposure - unpredictable increased exposure of personnel and / or the public as a result of a radiation accident.

Emergency plan - an action plan in case of an accident at any facility where practical activities related to radiation or radiation-nuclear technologies are carried out.

An industrial accident is a radiation accident, the consequences of which do not extend beyond the territory of the production premises and the industrial site of the facility, and only personnel are exposed to emergency radiation.

Limits of safe operation of NPPs - the values of technological process parameters set by the project, deviations from which can lead to an accident.

The International Nuclear Event Scale (INES) defines the term accident as an event related to the violation of the limits of safe operation, which has three main types for nuclear power plants:

radiation - an event that characterizes the violation of the limits of safe operation, in which there was a release of radioactive products and / or ionizing radiation beyond the prescribed limits in quantities exceeding the values set for normal operation, which requires the termination of NPP operation;

nuclear - an event that characterizes the damage of fuel rods above the established limits of safe operation, and / or exposure of personnel beyond acceptable for normal operation, caused by violation of control and management of nuclear fission chain reaction in the reactor core or critical mass formation during reloading, transportation and storage of fuel rods ; violation of heat dissipation from fuel rods;

technical - an event that characterizes the loss of strength of equipment and pipelines, failures of which can lead to a violation of heat dissipation from the reactor core and the ability to keep in a sealed zone stood out radioactive materials.

The division of accidents into radiation, nuclear and technical for NPPs is very conditional, as the occurrence of a nuclear or technical accident can lead to a radiation accident.

According to the spread of radionuclides in the surrounding space, accidents are divided into three types: local, local and general.

Local incident - radiation consequences are limited to one building or structure on the industrial site of the reactor (requires certain measures to protect personnel).

Local accident - radiation consequences are limited to the territory of the industrial site (dose rate in some rooms and on the site is higher than the design value for normal operation of the reactor, personnel protection measures are required).

General accident - radiation effects extend beyond the territory of the industrial site and the sanitary protection zone (SPZ) of the reactor (dose rate and level of environmental contamination by radionuclides in the area of the reactor location not above the established limits for normal operation).

According to INES, a serious accident is defined as an event at a nuclear power plant in which safety barriers were violated with damage to the core and the release into the environment of a large number of radioactive products accumulated in the core.

According to modern international trends, the formulation of operational and emergency states of NPPs is characterized by conditions of normal operation and deviations from the conditions of normal operation (did not go into an accident / emergency situation); an emergency is defined as a design basis or beyond design basis.

A design basis (project) accident (PA) means an accident for which the project defines the initial events (IE) and end states and provides safety systems (SS) that provide, taking into account the principle of single system failure (system channel) safety or one independent of the personnel error) limitation of its consequences by the limits established for such accidents.

A beyond-design basis accident **(**BA) is an accident caused by initial events not taken into account for the PA or accompanied by additional failures of the SS in comparison with the PA in excess of a single failure or the implementation of erroneous actions of personnel (independent of the IE) [18] .

Modern general safety regulations of Ukraine also define a severe accident as BA, in which there is severe damage to the core (exceeding the maximum design limit of damage to the fuel rods). At the same time, according to the RSSU, it is necessary to distinguish between the concepts of accidents and emergencies. An accident is a disruption of a NPP operation in which a radioactive material (RM) and / or IR has gone beyond safe operation, and an emergency situation is a state of a NPP characterized by a violation of the limits and / or conditions of safe operation but not an accident.

In this case, in contrast to the previous provisions of safety regulations, it is assumed that:

1) the BA also includes emergency situations that were not taken into account in the projects, but covered by the design analysis and justification;

2) BA includes both accidents with damage to the core and without damage to the core;

3) the term of accident management is applied only to BA.

Permissible values of RM discharge and release into the environment are deterministic safety criteria in case of NPP accidents.

According to the RSSU:

allowable emission - regulated maximum total level of aerosol emissions.

Permissible emission - an emission at which the total annual effective dose of a representative of a critical group of the population (outside the SPZ) due to all radionuclides present in the emission does not exceed the dose limit quota;

allowable discharge - regulated maximum total level of water discharge. Permissible discharge - a discharge in which the total annual effective dose of a representative of a critical group of the population due to all radionuclides present in the discharge does not exceed the dose limit quota;

dose limit quota - the proportion of the effective dose limit (DLE) for category B, which is allocated for the mode of normal operation of a single industrial source.

Basic regulatory requirements and regulations for accident management at NPPs.

In accordance with the norms and rules of nuclear energy safety of Ukraine, as well as the international experience and recommendations of the International Agency from nuclear energy (IAEA), special guidelines or procedures for the management of beyond design and severe accidents must be implemented at NPPs.

The concept is in principle reflected in the General Safety Regulations of Ukraine, and in the regulations, it is supplemented by some more specific requirements. These requirements largely coincide with IAEA recommendations. The concept is based on the requirement to limit the radiation exposure in case of emergency by applying accident management measures and implementing action plans for the protection of personnel and the population at the NPP site and the surrounding area. These measures are part of the deeply echeloned protection.

The main requirements for operational documentation for accident management are as follows:

1. The NPP Administration on the basis of reports on safety analysis, technological regulations for safe operation, and other operating documents organizes the development and approval of instructions and guidelines that determine the actions of personnel in case of normal operation, emergencies, design, and beyond accidents, including severe.

2. Instructions and guidelines are based on the symptoms and/or events, modes, and conditions of the power unit, expected in the process of development of transients, emergencies, and accidents. Emergency instructions and guidelines are brought in line with other operating instructions and regulations.

3. The requirements of emergency instructions and guidelines are substantiated by calculation, are verified and validated to reflect the actual

condition of the NPP and its operating conditions. Validation of emergency instructions and manuals is performed using full-scale simulators.

4. Analysis of the consequences of BA is the basis for drawing up action plans for the protection of personnel, the population, as well as for the preparation of special instructions for personnel to manage such accidents. The Safety Regulations for Nuclear Reactor Systems of Nuclear Power Plants also set requirements for the development of special instructions defining the actions of personnel to ensure safety, as well as measures to prepare personnel for such actions.

Personnel actions are aimed at restoring the safety functions and limiting the radiation consequences of the accident. Instructions for BA management should be included in the set of documents substantiating the safety of NPP power units when licensing all stages of the NPP life cycle: commissioning after construction of the power unit, operation of the existing power unit and decommissioning.

In order to localize at the NPP, technical means must be provided to prevent damage to the sealed fence and its reinforced concrete structures when the pressure and temperature rise above the design values, keep molten fuel inside the area of accident localization to ensure subcriticality of the molten fuel, prevent hydrogen explosion and reduce emissions environment. Safety systems designed to localize the accident and their elements (including the protective shell) must perform the following basic:

1) to prevent or limit the spread of radioactive substances released during accidents outside the accident localization zone (ALZ);

2) protect the system and/or elements from external environmental influences, the failure of which may lead to the release of RM, which exceeds the design value of the leak;

3) limit the output of ionizing radiation outside the ALZ ;

4) reduce the pressure of the environment in the ALZ;

5) to remove heat from the ALZ;

6) reduce the concentration of RM in the ALZ;

7) control the concentration of explosive gases in the ALZ;

8) maintain the concentration of explosive gases in the ALZ less than the lower concentration limit of flame propagation. The NPP design must also contain an analysis of the operation of the LSS under the effects associated with severe damage to the core and the release of the melt outside the reactor.

According to the European safety requirements, the following approach to the design of the protective shell system is required, which mitigates the consequences of the destruction of the core due to:

1) retention and cooling of fragments of the core;

2) the effects of the interaction of the core and concrete;

3) limitation of leaks taking into account the loads associated with the oxidation of fuel rods and hydrogen combustion (adjusted for measures to ensure the removal of hydrogen) and other loads in the most likely technical accidents (TA);

4) increasing the time interval for accident management, during which operator intervention is required.

In accordance with the current general provisions for ensuring the safety of nuclear power plants, accident management means actions aimed at preventing the development of accidents in the off-design and mitigating the consequences. For these purposes, any means intended for normal operation, for safety in the event of a design basis accident or specifically designed to reduce the consequences must be used.

Radiation safety standards of Ukraine (RSSU) **s**ets quotas of dose limits used to determine permissible emissions and discharges at NPPs:

1) the quota of the limit of the effective dose of DLE due to all ways of forming the dose - 40 μSv (4%);

2) the quota of the limit of the effective dose of DLE due to the critical type of water use - 10 μSv (1%);

3) the total quota limit of the effective dose due to air and water routes of dose formation - 80 μSv (8%).

4) Based on the dose limit quota, permissible discharges and permissible emissions are set for each individual facility. The migration of radionuclides in the environment and along food chains, the structure of land use, and the actual use of water bodies must be taken into account when establishing the values of permissible discharge and permissible emissions.

Restriction of exposure of the main personnel engaged in emergency works is carried out so that the values of regulations of the first group for category A established by the RSSU are not exceeded. that the value of the total irradiation does not exceed 100 mSv.

In the case of TA at NPPs, the pan-European requirements define the following deterministic safety criteria:

1) the fragments of the core are in the solid phase, and their temperature is stable or decreasing;

2) the heat release of the fragments of the core is removed and transferred to the final heat runoff;

3) the configuration of the fragments is such that K_{ef} is much lower than 1;

4) the pressure in the volume of protective shell is so low that in the case of depressurization of shield the criterion of limitation of radiation consequences for the population is satisfied;

5) stopped the release of fission products into the protective shell.

Also, the requirements of regulatory and design documents establish the following deterministic safety criteria:

1) allowable values of pressure, temperature, humidity and hydrogen concentrations in the impermeable shell system;

2) permissible characteristics of metal structures of equipment and pipelines;

3) permissible leaks of physical safety barriers;

4) allowable seismic loads;

5) fire safety rules, etc.

The RSSU also sets probabilistic safety criteria for existing and projected NPP power units, as well as targets to be pursued (Table 3.3).

Table 3.3. Probabilistic safety criteria for nuclear power plants

Safety criterion	Operating NPPs 1/(reactor year)	Design NPPs 1/(reactor year)	Targets 1/(reactor year)
Frequency of severe damage to the reactor core	10^{-4}	10^{-5}	$10^{-5} \div 5 \cdot 10^{-6}$
Frequency of maximum emergency release of RM into the environment	10^{-5}	10^{-6}	$10^{-6} \cdot 10^{-7}$

Standardized probabilistic safety criteria are important not only for the regulation of NPP safety (possibility of quantitative assessment of the overall safety level; assessment of the impact of modernization on total safety indicators; impact of degradation / aging processes on the overall safety level; justification for continued operation, etc.), but also for formation of operational documentation for the management of design basis and severe accidents. Established probabilistic safety criteria determine the need and actually "legitimize" the use of probabilistic methods and risk-based approaches to safety analysis. targets.

However, it should be noted that so far there is no unambiguous attitude of experts to the feasibility of widespread use of probabilistic safety criteria. Opponents of the probabilistic safety criteria are mainly based on the fact that the low probability of an accident does not in fact exclude the possibility of such unacceptable events for humanity as the Chernobyl disaster.

Measures to prevent industrial radiation accidents

According to determination - radiation accident (RA) is an event as a result of which control over a III or nuclear installation is lost and which causes or may lead to radiation impact on people and the environment, exceeds the permissible limits established by norms, sanitary rules and safety standards.

There are the center of the radiation accident and the area of radioactive contamination.

The extent and degree of radioactive contamination of the terrain and air determine the radiation situation. Radiation situation is a set of conditions arising from pollution of the terrain, air, water sources, negatively affects the livelihoods of the population and rescue operations. The dynamics of the radiation situation is influenced by the type of radionuclides and their half-life, it is these indicators that determine the rate of reduction of radioactive contamination of the environment.

All RAs are divided into two large groups: All RAs are divided into two large groups:

- The first group - accidents not accompanied by radioactive contamination of industrial premises, industrial site of the facility and the environment;

- The second group - accidents resulting in radioactive contamination of industrial premises, the industrial site of the facility and the environment.

As a result of accidents of the first group there can be the increased irradiation of the person only by external X-ray, gamma, beta and neutron radiation.

Accidents of the second group include accidents at facilities where work with radioactive substances is carried out in the open, during depressurization of closed sources of gamma, beta alpha and neutron radiation, as well as at radioactive material warehouses and radioactive waste disposal sites where emissions into the atmosphere and discharges are possible. into the reservoir of radionuclides in quantities exceeding the permissible limits for the environment.

As a result of the accident of the second group, people can receive radiation exposure due to external, internal and contact radiation.

In terms of scale, ie the size of the territory and the possibility of irradiating personnel and the population, RAs are divided into two classes: industrial and communal.

In industrial RA, the radioactive contamination does not go beyond the production premises and the industrial site area [19,201. Only the personnel of the enterprise can be exposed to emergency radiation. Industrial RA with a radionuclide source includes cases in which the following occur:

- theft or loss of a radiation source or a protective unit with a source, if the source did not fall outside the enterprise;

- falling of sources from the protective block or falling of the block with a source from a fastening place;

- depressurization of the source, if timely measures are taken to prevent the spread of radioactive contamination outside the production premises;

- destruction or deterioration of the quality of radiation protection of the protective unit with the source;

- identification of previously unaccounted for sources;

- irradiation of personnel with a dose exceeding the current standards as a result of a critical event;

- radioactive contamination of equipment and territory of the enterprise.

- destruction of the radionuclide source during its transportation. Any accidents, the consequences of which have spread outside the enterprise and caused increased exposure of the population, are considered utility accidents.

Accidents with radionuclide sources are usually associated with their use in industry, gas and oil production, construction, research and medical institutions, in transport during the transportation of radionuclide radiation sources.

RA can occur both without depressurization of sealed sources, and with depressurization. The nature of the radiation exposure is determined by the type of radioactive source, its activity, conditions, duration of exposure, and the like.

In an accident with sealed radioactive sources (ZRD) in the form of ampoules or small cartridges (several centimeters) without depressurization, a limited number of people who had direct contact with the source are exposed to radiation, while the radiation clinic has a local (local) character with damage to individual parts of the body and organs or the whole body.

In case of depressurization of the radionuclide source, radioactive contamination of large areas, vegetation, contamination of the body of people living in this area is possible.

The nature of the impact on the environment is determined by the state of aggregation of RR propagating in the external environment, and, thereby, by the mechanism of entry of radionuclides into the human body. The combination of radioactive contamination with fire, explosion, meteorological factors is also of great importance. The peculiarity of RA is the difficulty of establishing the fact of the accident. They learn about it after registering radiation damage.

The most common causes of RA can be:

- equipment malfunction;

- equipment design flaws;

- wrong actions of the personnel;

- natural disasters, a sharp change in the intensity of meteorological factors (showers, floods, high wind speed)

- insufficient physical protection of radiation sources;

- violation of traffic rules in case of transportation of radioactive materials.

The IAEA has developed a system for categorizing sealed radionuclide sources according to their potential radiation hazard in the worst-case scenario, including the possibility of dispersing PPs and spreading radioactive dust and aerosols into the environment. The system is based on the potential for such effects of RA that may be the cause of deterministic effects in humans. This system is based on the concept (concept) of a "dangerous source", defined as a source, can lead to human exposure sufficient to cause deterministic effects, if it is not under proper control. Depending on the type of practice, the type of product or installation containing the SRD, and the activity of the radionuclide, the limits of the five categories of SRD hazards are set so that the most dangerous sources belong to the IAEA first terminology category - "extremely dangerous to humans" and the least dangerous to category 5 - "danger to humans is unlikely".

The minimum activity of PP for individual radionuclides, which can lead to severe deterministic effects, is called the D-value (from the English. Dangerous)

The main directions for preventing RA and reducing losses from its consequences are measures for the expedient location of radiation-hazardous facilities, special measures to limit the spread of RR emissions outside the sanitary protection zone, measures to protect personnel and the public. The wind rose, seismicity of the zone, geological, hydrogeological and landscape features are taken into account.

It is important to constantly improve the qualifications of workers, knowledge of technological processes and radiation safety rules is a guarantee of reducing the likelihood of RA. There are design, beyond design and hypothetical accidents. Project (PA) includes accidents for which the project determines the initial and final states, for such accidents safety measures are provided.

Extra-design (PO) accidents include accidents that do not take into account the initial conditions, the degree of radiation protection is not calculated for them, and the consequences are extremely severe. In case of beyond-design basis accidents, a large probability of a large number of people being exposed to radiation is very high, and radioactive contamination spreads over large areas. There are large material losses.

Hypothetical RA is an unlikely accident, the consequences of which are difficult to predict. However, such accidents can also occur if several unlikely factors coincide.

Measures aimed at preventing industrial RAs are a set of technical and organizational conditions that must be observed during the operation of SIR at the enterprise. Prevention of RA is facilitated by the correct placement of the radiological object relative to the settlement, as well as the premises where they work with III relative to other premises not related to the use of SIR.

Each radiological facility should have an Instruction on personnel actions in case of RA and elimination of their consequences, which should include:

- general provisions;
- list and characteristics of the main premises where they work with SIR, as well as the characteristics of adjacent premises where they can work with chemicals and explosives;
- forecast of possible accidents at this facility;
- the list of emergency situations, is the basis for the beginning of performance of actions for liquidation of accident;

- list of responsibilities of the head of the enterprise at RA;
- actions of the personnel in case of emergence of an emergency situation;
- appointment of the composition and responsibilities of the commission in the liquidation of the accident;
- first aid to victims.

The instruction is developed for a concrete object taking into account its features

Acquisition of sources and their transfer from one enterprise to another is allowed only on specially executed orders-applications, coordinated with the corresponding territorial bodies.

All sources used in the enterprise must be recorded in the income statement. The company must have a layout of sources on the equipment and the location of such equipment.

An important point is the observance of the operating conditions of the sources provided by the technical conditions - temperature, humidity, dust, mechanical and chemical effects, etc.

Installation and dismantling of sources on the equipment is allowed only to the persons having special preparation, the license and in the presence of the project executed by the licensed organization.

When placing the source in the protection unit on the process equipment, it is necessary to regularly check the reliability of the unit mounting with registration in a special log. The presence of the source in the protective container should be regularly monitored using a dosimetric device that has the required measurable capacity.

When working with a mobile source in case of temporary cessation of work, the source is put into a non-working state with the sealing of the movement mechanism. The presence of the seal must be checked regularly. Stationary sources, not operated, must be dismantled and kept in special storage. It is forbidden to remove the source from the protection unit, unless it is provided by the technological instructions.

When working with the source in the field, it is necessary to make sure that it is present in the protection unit using a dosimetric device.

It is necessary to regularly monitor the level of radiation and the presence of radioactive contamination of the surface of the protective unit with the source.

At the end of the service life of the source, the unit with the source must be dismantled and placed in a special storage for subsequent burial in the cemetery of the state association "Radon".

It is necessary to store the source in special warehouses (storages) equipped with hoisting-and-transport mechanisms and the security and fire alarm system. PP packages must have clear labels indicating the name of the radionuclide, its radiation and chemical characteristics. Packages with compromised integrity are considered radioactive waste.

Violation of the sanitary condition of the premises where they work with III - leaking water supply or heating system, sewerage, do not lead to disruption of the technological process and do not cause excessive exposure of personnel are not considered RA.

Transportation of sources is carried out only on specially equipped transport, has means for liquidation of RA, fire, and also the dosimetric equipment.

All work related to the manufacture, use, transportation and disposal of PP must be carried out in the presence of a license and in accordance with the instructions on radiation safety. When working with PP, where necessary, personal protective equipment should be used in accordance with occupational safety requirements.

Procedure for investigation of industrial radiation accidents

The set of measures for radiation safety of personnel and the population in the event of an RA should ensure that the negative consequences of the accident are minimized, first of all, preventing the occurrence of deterministic effects and minimizing the probability of nondeterministic (stochastic) effects. When RA is detected, urgent measures should be taken to stop the development of the accident, restore control over the radiation source and minimize radiation doses and the number of exposed persons from personnel and the population, radioactive contamination of industrial premises and the environment, environmental and social losses accidents. The actions of personnel in the event of RA at the enterprise should be determined by the "Instructions on the actions of personnel in the event of a radiation accident" for this facility.

In case of industrial RA, the administration of the enterprise must immediately notify the territorial bodies of the State Inspectorate for Nuclear Regulation. In case of loss, theft sources are also informed by law enforcement agencies. Prior to the arrival of the representatives of the regulatory bodies at the scene of the accident, the administration of the enterprise must take all urgent measures to locate it and prevent unpredictable overexposure of personnel.

To investigate the causes of the accident and eliminate its consequences at the enterprise, the commission establishes a commission chaired by the technical director or his deputy. The commission shall include representatives of regulatory bodies and specialized agencies, with the participation and under the control of which the consequences of the accident shall be eliminated.

The commission establishes the cause of the accident, determines the persons responsible for the accident, as well as develops measures to eliminate the accident and its consequences. The commission gives recommendations to the administration of the enterprise aimed at preventing such accidents in the future.

When carrying out activities aimed at eliminating RA and its consequences, the main task is to resolve the following issues as soon as possible:

- identify and prevent the development of the accident and eliminate its cause;
- to prevent the possibility of further impact of ionizing radiation on the personnel of the enterprise;
- identify all possible sources of contamination and clarify possible ways of spreading radioactive contamination;
- to prevent the spread of RR into the environment;
- eliminate the consequences of RA as much as possible;
- provide the necessary medical care to the victims.

The following issues are resolved during the investigation and liquidation of the consequences of the accident:

- carrying out preliminary radiation control;
- identification of persons who could experience emergency exposure and their referral to appropriate medical institutions;
- control over ensuring radiation safety of persons involved in the investigation and liquidation of the accident;
- control over the levels of radioactive contamination of industrial premises and the environment;
- hygienic assessment of the radiation situation and individual radiation doses of personnel, as well as persons involved in emergency work;
- assessment of the effectiveness of decontamination of premises and sanitation of people;
- development of proposals for the protection of personnel and the population, as well as the implementation of the necessary sanitary and epidemiological measures;
- control over the seizure, collection and disposal of radioactive waste.

Elimination of consequences and measures to protect personnel and the population

Legal entities responsible for the protection of people in RA must have:

- a list of possible RA and forecasts of their consequences;
- plans for the protection of personnel and the population, in coordination with the relevant authorities - local authorities and the sanitary-epidemiological service;
- means of notification;
- means to ensure the elimination of the consequences of RA;
- means of individual dosimetric control;
- emergency rescue formation.

All works in the RA zone are performed by emergency personnel (emergency rescue formation), which includes the personnel of the emergency facility and members of emergency crews prepared in advance. Representatives of the regional special plant, as well as employees of special commissioning organizations with appropriate licenses and experience in working with radioactive sources may be involved. All work is performed on a voluntary basis with the written consent of the liquidator of the accident. Men under 30, as well as women are not involved in such work.

Increased exposure of "liquidators" provided for in section 7.19 of RSSU-97 is allowed only in exceptional cases when it is necessary to rescue people or prevent their exposure, if appropriate protective measures cannot be provided without measures related to exceeding the dose limits for category A personnel. .

In the event of an RA, the person responsible for radiation safety in the institution, and in its absence at the scene - the senior staff member, must take urgent measures to localize the emergency, prevent further development, minimize human exposure and radioactive contamination of industrial and environment provided by the "Instructions on the actions of personnel in the event of a radiation accident."

When establishing the fact of RA, the responsible persons must immediately stop all types of work in its area, notify the staff and other people close to the source, the administration of the institution, and if necessary - ambulance dispatchers, fire protection with a warning system, existing on the object. The person responsible for radiation safety is obliged to immediately report to the administration of the institution not only on the occurrence of RA, but also on any violation of the rules of handling sources, as such violation may lead to an accident or be a signal of a hidden accident.

Based on the initial information about the accident, the person responsible for radiation safety or older at the site performs the following actions:

- stops work in the accident zone;
- conducts preliminary control of the radiation situation (radiation monitoring);
- establishes and indicates possible (not final) boundaries of the accident zone;
- organizes the withdrawal of people from the RA zone and takes measures to restrict the access of outsiders to the danger zone;
- identifies people who need immediate medical attention;
- organizes the provision of medical care to victims;
- gives a preliminary assessment of the type and scale of the accident;
- determines the priority protective measures and appoints their executors;
- organizes the delivery of protective equipment, dosimetric equipment, other equipment and materials required for priority protective measures;

- organizes individual dosimetric control (IDC) with the help of dosimeters, in case of their absence provides IDC with thermoluminescent dosimetry (TLD) and ensures minimization of human exposure during protective measures.

In hazardous areas, in the sanitary checkpoint and in the first-aid post, there should be first-aid kits with a set of means for first medical (pre-medical) aid, as well as a supply of means for decontamination and sanitization of people. In the case of a large number of victims, medical assistance is primarily provided to children and women.

Restrictions of the RA zone should be carried out immediately after the assumption of a possible radiation hazard based on primary information about the circumstances and possible scale of the accident, the results of dosimetric and radiometric measurements. The limitation of the RA zone affects so that the dose rate of gamma radiation outside of it for persons who are not involved in the performance of specific emergency work does not exceed 10mkSv 1 - for the population in places where people stay outside industrial premises and the territory of a radiation facility. On the existing physical and disciplinary barriers (walls, doors, fences, stretched belts, well recognized from a distance of 3 m, etc.) and special fences, warning labels are posted, notifying of the radiation hazard and the prohibition of entry into the RA zone. With a large size of the zone, if necessary, its borders are protected by the forces of auxiliary personnel, internal affairs bodies, military personnel, and the like. In the process of clarifying the radiation situation, the boundaries of the RA zone can be corrected.

Access control to and from the RA zone is introduced immediately after the zone is restricted. Access control prevents exposure of people not involved in the accident and minimizes the number of people who may be exposed or become contaminants, and reduces the time-consuming and costly work of radiation control and decontamination of people, their clothes and personal belongings. Only members of the emergency brigade can be in the accident zone, performing specific emergency response work provided for by the plan. Persons not currently performing work to eliminate the accident must leave the danger zone or go to shelters.

Reducing the duration of contact with the source through careful planning and qualified organization of emergency work can significantly reduce individual and collective radiation doses. All work should be excluded, except for those that are reasonably necessary.

When performing works on liquidation of RA and its consequences it is prohibited:

- in the presence of radioactive contamination to carry out works without means of individual protection - respirators, overalls, special. shoes, rubber gloves, hats;

- to be in the RA zone without means of individual dosimetric control;

- to take out of the RA zone any objects without preliminary dosimetric control;
- smoking and eating in the RA zone.

To protect people from external gamma radiation, shielding involves the use of existing (walls, equipment, etc.) or specially designed protective barriers that reduce radiation levels.

All workers in the area should be provided with individual (preferably thermoluminescent) dosimeters and dosimeters of the integrating type, allows to monitor the dynamics of dose accumulation during operation and prevent radiation above the planned (permitted) level.

Protection against internal radiation at high levels of air radioactivity in the accident area should be provided by the use of personal respiratory protection - respirators, gas masks or cotton gauze masks. Skin protection is provided by use of overalls, working clothes, rubber footwear, gloves, hats, canned glasses.

Sanitary treatment of people, change of clothes and decontamination of work surfaces are carried out when the permissible levels of radioactive contamination specified in RSSU -97 are exceeded.

Decontamination works on the territory and in the premises begin after radiation control and assessment of the radiation situation. In the case of contamination with short-lived radionuclides, it is sometimes advisable to wait a while, during which the dose rate will be significantly reduced, while protecting the area, than to carry out decontamination immediately. This event is decided in each case individually.

Prior to the start of work to eliminate the consequences of the accident, personnel are instructed on radiation safety with an explanation of the nature and sequence of work. If necessary and possible, it is necessary to carry out preliminary working off of future operations on non-radioactive models or models.

Work to eliminate the consequences of the accident and the implementation of other measures in the area where the dose rate of gamma radiation is above 100 μSv h-1, is carried out under a special tolerance, which provides for the duration of work, the necessary means of protection and dosimetric control.

Upon detection of radioactive contamination of residential premises, it is prohibited for people to live in them until appropriate measures are taken to normalize the radiation situation. Radiation control of floor, wall, furniture, equipment, household appliances and clothing should be carried out in the premises. Contaminated surfaces should be decontaminated and household items should be decontaminated or buried. After completion of decontamination works on the results of radiation control the act and protocols of radiation control are made. The received doses of irradiation are carried out by inhabitants who in case of need go on unscheduled medical inspection.

In case of loss or possible theft, sources should immediately inform the internal affairs bodies for a special investigation in order to identify the persons involved and search for the radiation source, as well as inform the population about the loss of the source, characterizing its external features, and also provide data for feedback (phone numbers , e-mail address) in case of identification of the source by citizens or suspicion of the source.

To search for the source, a search team is created from category A personnel and employees of the radiation safety service of the radiological facility. If necessary, the staff of the Radon association and the Ministry of Internal Affairs are involved in the brigade. Before leaving the brigade, the most probable locations of the source are analyzed and the route of movement is determined.

Brigade members are instructed on search tactics and radiation safety measures if a source is found. The team is provided with individual dosimeters, a remote instrument, a source container, protective clothing in case of radioactive contamination, means of fencing the accident zone and dosimetric and radiometric search devices. Among them should be both instruments with a sensitivity sufficient to measure the natural background of gamma radiation, and instruments for measuring high dose rates, or instruments with a wide range of dosimetric values. The most convenient devices are for remote measurements, in which the radiation detector is located at the end of the telescopic rod. This allows you to reduce the operator's radiation dose by increasing the distance from the dosimetrist to the radiation source.

For radiation reconnaissance of large areas, aerial and / and automobile gamma surveys are used. The vehicle speed should not exceed 10 km / h. If an increased level of gamma radiation is detected, a ground pedestrian search is carried out using portable dosimetric devices (STORA-TU, TERRA and others).

If a lost source is found, it is necessary to take a cartogram of the dose rate of gamma radiation near it, determine the RA zone, and remove from it people who are not involved in emergency work. Then, the most radiation-safe approaches to the source are determined, the remote instrument and containers are prepared, and the operation is planned so that the exposure of the participants in the operation is minimal. The source is transferred to a protective container using remote instruments and, if possible, additional personal protective equipment is used.

After the source is placed in the container, a thorough dosimetric inspection of the location of the container with the source is performed, as well as a radiometric inspection of the location where the source was found to determine the presence of radioactive contamination or to confirm its absence. Persons who could receive additional radiation load are revealed, approximate doses of irradiation are defined by calculations. In the presence of radioactive contamination due to damage to the shell of a closed source, it is necessary to control the surface contamination of clothing and exposed areas of the body of persons who have been in contact with the source. Depressurized radionuclide source is not repaired, is always considered radioactive waste and is subject to disposal.

When transporting a container with a source, the requirements of the "Rules for Nuclear and Radiation Safety in the Transport of Radioactive Materials" 2006 should be observed.

If the transportation of a container with a source can lead to exposure of personnel and the public above the main dose limits established by RSSU-97 for the conditions of normal operation of radiation sources, the container should be left in storage in safe conditions, providing security and using warning signs, then develop and provide the most safe transportation option.

As a warning by the International Organization for Standardization, together with the IAEA, in 2007 a new radiation hazard sign was introduced, on which, in a triangle on a red background, beams emitted by a shamrock source, as well as a skull and a person running from them, are depicted in the form of wavy arrows. According to the IAEA, this sign will better communicate the danger of a radioactive source.

If the source is not found, then the decision to suspend or completely terminate the search is made by the commission in agreement with the regulatory authorities and the relevant bodies of the Ministry of Internal Affairs.

Persons who, during the liquidation of the accident, received radiation doses of 100 mSv and above, as well as those with clinical manifestations of radiation pathology, are sent for examination and treatment to specialized medical institutions - the Kiev Republican Dispensary for Radiation Protection, the Scientific Center for Radiation Medicine of the AMS of Ukraine and the Kharkov Research Institute of Medical Radiology. The act of investigating the causes of the RA is submitted to the higher authorities, as well as to the State Nuclear Regulatory Inspectorate of Ukraine. These regulatory bodies must draw appropriate conclusions to prevent similar RA.

3.5 Emergency planning

Emergency planning and preparedness refers to the activities that are necessary to ensure that, in the event of an accident, all the measures required to protect the public and plant personnel can be taken, and the orderly decisions on the use of the appropriate services are made.

In 1986, the Convention on Early Notification of a Nuclear Accident entered into force. In the event of a nuclear accident in one of the States Parties to this Convention, entailing a real or potential release of radioactive materials that may lead to transboundary effects significant for the radiation safety of other States, this State must notify, directly or through the IAEA, those States that may be affected by this accident. The ability to act in accordance with this Convention is an essential aspect of emergency preparedness.

To ensure that protective measures are implemented in the event of an accident that leads or potentially leads to a significant release of radioactive material on and off the site, emergency plans are developed, on the basis of which exercises are conducted periodically. Emergency planning zones are defined around the plant to allow for a differentiated response.

Emergency plans are being prepared for on-site and off-site action to protect the public from any major releases of radioactive material outside the plant. These plans are validated through exercises using their communication and logistics components and updated based on lessons learned. The regulatory body reviews such inspections and, if necessary, is present at them. The emergency plans define organizational measures and assign responsibility for actions in an emergency; they are flexible enough to adapt to specific conditions as they arise.

The emergency plans define the actions to be taken in the event of a severe accident to regain control of the plant, protect personnel and the public, and promptly communicate the necessary information to the regulatory body and other competent authorities. The emergency planning zones around the plant provide a geographic basis for decisions to implement protective measures as part of a differentiated response. Such measures, if necessary, include prompt notification, shelter and evacuation, radioprotective prophylaxis and provision of protective equipment, radiation control, entry and exit control, decontamination, medical assistance, food and water supply, agricultural control and information dissemination.

Facilities of the emergency reacting

Principle: A permanently equipped emergency technical center is provided for off-site emergency response. A similar center is provided at the site to manage an emergency at the plant and to liaise with the off-site emergency response structure.

The off-site emergency center is where all emergency actions are defined and initiated, other than on-site measures to regain control of the plant and protect personnel. It is equipped with reliable means of communication with a similar center at the station, with all important units of organizations and emergency response services such as the police, fire brigade, as well as with government and public news agencies. Since commercial telephony may be unreliable in an emergency, other forms of communications are also provided, such as leased lines or radio communications. The emergency technical centers receive information about the meteorological conditions at the site and the levels of possible radiation. Terrain maps are available showing emergency planning zones and their characteristics. Means of permanent registration of important incoming and outgoing information are provided.

The location of the on-site emergency center allows for the identification and initiation of all on-site measures that are not directly related to keeping the plant under control. It is equipped with instrumentation transmitting important plant conditions. This center is the place where data on station conditions will be collected for transmission to an off-site emergency technical center. Protective equipment is provided for emergency personnel [21].

Creation of an operational local warning system

An operational local warning system is being created at nuclear power plants with a range of 5 km in the proactive evacuation zone. In areas of possible radioactive contamination, a warning system is organized on a general basis. The population in these areas is alerted by radio and television. To attract the attention of the population, sirens of the civil defense system are switched on, duplicated by intermittent beeps of enterprises and transport. The voice information of the notification should contain a message about what happened (about the nature of the emergency, the actual situation, the forecast of its development) and recommendations for the actions of the population. A notification scheme is being developed at the NPP, which is one of the appendices of the "Action Plan for the Prevention and Elimination of Accidents". Notification of NPP personnel at the industrial site, in the sanitary protection zone, in the power engineering camp is carried out by the dispatching service of the station. Notification of the population in other areas of possible radioactive contamination is carried out by the authorities of various levels after information received from the NPP.

3.6 Engineering and technical measures to ensure the safe operation of nuclear power plants

The main requirement in the design, construction and operation of a nuclear power plant is to ensure the radiation safety of both the facility personnel and those living near the population. NPP design is carried out taking into account the assessment of emergency risks as a result of a possible accident. In this case, the individual risk of the population near the station should be 10 times less than the personnel of the facility. The design and placement of nuclear power plants is achieved taking into account the use of natural conditions that reduce the impact of damaging factors of conventional weapons, secondary damaging factors, as well as emergency situations of a natural and man-made nature. Further development of the nuclear power plant should be carried out through its reconstruction and technical re-equipment without increasing the volume of harmful emissions. The placement of new nuclear energy facilities should not worsen the ecological and radiation safety of the population and the environment.

The NPP site should be located on an unheated area at any level of flood waters, and the groundwater level should be at least 1.5 m below the bottom of underground radioactive waste tanks. The NPP site is designed from the leeward side in relation to the power engineering camp. The population of the power engineering camp should not exceed 50 thousand people, and its distance from the station should not be less than 8 km. Within a radius of 25 km from the NPP, the average density of the population living there should not exceed 100 people / km 2. The distance from the nuclear power plant to the objects that can become sources of explosions, as well as the storage facilities of emergency chemically hazardous substances, is provided for at least 5 km, and from the ammunition depots - 10 km. The distance from the NPP of airports is at least 12 km, of enterprises of the chemical and metallurgical industry - 25 km. The standard distances from the nuclear power plant to the nearest cities depend on the power of the plant reactors and the population. (Table 3.4)

Table 3.4 Standard distances from NPPs to settlements

Population	Distance from NPP at power units, km	
	Up to 4 Gw	More than 4 Gw
From 100 to 500,000 people	25	25
From 500 thousand to 1 million people	30	30
From 1 million to 1.5 million people	35	40
From 1.5 million to 2 million people	40	50
More than 2 million people	100	100

To ensure the radiation safety of the population, ventilation pipes are installed at the NPP through which radioactive substances are removed into the atmosphere. Height of pipes depends on the power of the reactor and should be at least 100 m. The polluted air removed through the pipe passes through the filters. Average daily allowable emissions of inert gases and aerosols into the atmosphere, as well as the annual permissible discharge of radionuclides from liquid effluent into water bodies is established by regulatory documents [22].

CHAPTER 4. RADIOACTIVE WASTE MANAGEMENT

4.1 Legislative and regulatory framework in the field of radioactive waste management

Radioactive waste (RW) management activities , including the disposal of radioactive waste in a facility intended for RW management without the intention to use them (RW disposal); placement of radwaste in facilities where isolation from the environment, physical protection and radiation monitoring is provided, with the possibility of subsequent removal, processing and transportation (storage of RW); RW immobilization (transfer of RW to different phase states); decontamination, collection, sorting of radwaste; systematization of information on the condition of radwaste disposal / storage facilities; radwaste preparation operations for transportation, storage and burial; processing and safety, is regulated by the laws of Ukraine "On the use of nuclear energy and radiation safety", "On radioactive waste management", "On permitting activities in the field of nuclear energy", "On waste", "Environmental protection" and others regulations of both sectoral and intersectoral level.

According to the current legislation, RW means material objects and substances, the activity of radionuclides or radioactive contamination of which exceeds the limits established by current regulations, provided that the use of these objects and substances is not provided, but under the object intended for treatment. from RW - a structure, premises or equipment intended for the collection, transportation, processing, storage or disposal of radioactive waste. Radiation safety in the management of RW - not exceeding the permissible limits of radiation exposure to personnel, the population and the environment, established by norms, rules, safety standards, as well as restrictions on the migration of RW into the environment [23-25]

4.2 Purpose, principles, criteria and basic requirements for ensuring the safety of radioactive waste disposal

The purpose of ensuring the safety of radioactive waste (RW) is their reliable isolation, which ensures the radiation safety of humans and the environment for the entire period of potential RW hazard.

The following principles must be observed during RW disposal:

Radiation exposure associated with radwaste disposal should be kept as low and achievable as possible, taking into account economic and social factors (optimization principle).

Long-term safety of radwaste disposal in the period after the closure of of Ground of burial place of radioactive wastes (RW disposal **(**RWD**))** should be ensured by the use of a system of barriers to the spread of ionizing radiation and radioactive substances into the environment. Violation of the integrity of one of the barriers or a probable external event of natural or man-made origin should not lead to a decrease in the level of long-term safety of radwaste disposal (multi-barrier principle).

The projected levels of exposure of future generations due to radwaste disposal should not exceed the permissible levels of exposure of the population established by current regulations. Any individual of future generations must be protected from the harmful effects of buried radwaste to the same extent as any individual of the current generation (the principle of protection of future generations).

RW disposal should be carried out in such a way as not to impose on subsequent generations an unreasonable burden associated with the need to ensure safety in the management of radwaste (the principle of not burdening future generations).

The rules for the disposal of radioactive waste meet the safety requirements during normal operation, violations of normal operation, including accidents, if the radiation exposure to workers (personnel, population and the environment does not lead to exceeding the dose limits for exposure of workers (personnel) established by regulatory documents and the population and standards for emissions and discharges of radioactive substances into the environment.

The rules for the disposal of radioactive waste meets safety requirements in the period after its closure, if:

- under the normal (evolutionary) course of natural processes at the site of the RW disposal (the most probable scenarios for the evolution of the RW disposal system), its radiation effect will not lead to an excess of the annual effective dose limit set for burial
- in case of unlikely (catastrophic) external influences of a natural and man-made character at the site of the RW disposal (probable scenarios for the spread of radionuclides from the RW disposal system), the individual total risk limit will not be exceeded, equal to 1.0 · 10-5 year for a critical group of the population 1.

The choice of radwaste disposal method (near-surface burial or burial in deep geological formations, storage structures and barrier properties should be determined and justified in the near-surface RWD design depending on radwaste characteristics (radionuclide composition, specific activity, period of potential danger, physicochemical properties) taking into account the natural conditions of RWD placement.

Permissible content of radionuclides in radwaste, which are buried in near-surface disposal, are listed in table 4.1. RW containing radionuclides in quantities exceeding the above limits should be disposed of in deep embankment.

Table 4.1. Permissible content of radionuclides in radwaste at near-surface disposal

Radionuclides	Activity, Bq / m3 (Bq / g)
Radionuclides with a half-life of less than 5 years	Not limited
H_3	Not limited
C-14	$3{,}0 \times 10^{11}$ Bq/m^3
C-14 in activated metal	$3{,}0 \times 10^{12}$ Bq/м^3
Ni-59 in activated metal	$8{,}1 \times 10^{12}$ Bq/m^3
Co-60	Not limited
Ni-63	$2{,}6 \times 10^{13}$ Bq/m^3
Ni-63 i in activated metal	$2{,}6 \times 10^{14}$ Bq/m^3
Sr-90	$2{,}6 \times 10^{14}$ Bq/m^3
Nb-94 in activated metal	$7{,}4 \times 10^{9}$ Bq/m^3
Cs-137	$1{,}7 \times 10^{14}$ Bq/m^3
Tc-99	$1{,}1 \times 10^{11}$ Bq/m^3
I-129	$3{,}0 \times 10^{9}$ Bq/m^3
Pu-241	$1{,}3 \times 10^{5}$ Bq/g
Cm-242	$7{,}4 \times 10^{5}$ Bq/g
Uranium and transuranic alpha-emitting radionuclides with a half-life of more than 5 years	$3{,}7 \times 10^{3}$ Bq/g

For wastes containing a mixture of radionuclides, the total concentration is defined as the "sum of the particles" by dividing the concentration of each nuclide by the corresponding allowable concentration. The sum of the shares should not exceed 1.0.

If the radwaste does not contain the radionuclides listed in the table, this waste belongs to the category for which there is no restriction on near-surface disposal.

Deep burial of liquid radioactive wastes LRW is carried out by injecting pre-prepared (LRW) through boreholes, geological horizons (reservoirs), which provide localization of LRW within the mining allotment.

The safety of RWD should be ensured through the consistent implementation of the concept of deep-layer protection, based on the use of a system of physical barriers to the spread of ionizing radiation and radioactive substances into the environment, as well as a system of technical and organizational measures to protect physical barriers. and maintaining their effectiveness, and to protect employees, the public and the environment. [26]

RWD **(**LRWD**)** must have a system of barriers (engineering and natural) that prevent the spread of ionizing radiation and radioactive substances into the environment. The number and purpose of RWD **(**LRWD**)** barriers are determined and substantiated in the project taking into account the results of studies of the properties of barrier materials and forecast calculation to assess the safety of the radwaste disposal system.

During normal operation, the barriers must be operational and measures to protect them must be in a state of readiness. If any of the barriers is found to be inoperable or measures to protect it are not ready, the RWD **(**LRWD**)** must be brought to a condition that satisfies the requirements of this document and other applicable regulations.

The safety of the radwaste disposal system (long-term safety) should be ensured on the basis of the implementation of the principle of multi-barrier, based on the application of barriers to the spread of ionizing radiation and radioactive substances into the environment, violation of the integrity of one of the barriers. of man-made origin did not lead to an unacceptable decrease in the level of safety of the radwaste disposal system.

The system of barriers RWD **(**LRWD**)** should:

- to ensure the safety of radwaste disposal during the period of their potential danger, taking into account the possible external influences of natural and man-made origin in the area of RWD **(**LRWD**)**, as well as taking into account physical and chemical processes occurring in RWD **(**LRWD**)**;
- retain insulating properties under the influence of rocks containing radwaste;
- to preserve insulating properties under the thermal influence of fuel-emitting radwaste;
- to prevent unintentional invasion of humans and animals.

Engineering barriers of RWD should prevent:

- contact of radwaste packages with natural waters;
- destruction of radwaste packages from the influence of tectonic processes;
- destruction of radwaste packages from exposure to host rocks;
- distribution of radionuclides in host rocks.

Engineering barriers of RWD **(**LRWD**)** must perform their functions after its closure during the period established and justified in the project without maintenance and repair.

For deep RWD, natural barriers (rocks) are the main barrier. The insulating (filtration and sorption) properties of natural barriers should limit the contact of groundwater with engineering barriers and the migration of radionuclides in violation of the integrity of engineering barriers. Rocks must be resistant to the thermal effects of fuel-emitting radwaste, retain their insulating properties and provide deep RWR thermal regime, does not violate the integrity of engineering barriers [27,28].

Natural barriers to LRWD should have low filtration properties and limit the spread of radionuclides above and below the horizons.

The capacitive properties of the absorbing formation-collector of LRWD must ensure the placement of LRW within the limited volumes of subsoil, for which it is possible to determine the boundaries of the mining allotment.

There should be no hydraulic communication channels of the absorbing horizon, reservoir-reservoir) with the given surface and above and below the aquifers within the mining diversion of LRWD and the area of the predicted distribution of radionuclides.

The velocities of natural groundwater movement in the absorbing horizon must be low enough to ensure the localization of LRW in a limited area of the geological environment. Most preferably, the use for the burial of LRW horizons with reservoir properties, occurring in the hydrodynamic zones of difficult water exchange, contain water that is not suitable for commercial use.

The system of technical and organizational measures to ensure the safety of radioactive waste disposal accumulated in surface reservoirs of LRW, the composition of the barrier system and the permissible content of radionuclides in radioactive waste, is established and justified by the design of barriers taking into account the properties of barriers safety assessment of radwaste disposal system.

The system of technical and organizational measures to ensure the safety of radwaste disposal should be presented in the draft RWD. The adequacy of the technical safety decisions adopted by the RWD project must be justified for the entire period of potential hazard of the buried RW, taking into account the possible external influences of natural and man-made origin in the RWD location area, as well as physical and chemical processes. which occur in the RWD.

The progect of RWD **(**LRWD**)** should indicate the methods and programs used to substantiate the safety of RWD **(**LRWD**)** and the forecast calculation when assessing the safety of the radwaste disposal system, and indicate the areas of their application. Used programs must be certified in the prescribed manner.

Safety requirements for the operation of RWD

Prior to commissioning, the RWD must be staffed with employees (personnel) who have the necessary qualifications and are allowed to work independently in the prescribed manner. Prior to the commissioning of the RWD, commissioning works must be carried out, which must confirm that the systems (elements) and equipment of the RWD are performed and function in accordance with the project, the identified shortcomings are eliminated.

Prior to the start of operation of the RWD, action plans must be developed and ready for implementation to protect employees (personnel) and the public in the event of an accident on the RWD. Prior to the start of operation of the RWD, the main and backup links with the organizations specially authorized in the field of protection of the population and territories from emergency situations should be involved.

During operation of RWD, the acceptance and input control of radwaste packages must be ensured. When accepting RW packages it is necessary to control:

- availability and completeness of documentation;
- integrity of radwaste packaging;
- labeling of radwaste packaging;
- radiation dose rate on the surface (at a distance of 10 cm from the surface) and at a distance of 1 m from the outer surface;
- the amount of non-fixed contamination of the outer surface of the package

When accepting radwaste packages, visual and radiation control of compliance of the actual characteristics of radwaste packages with their passport data, including compliance with:

- packaging labeling - passport data of radwaste packaging;
- passport data of radwaste packaging - real characteristics of radwaste packaging;
- real characteristics of radwaste packaging - the criteria of acceptability of radwaste for their disposal on RW established by the RWD project.

In case of non-compliance of the package with the established requirements and impossibility to bring its characteristics to the eligibility criteria, the RW package should not be returned to its sender.

There should be an organized system of accounting and storage of documentation on RW management on RWD, including accounting of the RW packaging nomenclature, their quantity, characteristics of RW packaging, address of their placement in RWD. Accounting is carried out on the basis of radwaste packaging passports, data of incoming control during acceptance and identification of specific locations of radwaste packaging in RWD. RW packaging passports and accounting documents with addresses for searching for RW packaging absorption in RWD should be kept in the organization's use until the RWD is transferred from the accounting documentation to the balance of regional or local executive authorities.

On the territory of the RWD site, radwaste transportation should be carried out:

- on specially prepared vehicles;
- according to the established project routes in accordance with the technological scheme of transportation on the site of the RWD;
- in special transport containers taking into account the dimensions and weight of transported radwaste, their physical condition, activity, type of radiation and dose rate on the outer surface of the containers

Control levels of emissions and discharges of radioactive substances into the environment should be established on the basis of design values of permissible gas-aerosol emissions and permissible discharges. The established emission and discharge levels are included in the list of operational limits of the RWD and should be periodically reviewed in the light of experience and technological improvements. The values of control levels of emissions and discharges must be lower than the permissible emissions and discharges of radioactive substances established by the project, taking into account the safety level of the RWD achieved during operation.

As the compartments (sections, chambers, cells, etc.) are filled with RWD packages, their preservation should be carried out.

CHAPTER 5. THE POSITIONS OF RADIATION MONITORING/ BASIC METHODS AND FACILITIES

5.1 The base positions of radiation ecological monitoring

The radiological monitoring is the subsystem of the general ecological monitoring. [29]

By the basic task of the radiation monitoring is realization of radiation control of objects of environment, i. e. by the dosimeter methods of ionizing radiation of collection of primary information about content of radioactive elements in air, water, foodstuffs, etc. with the further processing of the obtained data for an estimation and prognosis of radiation ecological situation.

The radiation monitoring envisages watching the background of gamut and permanent radiological control of dangerous radiation objects of industrial and economic activity.

The radiological monitoring on territory of Ukraine has the certain features caused by considerable contamination of environment as a result of catastrophe on Chernobyl' (ChNPP) nuclear power plant and plenty of nuclear power plants (NPP).

Tasks that belong before the radiation monitoring in Ukraine, first of all, conditioned by a radiation ecological situation that was folded in a country after the explosion of fourth power unit of Chernobyl' NPP in 1986. The radiological monitoring in Ukraine envisages the complex estimation of ecological situation in radioactively muddy territory, that arose up as a result of the Chernobyl' catastrophe, and her influence on an ecological situation in Ukraine on the whole.

Accordingly the main tasks of the radiation ecological monitoring are:

- it is an exposure of direction and character of change of the levels of contamination of environment, caused by functioning ecologically of dangerous radiation-nuclear objects, and also consequence of rehabilitation events that is conducted on muddy territories;
- on parameters, that characterize a radiation situation, study and control of the state of muddy zone of alienation, her especially dangerous parts and development of events in relation to the decline of their danger;
- it is a study of tendencies of change of indexes of the state of health of population, that lives on muddy by radioactive nuclei territories;
- it is a data ware of prognosis of radiation ecological situation in the zone of alienation and in Ukraine on the whole.

In the structure of the state radiation checking system it is possible to distinguish three basic directions of the radiation ecological monitoring: ***base*** (standard), ***crisis*** (operative) and ***scientific*** (base-line).

The ***base*** radiological monitoring is conducted systematic after the optimally chosen amount of radiation ecological parameters on the basis of the created network of points of supervisions, which embraces an entire country (including services of radiation control of radiation-nuclear enterprises).

The ***crisis*** monitoring envisages operative control after inhibition maximum of possible levels (concentrations, up casts) with the aim of the rapid reacting and localization of consequences of radiation accidents and catastrophes. The system of the crisis radiological monitoring is formed on the basis of activity of territorial services of supervision and control of parameters of environment on territories, where unfavorable radiological situations were.

The ***scientific*** monitoring is created with the aim of the detailed analysis of separate indexes of natural environment, for prognostication of long-term consequences of distorting the ecological balance, exposure of tendencies of anthropogenic influence on an environment and others like that. The scientific radiological monitoring will be realized by coordinating structures on the base of research establishments (subdivisions of Academy of Sciences of Ukraine), that develop methods and programs of radiological researches.

Scale even realizations of monitoring researches depend on the sizes of the investigated territories, character of objects of anthropogenic activity and decided tasks. Distinguish such even studies of the radiation ecological state of the natural and technogenic systems:

- ***national*** (scale 1 : 1 000 000 - 1 : 500 000), when a radiation situation is estimated on the whole after a country;

- ***regional*** (scale 1 : 200 000 - 1 : 100 000) that embraces large natural territorial units (regions) or their parts in certain natural or administrative limits;

- ***local*** (scale 1 : 50 000 - 1 : 25 000) is used during research of urbo-ecosystems and too muddy industrial districts;

- ***detailed*** (scale 1 : 10 000 - 1 : 2 000 and larger), sent to the study of elements of urbo-ecosystems and other naturally-technogenic systems of more subzero orders.

In Ukraine after a catastrophe on ChNPP carry out the radiation ecological monitoring of basic constituents of environment on different territorial levels after indexes, which are characteristic only for our state. In the zone of contamination (except the object of "Shelter" and 30-kilometre zone of alienation) the radiological monitoring comes true:

– landscape-geological environment with the aim of receipt of base information for an evaluation and prognostication of general radiological situation on muddy radio nuclei territories and her influence on an ecological situation in Ukraine;

– superficial and underground water systems;
– nature protection events and building;
– local of long duration sources of the real and potential contamination (object of "Shelter", pond-cooler, points of burial place of radioactive wastes, points of temporal localization of radioactive wastes);
– biocenosiss;
– medical and sanitary-hygienic.

Government hydro-meteorological service (MS) carries out watching the radio contaminate of atmosphere by daily intentions of doses of gamma-radiation display (GRD), settling of radioactive particles from an atmosphere and content radioactive to the aerosol in mid air. Intentions of radiocontammant of surface-water come true on 8 water objects. Near-by nuclear power plants Government hydro- meteorological service carries out intentions of radio contaminations of surface-water of caesium- 137 in and contamination of soils.
The laboratories of monitoring of Ministry of agro-politics conduct control in the places of concentration of radio nuclides in soils and food products.

ME carry out monitoring of doses of GRD on 10 automated points near-by nuclear power plants. Within the limits of 30-kilometre zone round Chernobyl' NPP (zones of alienation), MS carry out watching the concentration of radionuclides; radionuclides in atmospheric precipitations, and by the concentration of "hot" particles midair. International radio ecological laboratory of the Chernobyl' centre of atomic safety, radioactive wastes and radioecology in Slavutich, carries out monitoring of influence of radiation on біоту in the zone of alienation.

5.2 Complex radio-ecological monitoring. Constituents of the radio-ecological monitoring [30,31]

The complex radiological monitoring is based on the information got as a result of realization of base types of the radiation monitoring. The basic constituents of the radiological monitoring are:

- the radio-geochemical monitoring;
- monitoring of the superficial water systems;
- monitoring of radio-geohydrology;
- nuclear- radiation monitoring.

The radiogeochemical monitoring is the main source of receipt of the system organized information about spatial distribution of radionuclides of chemical elements, conformities to law of their localization and migration within the limits of ecosystems. For his realization necessary creation of permanent network of points of control that gives an opportunity with sufficient plenitude to overcome the spatially-territorial variety of radio-geochemical contamination and describe it with the possible fate of probability.

During realization of the radio-geochemical monitoring the radio-ecological state of the naturally-ethnogeny systems of different levels is estimated by means of survey of gamut by territories on national, regional, local and detailed levels.

For his realization form the regular network of view points, those give an opportunity with sufficient plenitude to overcome the elements of environment that is studied, and describe them with possible authenticity. On the basis of the got information fold the maps of closeness of superficial contamination of soils of cesium - 137, strontium - 90, get separate data about contamination of one-year and long-term vegetation.

In Ukraine for realization of the program of the radiogeochemical monitoring, taking into account character of migration of radioactive substance in a 60-kilometre zone, round ChNPP a radial-concentric network was created from 540 points of supervisions.

Monitoring of the superficial water systems. Principal reason of realization of this type of monitoring was a hit of plenty of radioactive precipitations in water intakes of rivers Pripyat, Desna, Dnepr, that are the basic waterways of storage pools of the Dnepr cascade. Establishments of AS, Ministries of health, hydrometservices in obedience to the program of the radiological monitoring of hydrosphere of pool of Dnepr carry out watching all cascade of the Dnepr storage pool, Black sea and all basic rivers of Ukraine, and also in the places of water intakes from underground sources.

Monitoring of Radiogeohydrology. To the Chornobyl' catastrophe round NPP there was not the special network of monitoring of radiogeohydrology. First for watching under waters were used rural mine wells and operating water intake mining holes.

In 1986-1987 in connection with organization of points of burial place and points of temporal localization of radioactive wastes, mainly within the limits of 5-kilometre zone there were the bored groups of mining holes for radiological control of the most harmful radiation-nuclear objects ("Shelter" - sarcophagus above the fourth block of ChNPP and "Vector" is a depository of radioactive wastes). In a 30-kilometre zone regime supervisions are conducted on the posts of geohydrology, drainage systems, on the certain areas of soil, mining holes.

The radiation-nuclear monitoring is intended for control after the operating state of potentially dangerous radiation objects to that take NPP, and also objects of "Shelter" and "Vector".

Building, that protect a natural environment from the sources of radio-activity, nuclear power stations accommodated in the reactor blocks of operating, is equipped by the corresponding systems of diagnostics that gives possibility of estimation of probability of exit of radionuclides from a reactor fuel in an environment.

The modern network of the radiation-nuclear monitoring embraces all most dangerous radiation objects of Ukraine.

Within the limits of the program of technical help of European Union "TACIS" in Ukraine from 1994 the system of the radiation monitoring is created GAMUT.

Realization of the first stage of this project envisages creation of posts of the radiation monitoring on territory of Ukraine round Rivne and Zaporizhzhya NPP. The basic tasks of the system GAMUT are exposures of the considerable exceeding of levels of radiation background on territories, that are controlled, notification of responsible persons about such exceeding and providing their information necessary for realization of protective events.

The system GAMUT on territory of Ukraine includes the national center (informatively-crisis center ICC) located in Ministry of guard of natural environment, and two local centers (in cities Rivne and Zaporizhzhya). Except that, 27 posts of control of power of dose of γ- radiation enter in the complement of the system, set in the zone of Rivne NPP; 11 posts of control of power of dose of γ- radiation, set in the zone of Zaporizhzhya NPP; one post of automatic control α- and β-activity aerosols, placed in the distance 5 kilometers from Rivne NPP; one automatic post of control of γ- activity of water is on Rivne NPP; two automatic posts of meteorological control - on Rivne and Zaporizhzhya NPP.

Information about the doses of irradiation comes from sensors to the local centers by radio channels, and farther passed the specially dedicaded telephone channels in a national center.

European Union within the limits of the program "TACIS" in parallel with the system GAMUT worked out and inculcated the system of support of making decision real-time at reacting on nuclear accidents - RODOS. The basic tasks of the system are providing facilities for treatment and management of information of meteorological and radiation character, evaluation and prognostication of radiation situation, and also designs of the use of counter-measures and variants of actions large volumes in an accident case.

Thus, the basic task of the radiation-nuclear monitoring is control after the state of nuclear – radiating objects and work of events in relation to the decline of degree of their harmfulness, evaluation and prognostication of radiation situation on the objects of natural environment.

The Normatively-legal providing on questions radiation safety

The radiation monitoring is part of the state system of monitoring of environment.

Creation of the state system of monitoring of environment (SSME) and realization of supervisions on the state a natural environment, it is envisaged the level of his contamination by Law of Ukraine "On the guard of natural environment" (incoterms20, 22). Basic principles of functioning of SSME are certain in resolution of Cabinet of Ministers of Ukraine from 30.03.1998 № 391 "About claim of Statute about the state system of monitoring of environment"

Implementation of functions of monitoring is fixed on Ministry of nature and other central executive bodies that are the subjects of the state system of monitoring of environment, and also enterprises over, establishments and organizations activity of that brings or can result in worsening of the state of environment.

The question of providing of radiation safety regulates incoterms23 of Constitution of Ukraine, in obedience to that:

"Enterprises, establishments of organization, that keep, transport, use radio nuclei and sources of ionizing radiations, carry out their burial place or utilization, obliged to restrain the norms of radiation safety, corresponding sanitary rules, and also norms, set by other acts of legislation, that contain the requirements of radiation safety. "

For today in Ukraine over 350 normatively-legal acts and over 200 resolutions of Cabinet of Ministers of Ukraine operate from radiation safety, Supreme Ukraine over 20 corresponding laws are ratified.

Among them is Law of Ukraine "On the legal mode of territory, that tested a contamination as a result of the Chornobyl' catastrophe" from February, 27, 1991 №791a-XII, that determines organs that carry out radiation control on territory of zones of radio contamination in particular.

Basic documents that regulate sanitary norms and rules and hygienic norms in industry of radiation hygiene are:

- "Norms of radiation safety of Ukraine " (NRSU - 97), are ratified by resolution of the Main state health-officer of Ukraine from 01.12.1997 N 62.

Norms of radiation safety of Ukraine (RSSU - 97) include the system of principles, criteria, norms and rules implementation of that is an obligatory norm to politics of the state in relation to providing of against radiation defense of man and radiation safety. RSSU-97 worked out in accordance with the substantive provisions of Constitution and Laws of Ukraine "About providing of sanitary and epidemic prosperity of population", "About the use of nuclear energy and radiation safety", "About handling radioactive wastes".

- "Norms of radiation safety of Ukraine, addition: radiation protecting from the sources of potential irradiation" (NRSU - 97 A-2000), ratified by resolution of the Main state health-officer of Ukraine from 12.07.2000 № 116.

Complement NRSU - 97 in part of the radiation protecting from the sources of potential irradiation, including in medicine.

- "The Basic sanitary rules of providing of radiation safety of Ukraine" (BSRU- 2005) are ratified in 02.02.2005 by the order of MQH№54.

ust not get the dose of irradiation more than 5mSv·year^{1}. [13,32,33]

5.3 Methods and devices .of the radioecological monitoring

The radiation monitoring system consists of the next successive stages:

- measuring of level of radiation on locality (field radiometry, dosimetria);
- sampling and preparation of them to research;
- a determination of radio-activity by express methods;
- a determination of radio-chemistry distribution radionuclides;
- radiometry of distinguished radionuclides;
- a calculation of activity.

Methods of radiation control, which provide authenticity and exactness of the information got in the process of radiological control, divide into an radio-metrical analysis, radio-chemistry, spectrometry. More applicable are the first two groups of control methods [34].

The field radiometry and dosimetria, express determination of radioactivity, radiometry of ash, radio-chemistry preparations belong to the ***radio-metrical methods*** of radiation control.

The field radiometry and dosimetria are the first stage of radiation control and monitoring of environment and objects of national economy. what envisages the receipt of data about a radioactive background and level of radio-activity of environment. In ordinary terms, they provide information about the level of natural radioactive background and allow in time to educe the cases of his increase and make decision on defense of population. It also is the basic method of controlling of radio-contamination of products of agriculture.

Principle of action of the most field dosimetric devices is based on ability of radioactive radiations to ionize an environment in that they spread. Devices that work on this basis are an identical construction and consist of transceiver (of sensor or detector of radiation), strengthening and measuring devices and source of feed. As an accepting device in the field devices ionization chambers and gas-unloading meters are used.

Devices that are used for realization of the radiation monitoring it are possible to divide into next groups: stationary, portable, individual and laboratory. Stationary, portable and portable devices, in turn, are divided into devices for realization of the radiation monitoring and monitoring of radio-contamination. By means of devices of the radiation monitoring it is possible to measure power of dose or dose.

Radio-chemistry and spectroscopy methods.

A кadio-chemistry method is based on measuring of exit of radiation-chemical reactions that take place in the liquid or hard chemical systems under the action of IR.

Operating of ionizing radiation on compounds results in the change of their composition. The amount of molecules that tested transformations depends on the dose of irradiation. This principle there is base on an action of chemical dosimeters.In quality of indicator substances that change the color or his intensity as a result of oxidizing or restoration reactions are used in chemical dosimeters. The size of absorbed energy (dose of radiation) in this case is estimated after degree of color. This method is used for registration of considerable levels by radiations.

Radio-chemistry methods are used, adhering to the certain sequence:

- selection and preparation of tests of the investigated objects;
- bringing of transmitters and mineralization of tests;
- a selection of radio nuclides is from tests;
- cleaning of distinguished radio nuclides is from extraneous nuclides and concomitant micronutrients;
- authentication and verification of radio-chemistry cleanness;
- radiometry of distinguished radio nuclides;
- calculation of activity and conclusions.

The standards of tests are selected by radiological departments must be typical for the investigated object, and mass - sufficient for realization of radio-chemistry analysis (after taking an ash - 20-40gr). The tests of soil, water, plants it is important to take away in places that are characteristic for this territory, and the radio contamination of that has most probability, but not in the most accessible places, id est., for example, on a top to the hill, plain, where a rain fell out, but not along a road or in a ditch under trees et cet. Tests place in capacities that allow, if necessary; to keep them in different condition, and mark with pointing of nature of standard, place, date and time of selection of test and sampling group.

At sampling in mark points measure γ - background by device of СРП-68-01 in the distance a 0,7-1 m from soil and 1-1,5cm from an object.

For determination of features of radiation-chemical, reactions of substance mostly use ***spectroscopy***, and also methods of registration of fluorescence and hemi-luminescence. These methods allow educing primary chemical forms that arise up because of absorption of energy of ionizing radiation, and also register the intermediate products of radiation-chemical transformations of substances.

For the study of fleeting processes of radioliz apply the different methods of spectroscopy, in particular absorbing spectroscopy, raman's resonant spectroscopy, spectroscopy of electronic paramagnetic resonance. At the use of these methods a research object is exposed to rays by the certain rationed portions of radiation, watching appearance of new chemical forms.

The **scintillation** method of measuring consists in registration of flashes of light, that arise up in sctintillator (sulfite of zinc, iodide of natrium) under an action IR, that by means of photoelectronic multiplier grow into an electric current. Anodic current of multiplier and speed of account are proportional to power of dose of radiation.

A **photographic** method is based on ability of molecules of bromide of silver, which is contained in photo emulsion, to disintegrate on constituents under the action of IB. Little crystals of silver, which appear here, cause of her blacking that is proportional to absorbed energy.

A **calorimetry** method is based on measuring of amount of warmth that is distinguished in a detector at absorption of energy of IR. All energy of radiation, which is taken in by a substance, as a result grows into warmth after a condition, that a substance is chemically inert to the radiation. Thus, the amount of the warmth is proportional to intensity of radiation.

A neutron-activating method is related to measuring of the activity resulted by neutrons, and sometimes is the only possible method of measuring of weak neutron-fluxes, when the ordinary methods of measuring do not give reliable results. Except that, this method is suitable at evaluation dose emergencies, when a brief irradiation is by the large streams of neutrons.

In biological methods to dosimetria used ability of radiation to change biological objects. The size of dose estimated after the level of lethality animals, amounts of chromosomal aberrations, to the fall hair and т. the Biological methods are other less exact and sensible comparatively with physical.

In calculation methods the dose of radiation is determined by mathematical calculations. It is an only possible method of determination of dose from incorporated radio nuclides.

The fundamental chart of any dosimetric and aerophare device is identical. She includes three obligatory blocks: detector device (detector), indicator and power (accumulators, batteries, elements, electric system and others like that) module.

Dosimeters intended for measuring of power of dose β- and γ- radiations usually calibrated on a source γ-radiation and some of them give a higher value to power of dose β-radiation. Devices for measuring of power of dose β- and γ-radiations have a window for the hit β-rays on a detector. Devices that have an open window measure γ- and β- radiation, with the closed window – only γ-radiation.

Dosimeters for measuring of power of dose β- and γ- radiation can be divided into devices that register doses in a subzero or base-line range, middle and high ranges.

Subzero (base-line) range: 0.05μSv/hour - 100μSv/hour
Midrange: 10μSv/hour - 10mSv/hour
High range: 1mSv /hours - 10Sv/hour

For the exposure of radionuclides, measuring of levels of radiation on locality and radio contamination of objects of external irradiation use devices as ДП- 5, СРП-88-Н and т. the Total display and taken in doses of irradiation are measured other by the dosimeters of ДП-22В, ДП- 24, ДП-23А, ІД- 1, ІД- 11, etc.

The express methods of radiation control use for the receipt of operative information on the degree of radio-contamination of objects of environment.

Express-method of determination of specific and volume activity of gamma-emitting radionuclides in water, foodstuffs, products of plant-grower and stock-raising is base on measuring with the help of device of СРП- of a 68-01 power of dose of radiation from cleanly washed-up and ground up tests by mass 0,7kg, that is accommodated in a with a capacity of one the liter jar or vessel of Marinelly, and count of her in unit of activity (Bc/kg). Methodology can be applied at the level of radio-contamination $2·10^3$ - $4·10^4$ Bc/l (kg).

An express-method of determination of specific and volume activity β - radiating radio nuclides is based on measuring of speed of read-out of particles from " thick-layers " preparations and next mathematical calculation of activity.

For realization of measuring use the radiometers of КРК-1, РУБ-01П, "Beta". Methodology can be applied at content of radio nuclides in tests not less than 37 Bc/kg. In the case of the small concentration of radio nuclides in tests total beta-activity of test determine on ash residue. To increase the concentration of radionuclides in tests, they are burned and take an ash. An ash is ground in fine powder. The measuring is carried out by a stationary radiometer.

For the express measuring of specific activity of cesium- 137 use the dual-link radiometers of РУБ- 01 П6, РКГ- 05, РУГ- 91, spectrometer "Progress-spectrum", that give an opportunity to calculate payment of potassium in total activity of test, id est in the radio-contamination of environment on the whole.

Application of various methods of radiation control gives an opportunity to carry out measuring of radio-activity of different constituents of environment, products and others like that. The choice of methods depends on the aim of radiation control.

5. 4 Personnel Monitoring

Personal monitoring is needed, when probably, that dose that is got by an individual will exceed a norm, set by NRSU.

According to Norms of radiation safety of Ukraine (NRSU - 97) and Basic sanitary rules of providing of radiation safety of Ukraine (BSRU - 2005) individual dosimetric control (IDC) is obligatory in next cases (self-controls over are brought from BSRU - 2005) :

- IDC in certain for every case volumes is obligatory for persons from a number a personnel (category of A), in that a total annual effective dose can arrive at $10mSv \cdot year^{-1}$ (in normal or emergency terms). IDC on NPP is obligatory for all persons that visit the zone of the strict mode (p.14.4.10);

- IDC of external local and general irradiation with the use of individual dosimeters must be conducted for the women of genital age (45 to), that belong to the category A, regardless of the expected dose of irradiation (p.14.4.12);

- in the obligatory order of IDC must be conducted for all categories of medical personnel activity of that is constrained with the use of the closed and open SIR (p. 14.4.14). Actually, according to BSRU - 2005, IDC is obligatory for all medical personnel of category of A.

In another cases IDC is not obligatory and assumed to carry out dosimetric control of personnel through the regular monitoring of radiation-hygienical parameters on workplaces, in apartments, on industrial ground and others like that.

Devices of IДК, that is appointed or for the use at extreme situations in a peace-time, or for the special period of war-time usually kept and given out to the population at the place of work or residence of civil defensive services.

Devices of IDC are miniature devices by means of that determine the personal dose got a man in some certain situation or for some certain interval of time.

All devices of IDC structurally can be divided into those in that a testimony can be taken off from the scale of device directly (direct indexes), and without the scale of indication ("blind"), testimony from that take off on the special devices, more often in stationary terms. It is related to the method of registration, setting and construction of devices.

Three major types of monitoring devices in use today are: pocket dosimeters that work on the base of ionization method of registration of radiation, the film badge, and the thermoluminescent dosimeter (TLD).

The Pocket dosimeters are small devices (about the size of a marking pen) one can carry in a shirt or lab coat pocket. An integrating ionization chamber and condenser in the corps of dosimeter are mounted, the feed of that comes before work from a charge device. When radiation passes through the sensitive volume of the dosimeter, there is an ionization current that diminishes the initial charge of condenser and chamber, and accordingly of potential of internal electrode of dosimeter. Reduction to potential, proportional to the dose irradiation is measured by means of electroscope with that a movable platinum filament is connected. Deviation of filament from a zero mark is the more than greater dose of irradiation. In the dosimeters of the direct measuring, a dose measured by means of counting out to the microscope the scale of that calibrated in roentgens. "Indirect" dosimeters need additional arrangement for the "read-out" of measuring results. A dosimeter is carried in the pocket of clothing and periodically looks after on the size of the dose of irradiation, got during work.

A typical device that works on the basis of photographic method of registration of ionizing radiation consists of cassette, the corps of that does not skip light, and filters that eliminate some types of radiations placed on the inside of corps. Into a cassette mortgage a film that is the detector of dosimeter. Usually use two tapes, one of that is sensible to x-rayed or gamut-radiation in a power range from 16keV to 3MeV, second - to beta-rays with energy from 200кеВ to 1Мев. Radioisotopes that radiate beta-rays of more subzero energies (for example, 3h, 14c, 35s) can not be educed by means of photo-detector.

The presence of filters gives an opportunity after operating on tape to distinguish a radiation after kinds (beta, x-rayed, gamut, neutrons) and energies. An "open" window (i.e., no filter) allows all radiations of sufficient energy to pass and expose the film. A plastic filter absorbs most low energy beta radiation. Other filters such as copper or lead absorb most high-energy beta radiation and all but high-energy gamma radiation. Fast neutrons interact with a cadmium filter to produce film blackening. Slow neutrons interact with the nitrogen atoms in the film's gelatin layer with formation of protons tracks of that are counted

The numeral value of equivalent dose is determined after the degree of growing closeness of black of film, which by photocell is determined and given out on a pointer device that gives result in rem.

Thermoluminescent dosimeters (TLDs) are modern devices that lately go to replacement a photo to the pellicle and ionization dosimeters. They present by a soba little чипи, made from fluorine lithium or fluorine calcium, etc., that accumulate energy under the action of radiation due to the transition of atoms to the crystal in the excited state and keep her to the moment of measuring (thermal liberation of energy). At heating of chip the accumulated energy frees oneself as light the light stream of that is proportional to the amount of radiation received. The light stream distinguished by a detector at heat treatment transforms a photoelectronic multiplier in an electric current, and farther by means of digital transformer in frequency of impulses.

Thermoluminescent dosimeters allow conducting control in the wide range of doses - from 5μrem to (5-10) $\cdot 10^3$rem.

5.5 Radiation-hygienical monitoring

The Radiation-hygienical monitoring is one of constituents of the state socialhygienical monitoring, that presents by system of supervision, analysis, estimation and prognosis of the state of health of population and environment of vital functions of man, and also exposure of causal connections between the state of health of population and influence on him of factors of environment of vital functions of man. After reorganization of sanitary-epidemic service creation and providing of functioning of the effective national system of monitoring and estimation in the field of a public health came to public institution "Center of public health of Ministry of health Ukraine"

Thus, the radiation-hygienical monitoring (RHM) is the state checking system after the radiation constituent of environment of vital functions of man.

On the initial stage to the basic tasks of RHM there was monitoring of the radio-activity of environment, related to the consequences of nuclear test. Later it was joined by monitoring radiation dangerous industrial objects (NPP, radio-chemistry enterprises, uranium mineries and other), and also productive environment on enterprises, where the sources of ionizing випромі' were used нювання (industry and medicine).

Determination of doses of irradiation of different contingents of population, that suffered as a result of irradiation (participants of liquidation of consequences of accident, evacuated population, habitants of radioactively muddy territories), became after the Chornobyl' catastrophe to the serious tasks of RHM.

Modern the stage of development of RHM, related to the necessity of estimation of natural component of irradiation of population, as it is the main in the general dose of irradiation of man. According to the "Complex program of realization of state sanitary supervision in industry of radiation safety of Ukraine" in the volume of RHM enter:

- control of background of gamut of territory and in apartments;
- doses of irradiation of personnel and patients of the x-rayed and radiological separations of curative establishments,
- control of levels of radio-activity of food products and drinking-water with the further calculation of doses of irradiation of population.

In recent year building and raw materials, ^{222}Rn in apartments, and also natural radio-activity of productive environment were added to the control.

Against radiation protecting of population from technogenic-increase sources of natural origin in the way of life and on a production provided by introduction of norms of two levels of control :

- *a level of obligatory actions* - at preventive radiation control;
- *a level of actions* - at current radiation control.

For both levels next radiation indexes that can be measured are set:

- effective specific activity of natural радіонуклідів in building materials and mineral building raw material;
- power of absorbed dose of gamma-radiation in mid air of apartments (taking into account a natural radiation background);
- average annual equivalent equilibrium by volume activity (EEVA) of isotopes of radon in mid air apartments;
- specific radio-activity of natural radionuclides in a drinking-water;
- effective specific activity of natural radionuclides in wares from porcelain, glazed pottery, glass and clay;
- effective specific activity of natural radionuclides in mineral fertilizers, dyes and glaze;
- effective specific activity of natural радіонуклідів in cardboard - paper products.

The quantitative norms of levels of action for technogenic-increase sources of natural origin are driven to the table 5.1.

At exceeding of norms that appear on the stage of preventive radiation control, always expedient is the interference sent to their decline.

According to the requirements of BSRU, the dose of irradiation of personnel, that works with materials that have enhanceable maintenance of natural radionuclides, must not exceed 5 мЗв on a year.

Table 5.1 The Quantitative norms of levels of action for sources of natural origin

List of indexes and rationed parameters		Level of realization of events	
		Level of obligatory actions (preventive control)	Level of actions (current control)
effective specific activity of natural radionuclides is in building materials and raw material ($Bc \cdot kg^{-1}$)	1 клас	< 370	-
	2 клас	370-740	-
	3 клас	740-1350	-
	4 клас	> 1350	-
power of absorbed dose of gamma-radiation in mid air of apartments ($\mu R \cdot hour^{-1}$)		30	50
average annual EEVA of isotopes of radon in mid air apartments ($Bc \cdot m^{-3}$)		^{222}Rn – 50 ^{220}Rn – 3	^{222}Rn – 100 ^{220}Rn – 6
effective specific activity of natural radionuclides in mineral fertilizers ($Bc \cdot kg^{-1}$)		1850	-

effective specific activity of natural radionuclides in wares from porcelain, glazed pottery, glass and clay (Bc·kg^{-1})	-	370
- effective specific activity of natural radionuclides in mineral dyes and glaze (Bc·kg^{-1})	-	1400
activity of natural radionuclides in a drinking-water (Bc·kg^{-1})	-	^{226}Ra - 1,0 ^{228}Ra - 1,0 ^{222}Rn - 100,0 U (природна суміш) - 1,0
effective specific activity of natural радіонуклідів in cardboard - paper products (Bc·kg^{-1})	-	сировина- 555; готова продукція - 370

On the stage of current radiation control of exceeding of norms sometimes requires the interference sent to other technogenic-increase natural source taking into account the total dose of irradiation from all technogenic-increase sources of natural origin.

In RSSU–97 the possible even receivabless of радіонуклідів are rationed through the organs of breathing and possible concentrations in mid air of working apartments for the persons of category A and B, and also possible even receivabless of radionuclides through the organs of digestion, concentration in mid air and to water for the persons of category of C. Calculations of receipt of радіонуклідів in an organism come true after the formulas driven in NRSU–97.

Numeral values over of possible levels of β- muddiness of skin, facilities of defence and working surfaces are here brought.

After an accident on Chornobyl' NPP there was a necessity of setting of norms of content of radionuclides for food products and water. In this connection by Ministry of health of Ukraine asserted norms the orders on these indexes. Last "Possible levels of content of радіонуклідів ^{137}Cs and ^{90}Sr in foodstuffs and drinking-water" Ministry of health of Ukraine ratified by an order from 03.05.2006. № 256. The value of possible levels is set for more than fifty groups of products and water.

The numeral sizes of possible levels are set coming from not exceeding of effective annual dose of internal irradiation of 1mZy at the consumption of average annual ration of feed of the grown man (table. 5.2).

Table 5.2 Value of possible levels of content of radionuclides ^{137}Cs and ^{90}Sr in basic foodstuffs and drinking-water (Bc·kg^{-1}, Bc· l^{-1})

№	Name of product	^{137}Cs	^{90}Sr
1.	Bread	20	5

2.	Potato	60	20
3.	Vegetables	40	20
4.	Fruit	70	10
5.	Meat	200	20
6.	Fish - fresh and frozen	150	35
7.	Milk	100	20
8.	Egg of bird	100	30
9.	Drinkable water	2	2
10.	Alcoholic beverages	50	30
11.	Soft drinks	20	20
12.	Medical plants	200	100
13.	Mushrooms (fresh)	500	50
14.	Child's food	40	5

For determination of accordance of food products to the criteria of radiation safety the index of accordance (B), the value of that settles accounts on results measuring of specific activity ^{137}Cs and ^{90}Sr:

$$B = \frac{A_{Cs}}{ДР_{Cs}} + \frac{A_{Sr}}{ДР_{Sr}},$$

where A_{Cs}, A_{Sr} are results of measuring of specific activity ^{137}Cs and ^{90}Sr in a food product; $ДР_{Cs}$ and $ДР_{Sr}$ are norms of content ^{137}Cs and ^{90}Sr in a food product.

$B + 0{,}6\Delta B \leq 1{,}0$, where ΔB is an absolute error of determination of index of accordance.

After the Chornobyl' catastrophe also there were the entered norms of content ^{137}Cs in the products of forestry. The last norms were Ministry of health of Ukraine ratified by an order from 31.10.2005. № 573 "About claim of state hygienical norm the "Hygienical norm of specific activity of радіонуклідів ^{137}Cs and ^{90}Sr in wood and products from wood".

At exceeding of the set norms wares and raw material are subject to the exception with a further burial place.

Radiation-hygienical monitoring of milk, potato and different other products of own economies and forestry comes true by regional radiological subdivisions.

The list of the food products selected for research must answer the ration of feed of population of this region, that gives an opportunity to the calculation of doses that is got by a population due to foodstuffs. Information about the amount of products, that consumes a population, is in the regional managements of statistics, for the children is possible to get it by the study of rations of feed in boarding-schools and child's preschool establishments.

The second direction of radiation-hygienical control of doses of internal irradiation of population is their determination from data of the direct measuring ^{137}Cs in the organism of man. Control will be realized by forces of laboratory of meters of radiation of man of Public institution the "National scientific center of radiation medicine of the National academy of medical sciences of Ukraine". Mass surveys of population of territories that suffered from an accident on Chornobyl' NPP, with the use of spectrometers the radiations of man showed the presence of settlements with the anomalously high levels of irradiation (higher than 1mZv/year) in parts of habitants, that does not answer a local радіоекологічній situation. Researches showed that the regionally-specific factors of forming of anomalous doses of internal irradiation of population of radiation muddy territories are applications of more accessible groups of products from the different sources of receipt.

5.6 Optimization of the monitoring system

Organization and optimization of the system of the ecological monitoring are straight related to conception that is fixed in his basis. At the beginning of the seventies two alternative conceptions of the ecological monitoring were worked out in the USSR. In first from them (author U.A.Izrael) the naturally-scientific approach was used, the aim of which was fixing of anthropogenic changes of natural environment. The basic blocks of this system are a supervision, estimation and prognosis of the state of natural environment. According to this conception the "Ecological monitoring … plugs a supervision, estimation and prognosis of anthropogenic changes of the state of no biotic component of biosphere (in particular changes of levels of contamination of natural environments), retroaction of ecosystems on these changes and anthropogenic changes in the ecosystems, related to influence of contaminations, agricultural use of earth, disafforestation, urbanization and so on”. Such positions, as a quality management of environment and activity of man did not enter conception. Efficiency of such, monitoring, not aimed at a management, is not high.

The author of the second conception (I.P. Gerasymov) under monitoring understood the "system of supervision, control and management of environment the state, that comes true in different scales and in particular in global" [5]. Besides, in opinion of author, this system must, first of all, be realized "… in relation to the phenomena most educed, with the help of the worked out methodology and concerning in relation to processes that easily yield to the management". Them the three steps hierarchy of monitoring was offered to: the first degree is the bioenvironmental (sanitary- hygienic) monitoring; the second degree is the geoecological monitoring (naturally economic) that includes supervision on the state natural ecosystems and converting of them into naturally technical; the third degree is the biosphere monitoring (global). Conception of management of monitoring aimed at an exposure and control of ecological dangers, creation of ecological corresponding economy, active international cooperation.

From the marked conception basic principles of the regional ecological monitoring swim out :

1. Principle of problem organization, that is opposite to the idea of the total monitoring and takes off the problem of lack of information at surplus of data. The program of research and supervision is opened out only under a certain ecological problem and coagulates at the decision of this problem. Intensity of supervisions goes down, and on certain indexes they cease. The regional monitoring consists of package of such problem organized softwares.

2. The system of the regional ecological monitoring is open for development: problem principle of organization abandons possibility for rising of new problems and development of new programs.

3. Management (organizational hierarchy) priority. According to this principle in system "management – monitoring - examination" a leading role belongs to the management. Exactly in this block set aims and problems under that monitoring will be built, and monitoring and examination are the important blocks of providing. As a west against the possible professional narrowity of decision of problem ecological examination is needed and used.

4. Principle of integrity consists in the three blocks – «management - monitoring – examination» unbreak.

5. Informative openness. All results of ecological researches and supervisions must be accessible for leaders, businesspersons, politicians and wide public. The closed or inaccessibility of ecological information is the source of social tension, and that is why realization of principle of informative openness is the necessary condition of monitoring efficiency.

6. The operation ability of the ecological monitoring consist not so much in the operation ability of processing and edition of information, but in the operation ability of making decision in critical situations, why quality and depth of the information given to the leader can promote.

Realization of the marked principles and is basis of optimization of the monitoring system.

CHAPTER 6. DECONTAMINATION. CLASSIFICATION OF DECONTAMINATION METHODS

6.1. Methods of decontamination

Decontamination - methods and means of removing radioactive substances from the human or animal body, from clothing or household items, household appliances, equipment, various structures or areas (land, vegetation, water), milk or other products and raw materials, vehicles or packaging, which fall on them as a result of technological processes related to the production and use of natural and artificial radioactive substances, as a result of negligence, accidents or the use of nuclear weapons.

The effectiveness of decontamination depends on the density of contamination of the object or its part, the nature of the material (metal, wood, glass, fabric, etc.), surface condition (smooth, rough, porous, sticky), the size of the radioactive dust particles, the solubility of radionuclides, time elapsed since the moment of contamination, means of decontamination.

The effectiveness of decontamination also depends on the time of its onset after contamination, as the long delay of radioactive contamination at any facility leads to greater fixation and makes it difficult to clean.

Modern methods of decontamination of radioactive contamination can be classified on several grounds. On the one hand, they are determined by the conditions of decontamination, as well as the characteristics of radioactive contamination. The choice of one or another method is determined by the specifics of radioactive contamination of a particular object.

Radioactive substances cannot be destroyed, accelerated or neutralized by a chemical. They can only be removed using physical (mechanical), chemical, or physicochemical methods [35].

The physical method consists of mechanically separating radioactive dust with a brush, broom, vacuuming or shaking and beating, wiping with rags, rags, rinsing with water, removing and separating the contaminated surface layer (soil, grain, hay, etc.), filtering.

In **the chemical method**, radioactive isotopes are either dissolved or combined into a complex compound and then isolated. To do this, use various solvents (hydrochloric or nitric acid, dichloroethane, gasoline, kerosene) or complexing agents (citric or javelin acid, sodium hexametaphosphate, etc.)

The physicochemical method of decontamination is more often used - the washing of radioactive substances with decontamination solutions. Solvents, complexing, and surfactants are used.

Another method of classification of all the main methods of decontamination is based on the physical state of the decontaminating substance and the peculiarities of the actual decontamination. From that point of view, all decontamination methods can be divided into dry, liquid, and combined. This method of classification of decontamination methods is presented in Fig.6.1.

According to the above classifications, the mechanical release of radionuclides from the surface by airflow should be attributed to dry methods, and decontamination by water pressure or decontamination with special solutions - to liquid.

The desire to increase the level and efficiency of decontamination has led to combined methods of decontamination, ie a combination of different methods. This method involves processing the same objects in several ways, such as in Chernobyl.

In Chernobyl, the first decontamination of facilities and premises was carried out with the help of vacuum cleaners, and then by other methods of decontamination. The same sequence was used during the decontamination of polymer floors of different rooms with local radioactive contamination, the decontamination of which was carried out using a powder preparation.

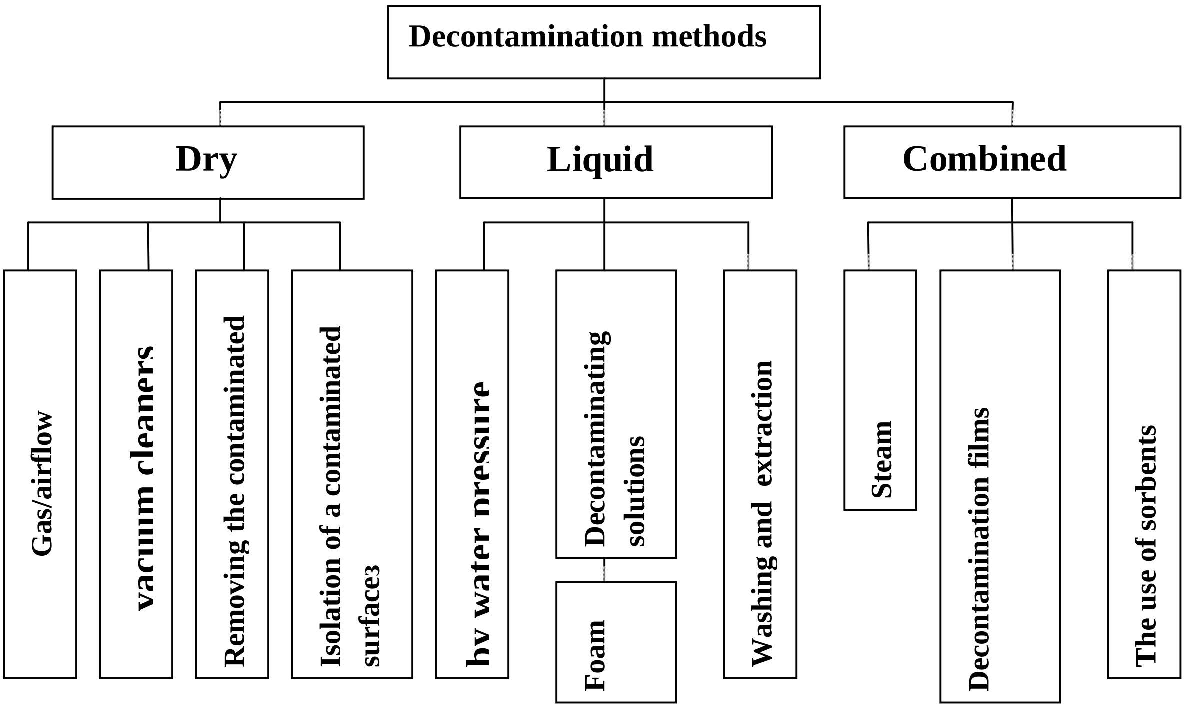

Fig. 6.1 Classification of decontamination methods

Repeated decontamination may also be necessary during mass radioactive contamination. For example, this was the case in Chernobyl, when they were forced to carry out multiple decontaminations due to high secondary contamination of all facilities and low efficiency of single decontamination.

However, not all methods are equally popular and effective, so the methods of decontamination can be divided into two groups - basic and auxiliary. The scheme of Fig.6.1 presents the main methods of decontamination, which will be discussed in more detail [4].

There are other methods of decontamination: when decontaminating surfaces, electrochemical decontamination can be used (radionuclide-contaminated part is placed in an electrolyte solution, a negative or positive potential is applied to the treated surface), laser decontamination (the mechanism is similar to laser cleaning of surfaces) rust, etc., used, for example, in the restoration of metal products), decontamination using ultrasound [36].

Methods that do not use technical means can be classified as ancillary.

Method of decontamination by gas jet and dust extraction

In the first stage of the decontamination process, a stream of gas (air) removes radioactive contamination from the surface in the form of liquid, small particles, and structured masses; radioactive contamination is transferred to a suspended or aerosol state. To increase efficiency, an air jet with a powder introduced into it is used, which has an abrasive effect and is able to remove the top layer, the contamination of which is caused by the penetration of radioactive substances into the material. The very good quality of decontamination is determined by the fact that the coefficient increases and can reach a mark of 200.

The second stage involves the removal of radioactive contamination from the object being treated, and when these contaminants in a suspended state become able to move by inertia.

This method should be used for the decontamination of painted metal products and porous materials such as concrete and brick if the contamination is deep. The disadvantages of this method are the consumption of abrasive powder, the occurrence of a mixture of radioactive contamination with spent abrasive powder, mechanical damage to the treated surfaces, and the impact of aerosols on humans. With these conditions, it is more reasonable to prefer devices that operate in a closed-loop mode.

When decontamination by suction, the filtration of the contaminated stream captures distant particles and carries out cleaning on a closed cycle, this is the advantage of the method of suction from decontamination by a jet of gas or air. Of course, the operation of vacuum cleaners contaminates their filters and the surface of the airway, which can be dangerous to humans. Also, this method is very time consuming and requires staff to strictly follow all safety rules.

Decontamination by removing the contaminated layer and isolating the contaminated surface.

In areas where there is no hard surface, decontamination can be carried out by cutting and removing the top layer of soil or snow, backfilling with clean soil, sowing with plants that accumulate radionuclides, flooring, etc.

When removing the contaminated layer, two stages of the decontamination process are combined: removal of the soil-contaminated layer of soil with its subsequent isolation (burial).

For decontamination to be effective, the top contaminated layer should be removed twice as deep as the depth of penetration of the radioactive radiation.
This method also has its drawbacks, such as the need for transportation and burial, which poses a high risk of secondary radioactive contamination and requires decontamination.

Also, this process is quite time-consuming. Isolation of the contaminated surface is aimed mainly at protection against gamma radiation.

Decontamination with a jet of water and steam

The method of decontamination using a jet of water and steam is quite affordable and widely used. This method is used for the decontamination of equipment, paved areas, vehicles, etc. (Fig.6.2).

Fig.6.2 Decontamination with a jet of water

The effectiveness of this method mainly depends on the pressure of the water jet and the nozzles used. Introduction into a stream of low - or average pressure of abrasive preparations, use of the pulse mode of processing allows achieving rather a high efficiency.

Treatment of transport, equipment, apparatus, buildings, and structures can be carried out by a jet of steam, where it is used as a working fluid for direct treatment of the contaminated surface.

But despite the good efficiency and relative availability, this method has a number of disadvantages:

- to generate steam requires special installations with relatively high productivity;
- application and operation of boilers require significant material costs and energy costs. In addition, when working with boilers, as with pressure equipment, requires strict compliance with many safety rules.

The reduction of steam consumption with sufficient decontamination efficiency is achieved by using the steam-emulsion method. It involves the use of decontamination solutions that are resistant to steam and do not lose their decontamination ability.

Decontamination with decontaminative solutions

Decontamination with decontaminative solutions is carried out by decontamination of a large number of objects, such as transport, clothing, equipment, buildings, premises, paved roads. This method is used using decontaminative solutions of different composition and purpose. Depending on the composition of the solution can be divided into three main groups: decontaminative solution (DS) based on surfactants (surfactants), oxidants, and sorbents. A more detailed list of decontaminative solutions and means of their use are given in Table 6.1 [35].

Table 6.1. Solutions for decontamination of surfaces

Material	**Means of use**
Surfactants	
Fatty soap (60%), washing powders	0.3-1% of solutions are used. Can be used together with complexing agents, acids, and other substances
Complexing agents	
sodium hexametaphosphate, citric, tartaric, javelin, hydrofluoric acid	0.4-2% of solutions are used. Can be used in conjunction with surfactant acids and other substances

Inorganic acids	
Nitric, hydrochloric and sulfuric acids	2–5% solutions are used for decontamination of acid-resistant materials
Oxidizers	
Potassium permanganate, hydrogen peroxide	0.1-0.5% solutions in alkaline or acidic media are used to release radioactive substances that are strongly bound to the surface.
Strong foundations	
Caustic sodium and potassium	1–5% solutions are used to isolate radioactive substances soluble in alkalis
Organic solvents	
Dichloroethane, alcohol, acetone, kerosene, gasoline	Used to highlight a contaminated layer of grease or paint

Regardless of the composition of the solution, the decontamination process follows the following scheme:

(Surface + RA contamination) + DS
Surface + (DS + RA contamination).

This scheme can be interpreted as follows: the solutions used for decontamination must overcome the connection of radioactive contamination with the surface of the object (the first stage of the decontamination process) and retain these contaminants, preventing their deposition on the already treated surface. Then it is necessary to create conditions for the removal of pollution together with the fulfilled decontaminating solutions.

When using the method of decontamination with decontaminative solutions, it should be noted that their use is not recommended for the treatment of porous materials as in the aquatic environment increases the penetration of radioactive contamination with water to an even greater depth.

DS based on surfactants

DS on the basis of surfactants is used for decontamination of various objects by irrigating the surface with simultaneous wiping with brushes, the mechanical effect of which allows intensifying the decontamination process, ie to facilitate the removal of contaminants and their removal together with spent DS. The result increases with the introduction of 10-40% of abrasive powder and can reach 80.

Some surfactants can be used for foam decontamination (Fig.6.3). Foam allows you to process aircraft, some types of optical, electronic and other equipment. The disadvantages of this method are associated with the implementation of the second stage of the decontamination process - the transport capacity of the foam is negligible. Over time, the foam fades, a very thin and sometimes not continuous layer of liquid is formed, which allows the radioactive contamination to return to the already treated surface. This circumstance causes two-stage processing: application of foam and its endurance (exposure) for a certain time; then the foam is removed by water jets, by vacuum, or by mechanical means.

Fig.6.3 Decontamination with foam

DS solutions based on multicomponent oxidants

Solutions based on multicomponent oxidants include acids (eg, nitric and oxalic), alkalis (sodium hydroxide), and some surfactants. DS based on oxidants are used for decontamination of oily, heavily contaminated, and corroded metal surfaces, as well as in cases of removal of deep radionuclides together with the upper contaminated layer. Solutions of this type are one of the main in nuclear energy in the decontamination of equipment and mainly the internal circuits of various units in contact with the coolant and corroded. In addition, these DS are used for the disinfection of spent NPP equipment. Usually, the numerical values of the resultes are not less than 30, which on the quality scale is defined as satisfactory.

The third group of DS consists of suspensions, ie such systems in the aqueous medium in which solid particles are distributed. These solid particles are sorbents, they will be discussed in more detail in the next paragraph. Bentonite clays, sulfite-alcohol bards, zeolites, and others can be used as sorbents. Suspensions of this group are used for decontamination of internal and external vertically located walls of buildings.

The use of sorbents and polymer films.

Sorbents are powders capable of absorbing various substances on their surface, including radionuclides (RN). The process of absorption of substances is called adsorption, as a result of which substances are spontaneously removed from different media: liquid and gaseous. The concentration of extracted substances on the surface is hundreds and even thousands of times higher than their concentration in the environment surrounding the sorbent.

The ability to adsorb various substances gives them a porous surface structure. Numerous pores dramatically increase the surface of sorbents, and hence the ability to adsorb. This ability is determined by the pore size and specific surface area. The pores are very small, sometimes commensurate with the size of the molecules.

The specific surface area of the pores is measured in m^2/kg, it shows the surface size of the sorbent, taking into account the pores per 1kg of powder. The specific surface of such a sorbent as clay exceeds 10000m^2/kg, activated carbon is hundreds of times more.

Sorbents are used to extract RN from gaseous and aqueous media, in the process of purification of water and air, as well as from various surfaces of contaminated objects. Sorbents used for decontamination may be mineral-based. Mineral sorbents include the previously mentioned clays and zeolites. Clay sorbents (bentonites of different classes, montmorillonite, kaolin, hydromica) are preferably activated, which increases their adsorption capacity. Mineral sorbents also include diatoms, crusts formed from the smallest microorganisms.

When using mineral sorbents in addition to adsorption, swelling occurs - the process of increasing the mass of a substance by absorbing water containing RN. Note that sorbents as a result of adsorption extract RN in molecular and ionic form.

Coal sorbents include carbon materials obtained by high-temperature treatment of various minerals of coal, wood, peat, and other substances rich in carbon. After treatment with steam or inert gases, which are necessary for cleaning pores, add additives that bind different RN.

The process of decontamination using sorbents goes in two stages, which differ from the stages of other methods of decontamination. First, there is a movement of RN to the surface of the sorbent, and then their actual adsorption on this surface. These stages of the process took time. If a stream of water, for example, the decontamination process is carried out in seconds, then in the case of sorbents, it is calculated in tens of minutes and sometimes hours. Sorbents are able to selectively absorb different RN.

For the formation of films are used mainly polymeric materials, as well as sorbents. Depending on the intended purpose, three groups of films should be distinguished: those that isolate (accumulate), inactivate, or localize radionuclides. Insulating films are pre-applied to a clean uncontaminated surface; in contrast to localizing, which are applied to the surface already contaminated with RN. The action of decontaminating films is to fix them on the surface of the object and the penetration of radioactive contaminants into the depth of the film material. The decontaminant will be removed from the surface of the object together with the radioactive contaminants contained in them.

6.2 Localization of radioactive contamination. Permissible radioactive contamination of various surfaces

The localization of radioactive contaminants means the use of means to prevent the transition of RN from the contaminated surface or from the air and water to other uncontaminated surfaces or to any environment that does not contain radioactive substances in dangerous quantities. Due to the fact that localization is carried out using the same technical means and methods as decontamination, it is appropriate to consider them together.

Localization is essentially the prevention of secondary contamination of objects. The main methods of localization are:

1. Isolation of the contaminated surface. Contaminated areas, roads, buildings, vehicles, and clothing are isolated.
2. Dust suppression. Refers mainly to the area. And at the same time there is an isolation of the polluted territory.
3. Embankment. It is connected with the consolidation of the soil that frames the water areas and the prevention of the spread of pollution during the year, floods, movement of groundwater and other waters.
4. Chemical - biological soil turfing. Aimed at the reclamation of contaminated lands in order to eliminate the possibility of damage to plants and animals.

Upon completion of decontamination, the surface contamination of various facilities should not exceed the permissible levels of surface radioactive contamination established by the RSSU, which are given in Table 6.2 [3].

Table 6.2. Permissible radioactive contamination of various surfaces (in particles/cm^2 per minute)

Object of pollution	Alpha-emitting radionuclides (uranium, plutonium, thorium, neptunium, americium, etc.)	Beta-emitting radionuclides (strontium-90, yttrium-90, cerium-144, ruthenium-106, cesium-137 - beta, gamma, etc.)
The skin of the human body, hair and inner, the surface of the headdress The same	0,1 0,1	10 2 (strontium-90, yttrium-90)
Towels, underwear, the inner surface of outerwear The same	0,1 0,1	10 2 (strontium-90, yttrium-90)
Outerwear The same	0,5 0,5	20 4 (strontium-90, yttrium-90)
Outer surfaces of shoes	5	200
Inner surfaces of shoes	0,5 0,5	20 4 (strontium-90, yttrium-90)
Internal surfaces of living quarters and household items that are in them	0,5	20
Exterior surfaces of living and utility rooms, outdoor items	5	200
Interior surfaces of vehicles and containers	1	100
Sacking, packing materials, an internal surface of boxes for foodstuff	Not allowed	Not allowed

6.3. Technologies of decontamination with application of graphene and graphene oxide

In recent decades, numerous new forms of carbon nanomaterials, including fullerenes, carbon nanotubes, and graphene layers, have been discovered or synthesized They are promising materials for many industries of the nano industry, as they have unique electronic, electromagnetic, thermal, optical, and sorption properties. Although fullerenes and carbon nanotubes have been invented, studied, and used before graphene, they are in fact derivatives of graphene, as their properties are a consequence of the corresponding properties of graphene. Graphite is essentially a large number of layers of graphene; carbon nanotubes can be represented as one or more layers of graphene rolled into rolls of different diameters; fullerenes are nanosized spherical molecules whose surface is formed by graphene planes.

Graphene is a two-dimensional allotropic modification of carbon, which is a carbon atom assembled into a flat grid of regular hexagons with a side of 0.142 nm. [6]. A hexagonal two-dimensional crystal lattice is formed by a layer of carbon atoms, which are in sp^2-hybridization and are connected by σ- and π-bonds.

Graphene has a monoatomic thickness. In fact, graphene is a component of graphite, the structure of which can be represented as a series of graphene planes located at a distance of approximately 3.4 nm from each other. Thus, graphene can be considered as one of the planes of graphite removed from the bulk crystal.

The stable existence of graphene seems to contradict the theory of L. Landau and R. Pierre, who mathematically strictly showed that two-dimensional crystals cannot be thermodynamically stable due to the fact that thermal fluctuations of the crystal lattice cause the atoms to shift from an equilibrium position of the same magnitude. with the interatomic distance in the original lattice.

In fact, as proved experimentally and theoretically, free graphene, although flat, has an uneven, slightly crumpled surface. Its atoms are not in the same plane, but, remaining tightly bound together in the space of the plane, come out of it at short distances. As a result, the surface of graphene is not flat but covered with hills and dents, which are called ripples.

As a result of these random displacements of carbon atoms in the third dimension, there is an effective thickness of atomic layers, which provides mechanical stiffness in the transverse relative to the plane direction and thus avoids the Landau-Pearls constraint valid for purely two-dimensional systems.

The unique properties of graphene make its use promising in various technologies and various devices, in particular in nanoelectronics.

Properties of graphene:

• Ultra-thin (one atom thick), light (density-0.77 mg / m2) mechanically very strong, flexible, and electrically conductive material.

• Has a tensile strength of 42 N / m, 100 times stronger than steel of the same thickness.

• The electronic properties of graphene differ significantly from the properties of three-dimensional substances and are a consequence of the theoretically predicted and experimentally confirmed linear law of dispersion (energy dependence on momentum) of electrons in graphene (A. Geim and K. Novoselov group at the University of Manchester, etc.).

On a macroscopic scale, the linear law of dispersion leads to the fact that graphene is a semimetal, ie a semiconductor with zero bandgap, and its conductivity under normal conditions is not inferior to the conductivity of copper. Moreover, its electrons are extremely sensitive to external electric fields. Passing an electric current through graphene strips, the experimenters found that the ability of free electrons to move (so-called carrier mobility) is almost two orders of magnitude (100 times) greater than that of silicon, and 20 times greater than that of gallium arsenide. These two semiconductors, along with germanium, are most often used in the creation of various high-tech devices (integrated circuits, diodes, detectors, etc.), and since the speed and efficiency of their work is determined by the mobility of electrons, the greater this value, the faster and more productive devices. Currently, the most discussed and popular project is the use of graphene as a new basis for microelectronics, which can replace existing technologies based on silicon, germanium, and gallium arsenide.

• Has high thermal conductivity. The measured thermal conductivity of graphene is 10 times higher than the thermal conductivity of copper, which is considered an excellent conductor of heat.

• Practically transparent and therefore has no color. The share of light absorbed by graphene in a wide range does not depend on the wavelength and is 2.3% of the intensity of the light incident on it.

The combination of transparency, good electrical conductivity, and elasticity of graphene has led to the idea of using it in the creation of touch screens and photocells for solar panels. Experiments have shown that almost all indicators of devices of this kind based on graphene are better than currently used devices based on indium tin oxide.

Method of decontamination using graphene and graphene oxide

Modern science knows the technology of decontamination of objects using graphene and graphene oxide [37-39].

]. In particular, there is a method of using a solution of graphene with polymers (which are resistant to ionizing radiation) or with other surfactants. Such graphene-containing compounds upon contact with water contaminated with radionuclides are mixed with it and adsorb

heavy metals and radionuclides, in the future, fall into the sediment, which is subject to industrial disposal or processing.

Anionic surfactants - in aqueous solution decompose to form negatively charged ions and give a powerful foam.

The addition of graphene oxide to the foam used to remove radioactive substances, heavy metals, and other contaminants from surfaces and solutions can significantly increase the efficiency of such methods.

Isolation of long-lived radionuclides from aqueous solutions of different compositions is an important problem, the solution of which is necessary both for the development of closed nuclear fuel cycle technologies and rehabilitation of areas contaminated with radionuclides.

The ability of graphene to extract radioactive materials from aqueous solutions at high speed was discovered by scientists from laboratories at Moscow State University and Rice University (USA). This property can be used to clean areas contaminated with radiation, such as Fukushima, as well as to improve technologies for the extraction of rare earth elements and shale hydrocarbons. During the experiments, the researchers found that microscopic scales of graphene oxide, as expected, in one atom quickly bind radionuclides of different origins and collect their individual ions into solids. These scales are easily soluble in water and, having extracted radioactive substances from it, are collected in lumps, which are easy to remove and somehow dispose of - for example, burn.

According to James Tour, who leads the group from Rice University, this discovery could be a real benefit in cleaning up areas contaminated with radioactive materials, such as the Fukushima-1 nuclear power plant. Moreover, according to Tour, it can significantly reduce the cost of so-called fracking technology, which is used today to extract shale gas and oil.

Graphene oxide is generally an excellent material. It appeared soon after graphene, and it immediately became clear that it has many different applications. It can be indispensable in electronics, can be a means of delivering drugs to cancer, an excellent chemical catalyst, and much more, it can be used to reduce pure graphene, and, most interestingly, it can be obtained much easier and cheaper than graphene itself. A couple of years ago, Chinese physicists discovered that graphene oxide also has bactericidal properties because it can bind toxins.

Therefore, the ability of graphene oxide with high efficiency to carry out radioactive water purification was quite expected.

Unexpected, according to the head of the laboratory of dosimetry and radioactivity of the environment of the chemical faculty of MSU Stepan Kalmykov, was the phenomenal speed of this cleaning.

Graphene oxide flakes were synthesized by the Tour group, and the experiments themselves were performed in Kalmykov's laboratory [11]. Scientists have tested these scales on solutions containing uranium, plutonium, as well as sodium and calcium, which interfere with absorption. But even with all these obstacles, graphene oxide is much more efficient and faster than sorbents traditionally used for radioactive treatment - bentonite clays and granular activated carbon. Radioactive impurities precipitated within minutes (Fig. 6.4).

According to James Tour, the idea to use graphene oxide for radioactive purification and to conduct joint experiments arose when his graduate student Alexander Slesarev and Anna Romanchuk, a graduate student from Kalmykov's laboratory, accidentally met at a conference.

One of the main directions of this joint work was the extraction of solutions of radioactive isotopes of actinides and lanthanides. These thirty elements of the periodic table are a family of so-called rare earth metals. The presence of radioactive isotopes in their ores and solutions makes the extraction of "rare earths" very harmful to health. In the United States, for example, it is virtually banned due to non-compliance with environmental requirements, although "rare earths" are needed for electronics and, in particular, for mobile phones in increasing quantities. There are no such environmental bans in China, and not least because of their absence, it has today become a monopolist in the extraction of rare earth metals. It is possible that the use of graphene to clean liquid lands will be able to significantly weaken this monopoly.

As for the fracking that James Tour spoke about, here, too, it also rests on radionuclides of natural origin. During this process, a mixture of water, sand, and a number of chemical compounds is forced into the horizontal shaft under pressure. Under the influence of this mixture, the inner surface of the shale drifts cracks, and when it is sucked out of the mine, after it from the cracks begin to flow released gas or oil. This is a very expensive and non-ecological procedure, the harmfulness of which is determined, including by radionuclides extracted to the surface together with water, which can also be purified with graphene oxide (GO).

However, the adsorption properties of GO can be significantly improved by the use of impurities of nanoparticles, organic compounds, or polymers. For example, with the use of polyanite.

GO flakes could be obtained by various methods, including the Hammers method.

Hammers method [14], based on the use of an anhydrous mixture of concentrated sulfuric acid, sodium nitrate, and potassium permanganate. According to the work, 100 g of fine graphite powder and 50 g of sodium is introduced into 2.3 l of technical sulfuric acid and thoroughly mixed at a temperature of 0°C. Subsequently, continuing to mix, slowly add 300 g of potassium permanganate to the suspension, making sure that the temperature does not rise above 20°C. After that, the oxidation reaction is carried out in suspension for 30 minutes at a temperature of 35 ° C. The reaction is accompanied by an increase in the volume of the mixture and the release of bubbles. Upon completion of the reaction, the suspension acquires a doughy structure and a gray-brown color.

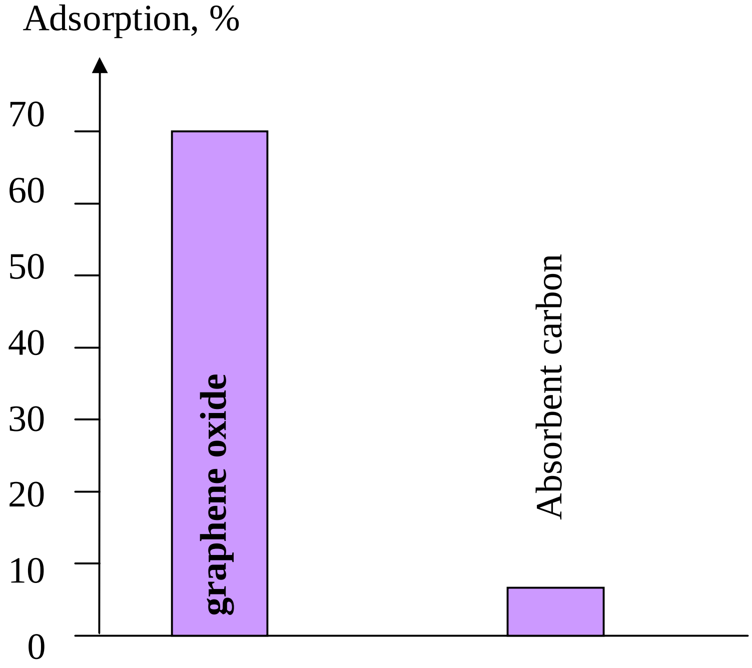

Fig. 6.4 Diagram of comparative persorption of ions of uranium by the graphene oxide and absorbent carbon

The paste is poured 4.6 liters. water during mixing, which leads to rapid gas formation and temperature rise to 98°C. At this temperature, the resulting suspension is kept for 15 minutes At the end of this time, the suspension is poured into 14 l of water containing 3% hydrogen peroxide, which helps to reduce the residues of potassium permanganate and manganese oxide to a colorless soluble manganese sulfate. As a result of treatment with hydrogen peroxide, the suspension becomes bright yellow.

Filtration of suspensions leads to the formation of a yellow-brown mass, multifaceted washing of which in a larger amount of thermal water allows you to get rid of almost all impurities and obtain a suspension of pure graphite oxide in water. To dehydrate the material use a centrifuge followed by vacuum treatment at 40°C in the presence of phosphoric anhydride. The chemical composition of the obtained graphite oxide is determined on the basis of the analysis of the combustion products of the material. Experiments show that the material contains 47% carbon, 28% oxygen, and 23% water and ash impurities (at 2%).

The layers of graphene oxide contained in the aqueous suspension have a significant negative charge due to the addition of cations present in the water. This leads to electrostatic reflection of graphene layers in water, which facilitates their separation and increases the stability of the suspension.

The fine graphite oxide obtained by the modified Hammers method [14] was filled with water of high purification to form a brown suspension, which was then dialyzed to completely remove residual salts and acids. The concentration of the suspension was 0.05% by weight. The distribution of graphite oxide on the exhaust gas was as a result of **RCD** suspension for 30 minutes In order to remove the graphite oxide particles that had not been opened, the suspension was subjected to centrifugation for 30 minutes at a speed of 3000 rpm (rotor radius was 14 cm). In order to further reduce graphene from CO, 5 ml of the suspension was mixed in an ampoule with 5 ml of water, 5 ml of 35% aqueous hydrazine solution, and 35 ml of 28% aqueous ammonia solution. The mass ratio of hydrazine to CO was 7:10. After mixing for several minutes, the ampoule was placed in a water bath, where it was kept for an hour at ~ 95°C. Thus obtained suspension containing graphene sheets, was further used to study and obtain films. After completion of the procedure, the recovery of hydrazine residues is removed by dialysis.

To obtain graphene paper, the suspension was filtered using a filter with a diameter of 47mm with a pore size of 0.2 μm.

The obtained samples of graphene sheets filling the suspension were examined by spectroscopy in the ultraviolet (UV) and visible region in the mode of absorption and transmission. In the process of restoring graphene sheets, their average size is continuously changed using a particle analyzer. The spectra of reflection of graphic films were measured by IR Fourier spectroscopy.

Studies show that the stability of the suspension is very sensitive to the presence of residual impurities of metal salts and acids, which are often present in the original graphite oxide. These impurities can neutralize the charge of the graphene layers, which leads to a deterioration of stability. In order to increase the charge density on graphene sheets, ammonia is added to the initial solution, the presence of which raises the RN to 10. Volatile ammonia is easily removed from graphene samples during the formation of films or composites. The increase in the RN value of the solution also contributes to the excessive content of hydrazine, which, however, is limited in use due to its toxicity.

It was found that in the recovery process, graphene layers at the water/air boundary tend to agglomerate.

Graphene oxides, as well as composites based on them - promising materials for environmental control (especially for industrial waste). In some cases, they can be considered as a reserve material for emergency disinfection of air and liquid waste. Functional groups at the edges and in the plane of graphene oxides are capable of both covalent and non-covalent interactions with various molecules. Moreover, the significant specific surface area of graphene oxides allows for absorbing significant amounts of heavy metal ions and organic spices. Due to the peculiarities of surface chemistry and different types of architecture of conglomerates based on graphene oxides, there are numerous opportunities for selective catalytic processes of decomposition of harmful gases into safe derivatives. In this, graphene oxides are orders of magnitude superior to activated carbon, which has proven itself so well in individual gas masks and filters during the two world wars.

In the ecological aspect, graphene oxides in the near future are relevant as preconcentrates of trace amounts of harmful substances - in order to monitor all components of the environment. The benefit of large amounts of sorbent will not be needed, because recently the method of so-called dispersion micro-solid phase extraction has been well developed. This method will reliably determine heavy metal ions at a concentration of about 1 ng/ml.

CHAPTER 7 ECOLOGICAL REHABILITATION OF NATURAL ECOSYSTEMS, AGROCENOSES AND CHNPP EXCLUSION ZONES

7.1 Methodological approaches to solving the problems of contaminated areas.

The problem of areas contaminated with radionuclides is a consequence of man-made activities. Restoration of contaminated areas and the livelihoods of the population living in them is one of the most difficult tasks in Ukraine after the Chernobyl accident.

According to experts, in any man-made accident or catastrophe can be divided into three-time stages:

- emergency protective measures or emergency period;
- ensuring long-term residence of the population in the contaminated area;
- ensuring the agricultural use of contaminated areas.

Accordingly, in the post-Chernobyl situation there are three stages:

- early (early phase);
- long-term phase;
- rehabilitation (a final restoration phase or rehabilitation phase) - 6-10 years after the accident.

Rehabilitation should be understood as a system of measures aimed at bringing unbalanced subsystems (environment, human, natural, and industrial resources) to a normative, safe for living and economically feasible state.

That is, the rehabilitation of areas contaminated with radionuclides, temporarily withdrawn from commercial use - is the implementation of measures for their return to economic use. The long process of rehabilitation involves the gradual introduction of the lost potential in the economic sphere as the creation of safe living conditions and development of those industries whose activities are possible in a situation of radioactive contamination without harm to public health, and products must meet established standards.

Let us consider partial and complete rehabilitation of such areas.

Partial rehabilitation is a set of measures that allows the conduct of certain types of economic activities, certain sectors of agriculture for a certain period of time with mandatory compliance with radiation safety standards, and acceptable levels of radioactive contamination of products.

Full rehabilitation is a set of measures that leads to the removal of radiological restrictions on land use, housing, and all forms of its activities.

The purpose of the territorial approach is a general assessment of the current ecological and radiological condition of the area and the forecast of their changes. These characteristics allow choosing the strategic direction of rehabilitation measures within the district, using as criteria economic indicators (eg, farm profitability) and radiation characteristics (total annual individual and collective doses, levels of radionuclides in agricultural products).

The local approach is carried out at the level of settlements in order to rank them according to the amount of radioactive contamination of the territory and agricultural products, as well as individual annual dose loads. This allows you to plan the necessary countermeasures for each settlement and provide appropriate funding.

The main principles of the general methodology of rehabilitation are:

- complexity, on the basis of which all aspects of life and activity of people living in the contaminated area are considered;
- radioecological forecasting of individual and collective doses in the territory being rehabilitated;
- sequential and parallel planning of protective and economic measures based on ideas about their significance and interaction;
- the relationship of socio-economic and radiological situations that have affected the general condition of the contaminated area and determine the possibility of state financial support for the rehabilitation process;
- making decisions on rehabilitation measures on the basis of established empirical patterns and expert opinions in conditions of uncertainty and incomplete data.

Countermeasures applied in the exclusion zone.

The accident at the Chernobyl nuclear power plant occurred in a zone of developed agricultural production. And one of its most severe consequences was radioactive contamination of agricultural land. The total area of radioactive contamination zones, defined by the current legislation, is 53.4 · 103 km2. About 2 million people live in this territory. persons. The area of radioactively contaminated areas for agricultural use is about 1.2 · 106 ha. In accordance with the requirements of the laws of Ukraine aimed at overcoming the consequences of the Chornobyl catastrophe, measures were taken in these areas to improve the radiological situation and reduce radiation doses to the population.

The set of measures for radiological protection of the population and revival of the territory includes:

- radiological monitoring, in particular, dosimetric certification of settlements of Ukraine;
- carrying out countermeasures in agriculture and forestry, control over the levels of radioactive contamination of food, forest products, medicinal plants.

Thus, radiation rehabilitation of contaminated areas is impossible without quantitative assessments of contamination levels of all parts of the food chain (from soil to dose loads per capita) according to a calculation algorithm that links soil contamination levels, radionuclide transition coefficients, and dose characteristics.

All these tasks have been successfully solved by scientists and specialists in the field of agricultural radiobiology, radioecology, and radiology since the very beginning of the post-Chernobyl period.

- The degree of contamination of agricultural lands with individual radionuclides is systematically carefully inspected and analyzed, pollution maps for 137Cs, 90Sr, and 239Pu are created and published.
- Administrative-territorial subdivisions of agriculture in the contaminated territories are armed with small-scale maps-plans of radioactive contamination of lands for 137Cs, and in some cases - for 90Sr.
- Components of **agrocenoses** have been identified and identified in contaminated areas - genera, species, even plant varieties that have an increased ability to accumulate certain radionuclides.
- Crop products, and especially livestock products, are subject to radiological control and, if necessary, discarded.
- When studying the peculiarities of radionuclide migration, separate trophic chains characterized by a high migration rate were identified: peat-wetland soils – plants, soils – meadow plants.
- Estimates of accumulation and transition coefficients of individual radionuclides for different types of soils and species of agricultural plants are estimated.
- The scientific and organizational bases of conducting certain branches of agricultural production in the conditions of radioactive contamination are formulated, the complex systems of radioprotective receptions and means (so-called countermeasures) covering all directions of managing are developed.

All this is reflected in a series of recommendations for agricultural production in terms of radioactive contamination due to the Chernobyl accident.

In the rehabilitation of withdrawn lands for agricultural production, priority is given to areas adjacent to the land used and have a lower pollution density and high fertility. The use of countermeasures is the main means to reduce the time of introduction of alienated territories into economic use, to expand its scope and direction. When planning the rehabilitation of the territory, the maximum effectiveness of radioprotective measures should be ensured on the basis of the principle of optimizing their application according to radiological, economic, social, and other criteria.

Reforming agricultural production should be accompanied by measures to reduce the export of radionuclides outside the contaminated area and reduce radiation exposure to the population associated with the consumption of contaminated products. According to experts, the specialization of agriculture in the production of products with low content of radionuclides, cooperation is effective. As well as the processing of agricultural raw materials directly by its producer.

The most profitable economic use of withdrawn land is a production with the least initial investment in special countermeasures. For example, it can be fattening young cattle, cattle, and horses on natural forage lands, breeding fish in stagnant water bodies, creating forest plantations, and producing bioenergy resources.

7.2 Optimization of nature management in areas contaminated with radionuclides

Living and any human activity in areas contaminated with radionuclides are appropriate and possible only if the existing radiation environment allows safe work in various industries. Therefore, such work should be carried out in accordance with the provisions of relevant regulations on living conditions and employment in areas with high levels of radiation contamination, in compliance with the principles of radiation safety and basic sanitary rules for working with radioactive substances and other sources of ionizing radiation.

Features of crop production on lands contaminated with radionuclides. Countermeasures.

Preventing the transfer of radionuclides from the soil to plants, ie inhibiting their movement in the initial and most responsible link of their short food chain - one of the main modern tasks not only of agricultural radioecology but also general radiobiology, as ultimately aimed at human radiation protection. Depending on the properties of the soil, the degree of contamination with radioactive substances, as well as the types of crops grown, ways of using the crop, and some other conditions, various means are used that can reduce the accumulation of radionuclides in crop and feed production many times

The receipt of radioactive substances into plants mainly occurs in two ways:

- *aerial* (foliar) pathway, in which radionuclides that have settled on plants, are adsorbed or penetrate, move and concentrate in individual organs. Receipt depends on the physical and chemical properties of radionuclides and the nature of the plant surface;

- soil, in which radioactive substances are extracted from the soil solution by plant roots.

Foliar contamination.

Areas of the most active absorption of radioactive substances in foliar contamination:

- through the leaves (leaf absorption);

- through the inflorescence (floral absorption);

- through the basal part of the plants or the surface of the roots (absorption from the turf in the basal part of the stem).

Means to reduce foliar radionuclide inflow due to wind uplift

- mixing with a certain layer of soil, moving radionuclides with plows into deep layers;

- the weakening of air erosion of soil by the sowing of **scenes** and grasses, planting of bushes and trees

Soil contamination.

The main factors that determine the root supply of radionuclides to plants are the type of soil and the type of plants.

The absorptive capacity of the soil is mainly a function of two indicators - the mineral compound and the content of organic matter. Therefore, different soils absorb radionuclides differently. Soils of heavy mechanical compounds, as a rule, have a higher absorption capacity compared to light ones. As a result of sorption, the bulk of radioactive substances in natural and sown meadows, as well as in virgin and fallow areas are retained in the upper (up to 5 cm) layer, on arable land - in the cultivated layer of soil. In the order of increasing ability of different types of soils to sorb radionuclides, they can be distributed in the following sequence: peat-podzolic-sod-podzolic-gray forest-meadow-gray soil-chestnut- chernozem.

The distribution of radionuclides in the aboveground parts of plants is also different. About half of their number, which got to the plant, accumulates in the stem. Much less radioactivity goes to the leaves, even less to the ears, and only a few percent to the grain. Thus, it is possible to find a natural dependence - ***the farther along the transport chain from the root is the body, the less, as a rule, it accumulates radionuclides***. In the case of cereals and legumes, the main products of which are grain, this dependence is very encouraging. But when the productive organs are leaves, and especially the underground parts of plants - roots, bulbs, tubers have to deal with more contaminated products.

There are five main integrated systems for reducing the influx of radionuclides into plants, which take into account both conventional and special mechanical, agronomic, agrochemical, chemical, and biological measures:

- tillage;
- application of chemical ameliorants and fertilizers;
- changes in plant composition in crop rotation, changes in irrigation regime;
- use of special substances and techniques.

Tillage. Most tillage techniques are effective only in the first year after the fallout. After precipitation, radioactive fallout is concentrated mainly in the upper rather thin layer of soil. At relatively low levels of soil contamination, the treatment of conventional milling machines or heavy disc harrows, as well as plowing with dump plows to a normal depth of 20–25 cm can be a sufficient measure. Mixing the contaminated surface layer with a deeper one sharply reduces the spread of radioactive fallout and plants by aeral, reduces the radiation background of the area. At high levels of contamination, an effective method is to wrap the contaminated layer of soil with a plantation plow to a depth of 50-75 cm with the rotation of the slice. This leads to a reduction in the accumulation of radioactive products by plants in the area of the predominant location of root systems by 5-10 times.

Other methods - deep plowing of radioactive substances, removal of the surface layer of the soil, deep backfilling of the surface radioactive horizon with a thick (0.5-1 m) layer of clean soil, selected from the depths, require a lot of effort and money. Therefore, they are recommended only in exceptional cases for certain crops and, as a rule, in small areas.

The use of chemical ameliorants and fertilizers. Radioactive substances that enter the environment in the form of insoluble and sparingly soluble non-exchangeable forms in contact with water, oxygen, air, they can go into a soluble metabolic state. This is especially facilitated by the acid reaction of the environment. It has been observed that on acidic soils, plants receive more radionuclides than on neutral or alkaline soils. Therefore, the method of liming acidic soils, not only improves plant growth conditions but also reduces the supply of radionuclides. The main component of lime is calcium - a chemical analog of strontium in the form of oxide, hydroxide, carbon dioxide. Therefore, due to competition, the antagonism between them, the supply of 90Sr to plants decreases. Similarly, the introduction of potassium fertilizers with a chemical analog of cesium - potassium reduces the supply of 137Cs to plants. The systematic use of phosphorus fertilizers promotes the fixation of 90Sr in the soil by precipitation with phosphates. The recommended doses of lime, organic, and mineral fertilizers are known, the application of which to the soil contaminated with strontium reduces its content in the crop yield by about 5 times, and on light sandy and loamy soils - up to 10 times.

Changing the composition of plants in crop rotation. Different species of plants with different intensities absorb and accumulate in their organs individual radionuclides. Therefore, when planning measures to reduce their receipts in crops should pay special attention to the selection in crop rotation as the species composition of plants and varieties.

The unequal sensitivity of plants to radiation is due to the volume of their cell nuclei, the size of chromosomes, and the content of DNA in the cell, and increases with the growth of these factors.

Seeds of plants of different species also have different sensitivity to radiation. The plants are divided into:

radiosensitive - beans, corn, thyme, rye, wheat;

moderately sensitive - peas, vetch, soybeans, lentils, lupins, oats, barley, sunflower;

resistant - flax, clover, alfalfa, castor, tobacco, melilot.

Yield losses due to plant damage depend not only on the total radiation dose but also on the growing season of plants during the fallout of radioactive dust.

The intensity of radioactive substances from the soil into plants is closely related to their biological characteristics. Cereals that absorb calcium in relatively small amounts accumulate much less Sr-90. Therefore, the accumulation of this radionuclide by different species of plants when grown under the same conditions can vary dozens of times. Radioactive isotopes that enter cereals and legumes through the root system are deposited mainly in the leaves and stems, less than 2% of them pass into the grain. Of the vegetable crops that make up a significant proportion of the human diet, 90Sr is probably the most accumulated by roots and tubers. According to their relative share in the diet, the first place is occupied by potatoes and beets. A significant share belongs to cabbage.

Similarly, potash plants such as lupine, corn, potatoes, beets, buckwheat, and others. together with potassium, its chemical analogs from the first group of the periodic table, including cesium with its radioactive isotopes1 134Cs and 137Cs, accumulate in large quantities. In order of decreasing 137Cs content in food parts, some plant species are placed in the following sequence: grains and legumes - buckwheat – soybeans – beans – beans – peas – oats – rye – wheat – barley – millet – corn; fodder (green mass) - yellow lupine – fodder cabbage – vetch – sunflower – clover – timothy – bonfire bezosta – corn; some technical - oil radish – rape – sugar beets – sunflower – flax; vegetables - cabbage – beets – salad – carrots – potatoes – cucumber – pumpkin – tomato.

Changing the irrigation regime. Under irrigation conditions, the intensity of radionuclide involvement in the biological cycle increases, favorable conditions can be created for the entry of radionuclides into plants. Their sources can be both contaminated water and soil.

The supply of radionuclides to plants depends on the method of watering. During sprinkling (and this means irrigates more than 95% of irrigated lands in Ukraine) radionuclides are absorbed by water contaminated mainly by the aboveground part of plants when irrigation water gets on leaves, flowers, fruits, stems. In this case, the flow of radionuclides to plants will be maximum. At superficial watering of the field on furrows, overflow on strips, flooding; under subsoil irrigation, when water enters the capillaries directly into the root layer of the soil from the system of subsoil humidifiers; under drip irrigation when water is brought to the soil surface in the area of the root collar, their entry occurs through the roots. In this case, the accumulation of radionuclides will be much smaller, as some of them are absorbed by the soil. part of the radionuclides is retained by the root system, absorbed by the walls of the leading vessels of the stem and other organs of the aboveground part.

There are the following general rules for changing the irrigation regime (mainly they apply to the most dangerous situation when watering is carried out with water containing radioactive substances):

- if it is possible to choose the method of irrigation, preference should be given to surface watering;
- to reduce the number of irrigations within the volume of irrigation norm;
- prefer watering in the first half of the growing season;
- do not allow watering, especially by sprinkling, during the formation and maturation of parts of plants that are the subject of the crop.

The use of special substances and techniques

Many natural and artificial substances are known, the introduction of which into the soil reduces the transfer of radionuclides to plants. Among them, there are two main classes - adsorbents and complexonates. The first ones absorb radionuclides, making them inaccessible to plants, the latter form complex compounds with radionuclides, converting them into sparingly soluble forms not assimilated by plants or, conversely, easily soluble, which are leached from the root layer into deep soil horizons.

Effective sorbents of radionuclides are considered to be such minerals as zeolites, illites, vermiculites, bentonites, to a lesser extent - montmorillonite and kaolinite, etc. Despite the relative cheapness, their use is associated with high costs, as it is advisable only at very high rates of their introduction into the soil - 10-12 tons of finely ground mineral per hectare of field. With such a single application it is possible to reduce the supply of radionuclides to plants by 1.5-3 times over the next few years.

The so-called "activated carbon" - a type of slag formed during the combustion of coal - has a pronounced sorption capacity. Its application on podzolic soils in quantities twice less than natural minerals allows achieving the same effect.

Basic principles of crop production in areas contaminated with radionuclides

In an area contaminated with long-lived radioactive substances, it is recommended to introduce a so-called "zonal" system of contaminated land use, which is based on the principle of separate specialized crop rotations on lands with varying degrees of radioactive contamination.

The first zone includes farmland on which crops can be grown, with the content of 90Sr in products not higher than the established safe level for food use. In this zone, crop rotation is developed from crops (cereals, legumes, vegetables, potatoes), which are directly included in the diet of humans and dairy cattle. All measures to reduce the transition of radioisotopes from soil to plants are carried out primarily in this area.

In the second zone (pollution levels in which can be 10 times higher than the level of pollution of the first zone) crop rotation is introduced from fodder crops for meat and dairy cattle, whose products are processed into oil, as well as for working cattle and birds. Cereals can be introduced into crop rotation with the subsequent use of the crop only for harvesting livestock (including dairy cows) or for seeds and technical processing into alcohol, starch, sugar, and vegetable oil.

In the third zone, which includes all other contaminated lands, crop rotation should include the production of industrial and oilseeds (flax, sunflower, hemp, sugar beet) and seed production of all types of crops. Straw and waste from the processing of all products grown on these lands for the consumption of agricultural livestock is prohibited.

When conducting agriculture on lands contaminated with radionuclides, it is necessary to follow the rules of use of local fertilizers, which can become a source of radioactive contamination of soil and plants:

- manure, compost, and ash obtained from areas with high pollution density should not be applied in fields with low levels of radioactivity. These fertilizers should be applied only to fields with a higher level of pollution under crops of industrial crops;
- with the same density of land pollution, organic fertilizers from natural meadows should not be applied to arable land, because it will inevitably lead to an increase in the level of pollution of arable land;
- Organic fertilizers contaminated with radioactive substances do not need to be applied to the fields of vegetable and potato crop rotations, because these products get directly into human food.

Application of a thin layer of peat, clay, etc. on the surface of alkalis. reduces the entry of radioactive substances into alkaline plants and eliminates the possibility of ingestion of radionuclides from the soil surface by animals during grazing.

Features of animal husbandry on lands contaminated with radionuclides. Countermeasures.

Ways of radionuclides entering the body of farm animals:

- oral or alimentary (through the digestive system);
- inhalation (through the respiratory system);
- percutaneous (through the skin).

The main one is oral - with food and in much smaller quantities - with water.

Radionuclides in pure form or mixtures thereof can enter the gastrointestinal tract in various forms: in the ionized state, in the form of adsorbed on the surface of the feed, melted carbonate and silicate particles, and the like. Most of them are immediately excreted from the body, but some, along with blood, enter the organs and tissues of animals, where they are partially delayed, selectively concentrating in individual organs.

The conception of the bioavailability of radionuclides for animals and birds gives the values of their absorption in the gastrointestinal tract and the transition from diet to milk, meat, offal, egg.

The magnitude and rate of absorption of radionuclides is influenced by the solubility of the quantities in which they enter the body, as well as the functional state of the body, age of the animal, anatomical and physiological features of the gastrointestinal tract, feeding, mineral metabolism, and chyme movement.

There are the following types of distribution of radioactive substances in mammals:

- skeletal type (characteristic of the elements of the alkaline earth group - calcium and its chemical analog strontium. In the mineral part of the skeleton also accumulate radionuclides of barium, radium, plutonium, uranium);
- reticuloendothelial (characteristic of radionuclides of rare earth metals - cerium, praseodymium, promethium, as well as zinc, thorium, and transuranic elements);
- thermotropic (for iodine);
- diffuse (for radionuclides of alkaline elements: potassium, sodium, cesium, rubidium, as well as hydrogen, nitrogen, carbon, polonium, etc.).

The degree of radiation exposure of incorporated radioactive substances on individual organs and on the body as a whole depends on their duration of stay in it. Those that join the metabolic process in tissues with an accelerated metabolism are rapidly excreted from the body along with the products of metabolism (tritium, etc.). Those involved in the formation of bone tissue (45Ca, 90Sr) are in the body of the animal throughout life. To characterize the period of stay of radioactive substances in the body, ***the concept of the half-life of a radioactive isotope*** *is introduced - the time during which the amount of radionuclide accumulated in the body (sometimes in a separate organ) is halved due to biological secretion during natural metabolic processes*.

However, when determining the degree of purification of the body from radionuclides, it is necessary to take into account the half-life of radionuclides T1 / 2, because the reduction of radioactive substances, as well as the action of ionizing radiation, is due to their removal and decay. In this case, talk about ***the effective half-life*** of the radionuclide ($\mathbf{T_{EF}}$), which is determined by the formula:

$$T_{E\Phi} = \frac{T_{1/2} \cdot T_{\Pi/B}}{T_{1/2} + T_{\Pi/B}},$$

where $T_{1/2}$ is the half-life of the radionuclide and $T_{P/B}$ is the half-life.

The main share in the pollution of livestock products belongs to 137Cs and 90Sr.

Ways to reduce the entry of radionuclides into the body of farm animals:

1. Constant control over the state of contamination of feed with radioactive substances during the preparation of rations. Thus, the conversion rates of 137Cs and 90Sr in milk and meat of cows, whose diet is dominated by green grasses (from contaminated natural substances of natural onions), 1.5 - 2 times higher than in animals whose diet is based on grain and coarse feed. A mixed or silage-concentrate diet is also preferred over the hay type of feeding.

2. Radical improvement of natural forage lands in areas contaminated with radionuclides, which is ensured by the creation of more productive grassland; the wrapping of radionuclide-contaminated turf, and formation of a new, less contaminated one; application of lime and mineral fertilizers in certain quantities and ratios.

3. Optimization of mineral nutrition - calcium and potassium. Disruption of calcium nutrition can lead to an increase in the body of its chemical analog 90Sr. Enrichment of the diet with foods high in potassium (corn silage, potatoes, fodder beets, some legumes, and fodder grasses) helps to reduce the accumulation of 137Cs. Calcium and potassium are *radioblockers* that reduce the entry of radioactive substances into the body.

***Radioblocker**s are substances that reduce the accumulation of radionuclides in the body by blocking their incorporation into tissues through competitive interaction, sorption, the formation of complex compounds, or other mechanisms.*

4. Enrichment of the diet with trace elements - salts of cobalt, zinc, copper, manganese, iron, iodine, etc.

5. Addition to the diet of **enterosorbents** salts of alginic acids - alginates of sodium, potassium, calcium, which bind radionuclides in the gastrointestinal tract, reducing their absorption. Made from some species of brown algae. Pectin substances have a similar effect, many of which are contained in roots and especially beets, including fodder, pumpkin, stone fruits, and seed fruits.

6. Co-administration of ferrocene, better known as Berlin azure, and its derivatives, ferrocyanides of iron, cobalt, and nickel, which limit the absorption of 137Cs. Ferrocene selectively forms insoluble compounds with this radionuclide, which do not penetrate the walls of the stomach and intestines and are excreted from the body with metabolic products.

7. The use of radio **decorrants** - substances that accelerate the excretion of radionuclides from the body. These are complex drugs that are able to form with most cations, including cesium and strontium, strong, but well soluble in water complex compounds that, participating in metabolism, accelerate their excretion from the body. (They are practically not used in animal husbandry due to their high cost.)

7.3 Basic principles of the organization of animal husbandry in areas contaminated with radionuclides

Systems of measures to reduce the concentration of radionuclides in livestock products, mostly coincide, and can be divided into 4 groups:
1) production of feed with a permissible content of radionuclides;
2) change of conditions of maintenance and rations of the feeding of cattle on final fattening and introduction to rations of the special additives reducing transition of radionuclides in livestock products;
3) technological processing of livestock products;
4) re-profiling of livestock industries (dairy replacement livestock for meat or livestock for pig, poultry, etc.).

Dairy farming. The release of 90Sr with milk depends on the period of lactation and productivity of animals: the higher the daily expectations, the lower the concentration of strontium in milk. If the level of contamination of milk does not allow the use of dairy products, then such milk should be used for processing into butter. In this case, feed for dairy cattle can be produced in a more contaminated area and used without any restrictions.

Meat production. In animals, Sr90 is concentrated mainly in bone tissue, so meat products are characterized by relatively low levels of radioactive contamination. Compared to milk, the content of 90Sr in the muscles of cattle is 2-5 times lower, 137Cs - about 5 times.

To reduce the concentration of 137Cs and 90Sr in meat products, diets that were least contaminated with these radionuclides should be used. An important measure to reduce the number of radionuclides in the body, in particular radiocaesium in ruminant meat, for which the half-life is only 20-30 days, should be considered the transfer of animals for a few weeks before slaughter to the most "clean" feed. In the absence of feed with low radionuclide content during this period, it is appropriate to add sorbents to the diet. But even without their addition after 2-3 months of feeding clean food, the amount of 137Cs, as a rule, decreases by 6-10 times. In combination with sorbents, the efficiency of reception increases.

For the production of meat products use for the slaughter adult animals, because the accumulation of radioactive isotopes in the body of animals depends on their age due to the different intensity of metabolic processes. Therefore, it is advisable to fatten young animals for meat for a longer time.

The most efficient livestock industry, which allows obtaining meat, 5-20 times less contaminated Sr90 than beef is pig farming. Given that the final fattening of pigs with clean feed is not an effective method of cleansing the body, when breeding them should be limited, and at the end of rearing completely exclude from the diet of contaminated feed.

Poultry farming. To reduce the radioactive contamination of chickens and eggs in the summer, poultry should be kept indoors and greens grown in the field should be included in the diet. In winter, the concentration of radionuclides in poultry products decreases even more. During this period, you should only provide the bird with complete mineral and vitamin feeds. In the production of eggs and broiler meat, the amount of 137Cs in the daily diet of poultry should not exceed 130Bq.

Farm redevelopment is one of the most radical organizational means of conducting economic activity in areas contaminated with radionuclides.

In farms located on low-fertile swampy soils with high values of **CN** accumulation and conversion of radionuclides in plants and high pollution density, even with the use of projective techniques, it is difficult to obtain milk that would meet regulatory requirements. Or the cost of implementing these techniques becomes unprofitable. In this case, it is better to convert dairy farming to meat

In areas where, due to very strong radionuclide contamination, it is impossible to keep productive animals, but labor is allowed, it is advisable to engage in breeding and rearing horses. For horses, you can use the forage resources of contaminated areas with almost no restrictions.

It is possible to conduct fur breeding without restrictions. However, in order to obtain fur with an acceptable content of radionuclides in the final period of animal husbandry, it is necessary to transfer to clean feed.

It is also possible to conduct beekeeping without restrictions, as the flower, as the last link in the migration path of radionuclides from the root, is the least contaminated organ of the plant. In addition, the **CP** of most radionuclides in honey, as the main product of beekeeping, is low.

Topic 7. Technologies and measures to minimize the entry of radionuclides into household products. Countermeasures to prevent and reduce radioactive contamination of agricultural, fishery, and forestry products.

There are three most typical situations of radioactive contamination of the territory used for agricultural purposes:

1. One-time formation of local radioactive contamination of the area during a nuclear explosion or major accidents at the enterprises of the nuclear industry and energy, which is accompanied by radioactive contamination and destruction of finished or produced agricultural products.
2. Continuous radioactive contamination of agricultural land from the atmosphere, which is slowly decreasing over time, caused by regional or widespread intense radioactive fallout (tropospheric or global fallout) caused by the release into the atmosphere of products of nuclear explosions or significant industrial emissions into the atmosphere. The difference from the previous situation is in the levels of radioactive contamination of the environment and agricultural products.

3. Residual radioactive contamination of the territory, which leads to contamination of agricultural products due to soil input of radionuclides, which is a consequence of the first or second situation.

The duration of the first situation is estimated at several days or weeks, the second - several years (until the complete removal of radioactive substances from the atmosphere).

The duration of the third situation is determined by decades and is primarily related to the rate of decrease in the soil of long-lived radionuclides 137Cs and 90Sr present in the mixture of radioactive substances. Thus, the doses of internal irradiation as a result of the penetration of 90Sr and 137Cs into biological chains and their accumulation in the human body have mainly a soil method of entry. Maintaining relatively constant levels of pollution for a long time, compared to the life expectancy of one generation of people, leads to the need to develop long-term measures to reduce soil pollution and agricultural products.

Permissible levels of radionuclides 137Cs and 90Sr in food and drinking water (DR-2004) have been developed in accordance with the Laws of Ukraine:

- On ensuring the sanitary and epidemic well-being of the population №3037-III of February 7, 2002.
- On the status and social protection of citizens affected by the Chornobyl disaster №24000-III of April 26, 2001, as amended.
- On the legal regime of the territory that was radioactively contaminated as a result of the Chornobyl catastrophe № 182/97-BP of April 4, 1997.
- On the use of nuclear energy and radiation safety № 1417-IV of February 3, 2004
- On the quality and safety of food and food raw materials №194-IV dated 24.10.2002
- On protection of a person from the influence of ionizing radiation №2397-III dated 26.04.2001
- On metrology and metrological activity № 1765-IV of 15.06.2004
- Current GOST, DSTU, guidelines of Derzhspozhyvstandart, NRBU-97 in Ukraine, taking into account the latest domestic and international achievements of science and practice in the field of radiation hygiene and radiation protection.

Numerical values of permissible levels are set based on not exceeding the effective annual dose of internal radiation of 1 mSv when consuming the average annual diet of an adult (Table 7.1).

Values of permissible levels of 137Cs and 90Sr radionuclides in basic foodstuffs and drinking water (bk • kg-1, l-1) Table 7.1

S No.	Product name	^{137}Cs	^{90}Sr
1.	Bread, bakery products	20	5
2.	Potato	60	20
3.	Vegetables	40	20
4.	Fruits	70	10
5.	Meat and meat products	200	20
6.	Fresh fish and frozen	150	35
7.	Milk and dairy products	100	20
8.	Poultry eggs	100	30
9.	Drinking water	2	2
10.	Alcohol	50	30
11.	Soft drinks	20	20
12.	Medicinal plants	200	100
13.	Fresh mushrooms	500	50
14.	Baby food	40	5

To determine the compliance of food products with radiation safety criteria, the compliance indicator (B) is used, the value of which is calculated from the results of measuring the specific activities of 137Cs and 90Sr:

$$B = \frac{A_{Cs}}{ДP_{Cs}} + \frac{A_{Sr}}{ДP_{Sr}},.$$

where ACs, ACr - the results of measurements of the specific activities of 137Cs and 90Sr in the food product; DRCs and DRSr are standards for the content of 137Cs and 90Sr in a food product.

The value of the absolute measurement error of indicator B is calculated by the formula

$$\Delta B \quad \sqrt{\left(\frac{\Delta A_{Cs}}{ДP_{Cs}}\right)^2 + \left(\frac{\Delta A_{Sr}}{ДP_{Sr}}\right)^2}$$

The food product is considered fit for use if

$$B + 0{,}6\Delta B \le 1{,}0,$$

where ΔB is the absolute error of determining the correspondence index.

After the Chernobyl disaster, standards for 137Cs content in forestry products were also introduced. The latest standards were approved by the order of the Ministry of Health of Ukraine dated 31.10.2005. № 573 "On approval of the state hygienic standard" Hygienic standard of the specific activity of radionuclides 137Cs and 90Sr in wood and wood products ". (Table 7.2). If the established standards are exceeded, the products and raw materials are subject to removal for subsequent burial.

Hygienic standard of the specific activity of 137Cs and 90Sr in wood and wood products Table 7.2

Forestry products	Admissible activity (Bq • kg-1)	
	^{137}Cs	^{90}Sr
1. Unprocessed timber		
1. Round timber		
- logs unrooted	1500	
- logs peeled	1000	
- fan raw materials, raw materials for veneer production	1000	
- lumber for industrial construction and temporary structures	1500	
- balances	1500	
- raw materials for **three-field** works (mine risers)	3000	
2. Wood for technological needs	1500	
2. Timber processed		
- unedged timber	1000	
- sawn timber	740	
- beam	740	
- parquet	740	
- blanks sawn, including for furniture production	740	
- blanks sawed for europallets	1500	
- tare board, tare beam	1000	
3. Cultural and household products		
- firewood fuel, fuel bundles	600	60
- fence	1000	
- souvenir products	740	
- household products (cuttings, kitchen boards, etc.)	740	

Purification of crop and livestock products from radionuclides using primary technological processing

Measures to prevent the entry and accumulation of radionuclides in agricultural plants and tissues of agriculturally productive animals may be ineffective under certain conditions, and therefore their content in the resulting products may exceed acceptable levels. However, this does not mean that such products should be destroyed. In some technological processing, which involves its division into several components, it may be found that the vast majority of radionuclides are concentrated in only some of them. Often such a component is not the main, but a by-product of processing. It should also be borne in mind that radionuclides enter plants, enter the body of animals, and are transported through tissues mainly in the form of water-soluble substances. Therefore, they are concentrated mainly in the aqueous part of the product and pass during processing to an aqueous solution. As a result, any technological processing of products, which involves the separation of water by extraction, filtration, centrifugation, and other means, but not drying and concentration, will lead to its decontamination.

Consumable products for agricultural production in the contaminated area can be obtained:

the choice of the most expedient means of processing and processing of production, accepted in ordinary practice;

- application of special means of processing and processing of production;
- changing the methods of disposal of intermediate products.

Purification of crop products. There are fairly simple methods of cleaning some types of crop products, and complex technologies that can only be implemented under industrial conditions.

Grain. As a result of cleaning the grains of cereals and cereals, flour, cereals contain 1.5-2 times fewer radionuclides than the harvested grain. Therefore, the higher the grade of such products, bakery products, the lower their content of radioactive substances. Waste from grain processing (bran) can be used in animal husbandry, especially when fattening cattle for meat.

Grain with a level of contamination higher than the allowable one can be used for the production of alcohol according to the usual technological schemes, fodder yeast, and a number of other technological products. In the processing of any carbohydrate products of crop and fruit growing into ethyl alcohol, almost all radioactive substances, as well as non-radioactive, remain in the fermentation medium. The product obtained by distillation is a thousand times more than the original material.

Vegetables. Because mineralized films and shells of tubers, roots, bulbs, and other vegetables, which often end up on the consumer's table without any cooking, can be contaminated with soil particles, they contain a lot of calcium and potassium salts, and with them, respectively, strontium and cesium. , rinsing with water, thorough deep cleaning can significantly reduce the number of radionuclides in them. When cleaning, keep in mind that the most contaminated parts of the roots are the head and tip, the head of cabbage - the head, the bulbs - the bottom, the salad species - the basal parts.

Preservation of vegetables by methods using soaking in brines, or cooking significantly reduces the concentration of 90Sr in them (for example, when salting cucumbers in brine passes 60-80% strontium, and when cooking cabbage - up to 49%).

A very high degree of purification of products can be achieved by processing radionuclide-contaminated potatoes into starch. The technology of starch extraction involves grinding the tubers, followed by the separation of cell juice and extraction of starch grains by washing with water. During these operations, the vast majority of radionuclides are removed with water, and the resulting product - polysaccharide starch contains them on average 50 times less than the potatoes themselves. In a similar way, after pre-soaking in water, starch is extracted from cereal grains.

Multiple contaminations with radionuclides in comparison with vegetable crops are permissible for sugar beets. The technology of obtaining sugar consists of grinding the roots into thin chips and then washing it with hot water, to which all the radionuclides pass together with the sugar. But the subsequent operations of removal and purification of sugar - defecting, saturation, sulfonation, evaporation, filtration, boiling, and, finally, crystallization, the so-called "white sugar" with the number of radionuclides 50-70 times less than in roots.

An extremely high degree of purification of products from highly contaminated with radionuclides plants is achieved by obtaining vegetable oils from sunflower seeds, flax, hemp, and other plant species. The technology of obtaining oils involves such operations as squeezing the liquid fraction, extraction of fat, its distillation, and purification. The main operation - extraction of fats is carried out using organic solvents in which 90Sr, 137Cs, and other radionuclides are insoluble. And already at this stage, it is possible to obtain a virtually pure from radioactive substances intermediate product, which in the course of subsequent distillation and purification by settling, filtration, hydration, and especially refining, is brought to an extremely high degree of purity.

When processing flax and hemp to obtain fiber, the usual methods of processing straw can remove with trust up to 80% of the contaminants contained in the plants. Additionally (99%) the fiber can be cleaned by washing with a weak solution of hydrochloric acid.

Purification of livestock products. The concentration of radionuclides in livestock products can also be significantly reduced due to its processing or treatment.

Milk. If the level of contamination of milk does not allow it to be used directly for food purposes, milk can be used to prepare the butter. After separation of whole cow's milk, only 8-16% of 90Sr, 131I, and 137Cs remain in the cream, and the rest goes to the milking. Washing the cream twice or three times with warm water and skim milk reduces the amount of 90Sr in them by another 50–100 times. When processing cream into butter, a significant part of radionuclides goes to buttermilk and wash water. The amount of 90Sr, 131I, and 137Cs in butter is reduced to 35, 75, and 50%, respectively, their concentration in the cream. Remelting the oil allows you to remove almost completely 90Sr and 137Cs. Due to the short half-life of 131I (8 days), keeping the contaminated oil in the refrigerator for 40-50 days allows waiting for its almost complete disappearance within the allowable storage time of the product. This technique was widely used in the spring of 1986, which avoided large losses of milk.

Processing of milk into low-fat cheese leads to a decrease in the content of 90Sr and 137Cs by 90%, and 131I - by 70%. Therefore, there is no doubt that it is advisable to produce some products from milk contaminated with radionuclides, especially cream and butter.

- Other means by which milk can be purified from radionuclides without significantly changing its chemical composition and properties:
- - use of strontium-binding pyrophosphates;
- - use of ion exchange resins;
- - purification of milk from 137Cs by sorption on ferrocene;
- - electrodialysis method of milk purification.

Meat. Before using meat for food purposes it must be preceded by the carving and removal of bones if the level of contamination is greater than the permissible values.

It is possible to reduce the number of radioactive substances in meat several times by prolonged (10-12 hours) rinsing it in running water, soaking in 0.8-1% solutions of table (table) salt, followed by rinsing. Soaking the meat in water acidified with acetic and citric acids is quite effective. The degree of purification of meat depends on the size of the pieces, the duration of soaking, the number of treatments, the reaction of the environment, and finally, the degree of contamination, the chemical nature of the radionuclide.

Cooking, which consists of boiling meat, is a very effective way to clean it. Bone digestion has almost no effect on the content of 90Sr, which, like calcium, is included in their structure and passes into the broth only 0.01-0.2%. The process of cooking veal in the broth goes up to 60% 90Sr and 137Cs, and after adding to the water citric or lactic acid - up to 75-85%. About the same amount of these radionuclides go into the broth when cooking chicken. In this case, half of the radionuclides pass into the broth in the first 10 minutes, but then with increasing time the rate of release of the radionuclide decreases, and this first portion of the broth without much regret can be discarded. When the lard is reheated, more than 95% of 137Cs remains in the greaves, as a result of which its amount in rendered fat is reduced by 20 times.

To assess the degree of reduction of the radioactivity of products due to the use of certain techniques, there is *a coefficient of purification of products* (PPC) *from radionuclides*, which *is determined by the ratio of specific radioactivity obtained by processing or processing of the product to specific radioactivity of raw material*. In fact, it is a kind of transition factor . In the table. 7.3 shows the values of the PPC, which can be obtained after the application of some culinary treatments and technologies.

Influence of culinary treatments and food technologies on the purification coefficient (PPC) of meat (beef, pork, lamb) from 137Cs (**L.O. Matola, M.L. Dolgiy**, 1993)

Methods of processing of production	**Coefficient of clearing of production** (PPC)	**Methods of processing of production**	**Coefficient of clearing of production** (PPC)
Baking	0,5-0,8	Salting	0,05-0,9
Cooking	0,25-0,5	Marinating	0,1-0,3
Stewing	0,5-0,6	Canning	0,5
Roasting	0,5-0,8	Sausage production	0,25-0,95
Pickles	0,1-0,6		

With regard to fish, it should be borne in mind that the body of fish (especially predators, collects and accumulates radioactive substances from the reservoir. reservoirs, the water of which is used for drinking or watering animals.

The system of the considered measures at their full or partial application does not give a simple arithmetic summation of radioprotective effects. However, it allows many times to reduce the accumulation of radionuclides by agricultural plants and in the body of farm productive animals and even on highly contaminated soils in most cases to obtain products that meet radiation safety requirements, significantly reduce the collective radiation dose of the population living in contaminated areas.

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Appendix 1. The ratio between units of the dose of ionizing radiation

Measure, its designation	Unit, designation		Relationship between units
	SI	Off-systemic	
The activity of radionuclides, A.	becquerel (Bq)	curie (Ci)	1 Ci = $3.7 \cdot 10^{10}$ Bq
Exposure dose of photon radiation, Dexp	coulomb per kilogram (C/kg)	rontgen (R)	1 P = $2.58 \cdot 10^{-4}$ C/kg
The power of the exposure dose of photon radiation, Pexp	ampere per kilogram, (A/kg)	rontgen per second (R/s)	1R/s = $2.58 \cdot 10^{-4}$ A/kg
Absorbed dose of radiation, D	gray (Gy)	rad (rad)	1 rad = 0,01Gy
The power of the absorbed dose of radiation, Pabs	gray per second (Gy/s)	rad per second (rad/s)	1 rad/s = 0.01Gy/s
Kerma, K.	gray (Gy)	rad (rad)	1 rad = 0,01 Gy
Equivalent (effective) radiation dose, H_T(E)	sievert, (Sv)	rem (rem)	1 rem = 0.01Sv
The power of the equivalent dose of radiation, $P_{H(E)}$	sievert per second, (Sv/s)	rem per second (rem/s)	1 rem/s = 0.01 Sv/s
Collective effective (equivalent) dose, D	man-sievert, (man- Sv)	man- rem, (man- rem)	1 man-rem = 0,01man-Sv

Appendix 2. General Safety Procedures for Using Radioactive Materials [16]

1. Work with radioactive materials will only be conducted in laboratories that have received a permit for using radioactive materials, and only by personnel authorised for work with radiation. The work will be conducted according to the terms of the permits issued to the worker and for the laboratory.

2. Any departure from the terms of the above permits requires prior approval of the Radiation Safety Unit.

3. Every worker with radioactive materials will maintain an accurate written record of all work done with radioactive materials. The record will include: date, type of material, activity, and special occurrences.

4. In the laboratory where radioactive materials are in use, every worker will wear a lab coat at all times.

5. A worker coming in contact with radioactive materials, or using instruments that comes in contact with radioactive materials, will wear disposable gloves. The gloves must be changed as frequently as possible.

6. Before work commences, the work area must be prepared: absorbent papers must be spread out on the lab tables and trays padded with absorbent material must be prepared. All activities involving radioactive liquids must be carried out in these trays.

7. The work area must be clearly labelled with "RADIOACTIVITY" stickers. These can be obtained from the Radiation Safety Unit.

8. Receptacles for disposal of liquid and solid radioactive waste must be prepared. In laboratory using P-32 , Rb-86 , Na-22 or any other high energy beta or gamma emitters , a proper shielding must be prepared.

9. It is most desirable to reduce the quantity of radioactive material in use to a minimum.

AS MANY STAGES OF THE WORK AS POSSIBLE SHOULD BE CONDUCTED IN A FUME-HOOD. WORK WITH THE "MOTHER SOLUTION" (THE ORIGINAL HIGH-CONCENTRATE) MUST ALWAYS BE PERFORMED IN A FUME HOOD.

11. When work is performed with materials emitting high-energy Beta radiation or Gamma-radiation (such as: P-32, I-125, Cr-51, Rb-86, etc.), a portable radiation detector must be at hand. The detector must be suited to the type of radiation and the type of materials being tested. In any doubt exists, consult the Radiation Safety Unit. **It is forbidden to start working if there isn't a proper detector at hand!!!!**

12. In work with materials emitting Beta or Gamma-radiation that can be detected by a portable detector (P-32, I-125, Cr-51, Rb-86, etc.), the worker must check him or herself and the work area as frequently as possible with a suitable detector. The worker must perform a check on him or herself and on the work area before leaving the laboratory and on completion of the work! At the

end of the workday, all personnel who were present in the laboratory must be checked even if they did not use radioactive materials.

13. In using materials emitting Beta-radiation that cannot be detected by a portable detector (Ca-45, S-35, C-14, H-3, etc.), “smear” tests of the personnel and the work area must be performed as frequently as possible! (swabbing the tested area with a moist piece of paper , inserting the paper into a scintillation detector and a radiation count by a suitable device; at the same time a count is made of a clean piece of paper to establish the background level.)

CHECKS MUST BE PERFORMED ON WORKERS AND THE WORK AREA BEFORE LEAVING THE LABORATORY AND ON COMPLETION OF THE WORK! THE FACT THAT THESE MATERIALS **ARE DIFICULD TO DETECT DOSE NOT MAKE THEM LESS DANGERUS!!**

14. It is forbidden to smoke, eat or drink, or to use cosmetics in the laboratory. Food must not be stored, drinks must not be prepared , nor utensils for food and drink kept, in the laboratory.

15. **Operations that involve the use of the mouth, such as taking up liquids with a pipette, are prohibited in a radiation laboratory. This regulation applies to all personnel in the laboratory, and on all types of work including using non-radioactive materials!**

16. It is best to use disposable utensils as much as possible. In any event, utensils used with radioactive materials must be kept separate from the other utensils in the laboratory.

17. All equipment that comes in contact with radioactive materials (furniture, utensils, laboratory utensils, etc.), must be labelled by a “radioactive” sticker. Such equipment must not be transferred to another laboratory, or sent for repair in or outside the University without inspection by and approval of the Radiation Safety Unit. Equipment must only be used for its stated purpose.

18. Personnel who have received a radioactivity badge must wear it at all times in the laboratory.

19. In every case of radioactive contamination of a worker, his or her clothing, or the work area, or of a suspicion of the spread of such contamination, and in the event of any mishap, the Radiation Safety Unit must be informed at once—see regulations for dealing with mishaps.

20. Non-disposable towels or wipes must not be used in a radiation laboratory, and solid bars of soap are prohibited. Hands must be thoroughly washed each time you leave the laboratory!!

21. Upon completion of work, radioactive waste must be taken to the collection point. All utensils that have come in contact with radioactive materials must be taken to the washing point. RADIOACTIVE WASTE MUST NOT BE ACCUMULATED IN THE LABORATORY! LIQUID WASTE MUST NOT BE DISPOSED OF DOWN THE DRAIN INTO THE SEWER SYSTEM! Radioactive waste must be dealt with according to the appropriate regulations.

22. Radioactive materials must not be left unattended on worktables, or anywhere else open to unauthorised personnel.

23. Radioactive materials can be stored in a refrigerator, cupboard or fume hood, on condition that the storage unit be kept locked and labeled.

24. A Radiation Safety technician is entitled to enter any laboratory at any time to inspect the laboratory or the personnel. A Radiation Safety technician is entitled to stop any work involving radioactive materials, radiation sources, or radiation emitting devices, if there is any deviation from the safety regulations or danger to the personnel and/or the surroundings.

25 A female radiation worker who becomes pregnant must inform the Radiation Safety Unit as soon as possible. The head of the unit will give written approval of continuation of work with radiation, or will set limits according to the safety regulations (according to female personnel regulations, 1979).

26. It is forbidden to bring students under the age of 18 to work or to study in a radiation laboratory without special permission from the head of the Radiation Safety Unit.

27. Before starting using radioactive materials, the worker must practice and thor-oughly prepare all the necessary equipment. Every stage of the experiment must first be practised without the use of radioactive materials. The head of the laboratory must teach a new worker on the laboratory procedures including safety procedures. A new worker must get permission from the head of the laboratory before starting working in the laboratory.

28. The first performance of experiments must only be carried out under the close supervision of the head of the laboratory and of the Radiation Safety Unit. Personnel must obtain permission from the laboratory head before using radioactive materials.

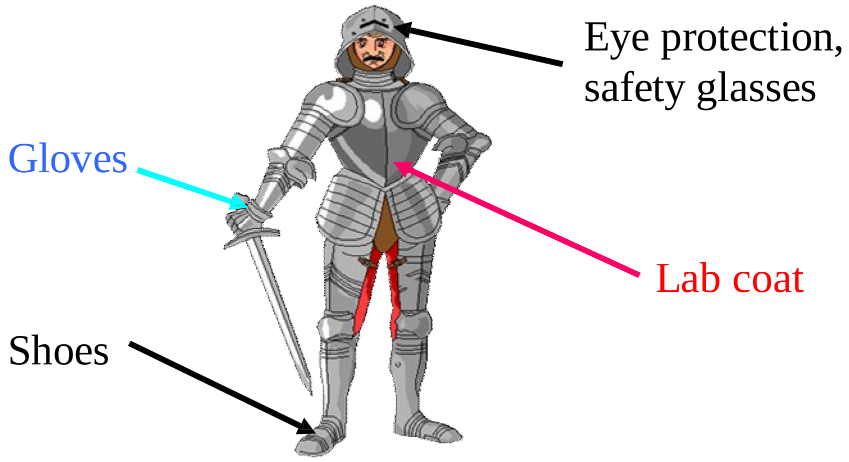
29. A radiation worker must be familiar with the properties of any radioactive material and compounds he or she uses (radioactive properties but also chemical and physical properties). For example, a worker using tritium must know that there is a difference in the level of risk between water labelled with tritium and thymedine labelled with tritium. Equally, every worker must be familiar with any physical change that may occur when working with the material, such as the emission of gas or the production of volatile compounds. IN ANY EVENT, TO WORK WITH RADIOACTIVE MATERIALS OR COMPOUNDS WITHOUT KNOWING THEIR PROPERTIES IS PROHIBITED.

30. Radioactive materials can only be ordered according to the appropriate regulations**.** A WORKER WHO HAS TAKEN DELIVERY OF A RADIOACTIVE MATERIAL IS RESPONSIBLE FOR IT AND MUST NOT TRANSFER A RADIOACTIVE MATERIAL TO ANOTHER WORKER WITHOUT PERMISSION OF THE RADIATION SAFETY UNIT. INTRODUCTION OF RADIOACTIVE MATERIALS TO THE UNIVERSITY EXCEPT VIA THE RADIATION SAFETY UNIT IS PROHIBITED.

31. The permit issued to personnel for use of radioactive materials applies strictly and **only to liquids**. Experiments using radioactive powders or gases are prohibited without the special approval of the Radiation Safety Unit.

32. The most important general rule regarding using radioactive materials is that safe methods of performing the work should be planned in advance. Mishaps occur when we try to improvise or when, for various reasons, we are pressed for time. Pre-planning will help to eliminate mistakes or accidents.

Note :These guidelines are only general. Detailed regulations governing each aspect of work with radioactive radiation, materials, sources, and radiation-emitting devices, are given further on in this handbook: You will also find pages of data and work procedures for most of the radioactive materials commonly in use at the University. You can apply to the Radiation Safety Unit on any topic concerning radioactive radiation.



Personal protecting

Appendix 3. Information Sheet and Regulations for Working with Phosphor (P-32) [16]

Physical half-life	14.3 days
Effective half-life	13.5 days
Type of radiation	Beta β
Radiation energy	1.71 MeV maximum, 0.69 MeV average
Risk level	Medium
Maximum activity	0.1 mCi

THE STRENGTH OF RADIATION EMANATING FROM THE OPENING OF A FLASK OR BOTTLE CON-TAINING 1 mCi IS 26 R/HOUR. THIS IS VERY HIGH AND MERITS ATTENTION TO THE DANGER OF EXPOSURE TO EXTERNAL RADIATION

Maximum range	through air – 6 meters in water – 8 mm.
Required shielding	Working with quantities of up to 1mCi, Perspex of about 12mm. in thickness can be used. For larger quantities, a lead sheet of at least 3 mm. Should be added.

General: in addition to the danger of internal exposure to radiation (as a result of the penetration of the body by radioactive material), there is a danger of external exposure. The long range of the radiation through the air and the high level of its energy require measures to reduce external exposure. Strict attention to the safety regulations will avoid unnecessary exposure.

Work Procedures

1. Work will only be performed by personnel and in laboratories authorised to use P-32. The regular permit only applies to use of the material in liquid form. All work with volatile or gaseous radioactive materials (or where there is a possibility of the escape of gas during an experiment), requires a special permit from the Radiation Safety Unit.

2. The work will be performed according to all the safety regulations applying to radiation as published in the Ben-Gurion University Radiation Safety Handbook.

3. A liquid radioactive material must always be transported from room to room or inside a room in a tray lined with absorbent material.

4. It is advisable to use as small a quantity of a radioactive material as possible.

5. Personnel must wear lab coats, closed shoes and gloves throughout the period of work with the material. The gloves must be checked and changed as often as possible.

6. Eating, drinking and smoking in the laboratory are prohibited! The use of the mouth to take up liquids (by pipette, etc.) is prohibited. Special means must be adopted to take up liquids.

7. Personnel must check themselves and the work area as frequently as possible with a suitable detector. In particular, before leaving the laboratory and at the end of the workday. In work with P-32, tests should be carried out with a suitable detector (Geiger counter). The device must be at hand throughout the work. Gloves, equipment, clothes, the floor and the work area must all be checked. Where necessary, “smear” tests should also be performed.

8 Waste must not be accumulated in the laboratory. At the end of an experiment or a work day, waste must be taken to a waste room. Liquid radioactive waste must not be poured down the drain!! Both solid and liquid waste from P-32 are significant sources of radiation because most of the radioactive material becomes waste. Waste must not be accumulated in the laboratory. Both solid and liquid waste must be placed inside suitable Perspex shielding.

9. All equipment that comes in contact with radioactive materials must be labelled with a “radioactive” sticker, and the work area must be suitably labelled.

10. Any mishap or suspicion of mishap must be reported immediately to the Radiation Safety Unit.

11. You must know the radioactive and chemical properties of any material or compound before starting to use it.

12. The follow-up of internal exposure to/absorption of radioactive materials is performed by means of urine tests. Urine samples must be supplied as requested by the Radiation Safety Unit.

13 Work with the “mother solution” (high concentration) must be performed in a fume hood and behind Perspex shielding. The flask or bottle containing the mother solution must remain inside a lead pot. You must not use an exposed flask. You must not work over an open flask that contains material of high concentration. The initial opening of a flask containing material of high concentration must be done with great care. Remember that the inner surface of the cork/cap is highly contaminated.

Even when using small quantities of P-32, Perspex shielding is mandatory.


14. When taking out the flask or bottle containing the stock of radioactive material is unavoidable , laboratory tongs must be used (the flask must not be

hand held) together with suitable Perspex shielding. Take as short a time to transfer the flask as possible.

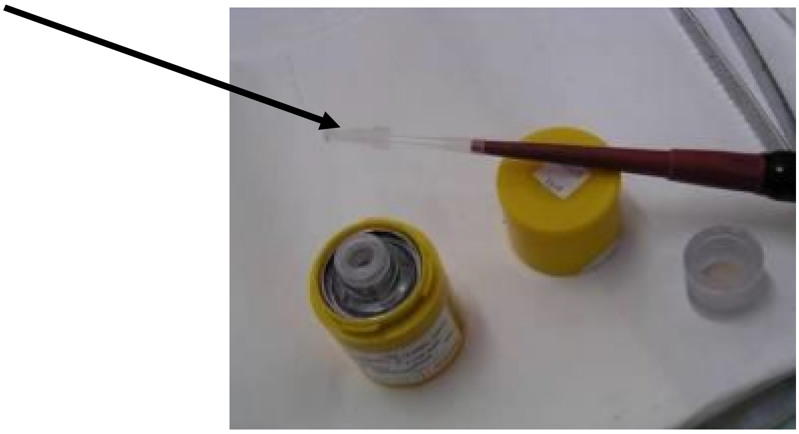
15. Some of the suppliers of P-32 have designed the lid of the lead pot to open the cap of the flask with no exposure of the hands (NEN Ltd. for example). Other companies use a Perspex cap to reduce the amount of radiation.

16. The taking up of liquids from a flask or bottle containing the stock of radioactive material must only be performed with an automatic pipette and not with a syringe or any other method that must be held close to the radioactive material.

17. Washing of utensils will be carried out in accordance with the regulations for washing utensils. In any event, you must check any utensil before washing it. Contaminated utensils must not be washed in the sink. Any utensil that was tested by a detection device and gave a result above the background level must be immersed in cleaning fluid (which must then be disposed of via the radioactive waste).

18. When experimenting with P-32 in quantities above 0.5 mCi, personnel will wear a badge for surveillance of external exposure to radiation.

19. When you buy p-32 from Amersham that is supplied at room temperature a spill guard is inserted inside the vial. The first user must remove it to the solid radioactive waste .This must be done very carefully and only by experience workers. Prepare a pipette with a tip, insert the tip into the spill guard and remove it.



Appendix 4. List of reductions

ALZ - accident localization zone
BA - beyond-design basis accident
BSR - Basic sanitary rules
BWR - boiling water reactor
DLE - effective dose limit
DS - decontaminative solution
HWR - heavy water reactors
IAEA - International Agency from nuclear energy
IDC - individual dosimetric control
IE - initial event
INES - International Nuclear Event Scale
IR - ionizing radiation
LMFBR - liquid metal fast breeder reactor
LRW - liquid radioactive wastes
LWR - light water reactor
NFP - nuclear fission products
NPP - nuclear power plant
PA - project accident
PWR - pressurized-water reactor
RA - radiation accident
RAW - radioactive waste
RHO - radiation hazardous object
RN - radionuclide
RS - radioactive source
RSSU - Radiation Safety Standards of Ukraine
RW - radioactive waste
RWD - RW disposal (ground of burial place of radioactive wastes)
SIR - sources of ionizing radiation
SN F - spent nuclear fuel
SPZ - sanitary protection zone
SS - safety system
TA- technical accidents
TLD - thermoluminescent dosimetry

Навчальне електронне видання

ГЕРАСИМОВ ОЛЕГ ІВАНОВИЧ
АНДРІАНОВА ІРИНА СЕРГІЇВНА

РАДІАЦІЙНА БЕЗПЕКА

Підручник
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