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INDUSTRIAL HYGIENE

Tutorial

Tomsk
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The tutorial on Hygiene is prepared in accordance with the Federal State Educational Standard of Higher Professional Education, for medical students. The textbook includes the main topics for practical classes on "Industrial hygiene" and reviews hygienic significance, pathogenic effects, methods and equipment for measurements, regulation and prevention of professional pathology regarding such industrial factors as – dust, harmful chemicals, noise, infrasound, ultrasound, vibration, ionizing radiation. The textbook also reviews the concepts of severity and intensity of work, methods for their assessment, pathogenic role and principles of regulation of harmful working conditions, the concept of fatigue and its prevention. In presenting the material, the current regulatory documents – State Standards, SNiPs and SanPiNs were used.

Reviewer:

Docent of Hygiene Department SSMU, PhD, Nagorniak Yu.G.

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ГИГИЕНА ТРУДА

Учебное пособие

**Томск
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Учебное пособие подготовлено по дисциплине «Гигиена» в соответствии с ФГОС высшего образования и предназначено для студентов, обучающихся по основным профессиональным образовательным программам высшего образования – программам специалитета по специальностям «Лечебное дело». В пособие включены основные темы практических занятий по разделу «Гигиена труда»: гигиеническое значение, патогенные эффекты, методы измерения, нормирования и профилактики профессиональной патологии, в отношении таких производственных факторов, как – пыль, вредные химические вещества, шум, инфразвук, ультразвук, вибрация, ионизирующее излучение. Рассматриваются понятия тяжести и интенсивности труда, методы их оценки, патогенная роль и принципы нормирования вредных условий труда, утомление и его профилактика. При изложении материала использованы действующие нормативные документы – ГОСТы, СНиПы и СанПиНы.

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1. DUST AS A HARMFUL FACTOR OF INDUSTRIAL ENVIRONMENT. METHODOLOGY FOR HYGIENIC EVALUATION OF INDUSTRIAL DUST

Purpose of the lesson: is to master knowledge about hygienic significance of industrial dust, its effects on the body; as well as the methods for hygienic regulation and evaluation.

Practical skills: mastering how to give an opinion about degree of the air pollution with industrial dust and to develop measures preventing occurrence of dust-associated occupational diseases.

Task for students:

1. To study hygienic value of industrial dust, its effect on the body and measures to protect workers from its harmful effects.

2. To get acquainted with equipment for air sampling, methods of investigation of dust, with hygienic regulations of this factor.

3. To determine the level of dust in the air (situational tasks); to give a hygienic assessment and make a list of preventive measures.

Theoretical part. Industrial dust is the most common harmful factor and the main cause of occupational diseases (~37%), most of which (60%) are diagnosed at the later stages when it is required to acknowledge disability health status of the workers. In practical activity, doctors need to focus on the early manifestations of dust-associated diseases in workers. Also we should not forget about a possibility of adverse effects of dust on the health of people living in the impact zone of industrial facilities. This requires ability to properly collect the eco-professional history, analyze emerging situations and plan for preventive and recreational activities.

Industrial dust is found in almost all industries and most of all in agricultural activity. Formation of dust occurs at all stages of mining and minerals processing (blasting, drilling, loading, transportation, crushing, grinding of rock), in production of building materials (brick, cement, refractory products), in porcelain, faience, chemical industry, in mechanical engineering (knocking out, stripping, blowing molds in foundries, polishing and polishing products in mechanical shops), in metallurgy (electric welding, plasma metal processing, etc.), with incomplete combustion of fuel, in textile industry, agriculture (plowing, tillage and fertilization, use of powdered pesticides, cleaning of grain, seeds, cotton, linen); in food industry (mixing, packing and packaging of bulk materials) and so on.

Millions of people are exposed to industrial dust, in them a variety of diseases can develop, including professional dust-associated diseases of the respiratory system. Beyond that, dust disables equipment, reduces quality of products, causes spoilage in the production of extremely clean materials, reduces illumination of work premises, carries away valuable materials with emissions, may cause explosions.

The concept and classification of industrial dust. Dust is the physical state of a solid substance, crushed into tiny particles. This is an aerosol, where the dispersing phase is a solid particle, and the dispersing medium is the air. It is characterized by a set of properties that determine its behavior in the air, the possibility and level of penetration into the respiratory tract, transformation inside the body and eventual impact on.

From the standpoint of occupational health, industrial aerosols are primarily classified according to the qualitative composition (origin), mechanism of formation, particle size (dispersion) and the nature of impact on the organism (***tab. 1***).

Hygienic significance of physical and chemical properties of dust. Physical and chemical properties of industrial dust are very diverse, but such indicators as chemical composition, dispersity, solubility, form, adsorption capacity, electric charge, explosiveness, radioactivity, and also structure, hardness and density are of the greatest hygienic importance.

The chemical composition of dust determines its biological effects in the body, specifically: fibrogenic, irritant, toxic, allergenic, carcinogenic, radioactive, photosensitizing and infectious.

An action of dust species that have a toxic, allergic, photosensitizing and carcinogenic effect is a resorptive chemical process, i.e., the transition of solid dust particles to a liquid tissue medium as a result of dissolution or extraction by chemical interaction with biological substrates. These types of dust are referred to industrial poisons (for example, dust of pesticides, lead, cadmium, etc.). Dust, having radioactive elements in its composition or on the surface, has an ionizing effect.

Mineralogical composition of dust is of primary importance for the development of dust-associated respiratory diseases, especially the content of silicon dioxide or silica (SiO_2), which is about 28% of the earth's crust in the form of quartz (free silica) and silicates (salts of silicic acid containing bonded silica). The presence and percentage of free silica in the dust determines degree of its fibrogenicity, whereas the solid particles

Table 1

Industrial dust classification

By composition	**By mechanism of formation**	**By dispersity, µm (10^{-6}meters)**
I. Organic *Natural:* • vegetable (wood, cotton, flax, cereals, etc.) • animal (woolen, fur, leather, bone, etc.) • microorganisms and the products of their decay *Artificial:* • plastics, rubber, resins, dyes and other synthetic products **II. Inorganic mineral**: • quartz, silicate, asbestos, cement, etc. Metal: zinc, copper, iron, lead, etc. **III. Mixed** *Mineral/metal:* • iron, silicon, etc. *Organic and inorganic:* • dust of cereals and soil, etc.	**I. Disintegration aerosol (dust) results from:** • mechanical grinding, crushing and breaking of solids (drilling, grinding, blasting); • transportation and packaging of bulk materials; • machining of products (cleaning of casting, polishing, grinding, etc.) **II. Condensation aerosol (smoke) results from:** • thermal processes of sublimation of solids (melting, casting, electric welding) due to evaporation, cooling and condensation of vapors of metals and non-metals, including polymeric materials; • chemical high-temperature gas reactions leading to formation of solid products (from silicon oxide when silica is heated up to 1350°C, silicon dioxide is formed)	• Visible (10–1000) • Microscopic (0.25–10) • Ultramicroscopic (0.001–0.25)

themselves incur pathological effect on tissues and especially it is so with respect to phagocyte cells.

Dispersity of dust particles determines their stability in the air and also possibility and depth of penetration into the respiratory tract. The sizes of dust particles vary in a very wide range and the smallest to largest particle size is compared relatively. Particles larger than 10 µm (up to 1000 µm) precipitate rapidly from the air and are retained in the upper respiratory tract by inhalation. Microscopic size particles (0.25–10 μm) are more stable in the air; they penetrate into the alveoli by inhalation, mainly of the size of up to 5 μm (respirable fraction). Ultramicroscopic particles (less than 0.25 microns) stay for a long time in the air and during respiration up to 60–70% of these particles are retained in the lungs. Despite the large specific surface area, their role in development of dust pathology is negligible, since their total mass is small. With a very high degree of grinding of the substance (up to 2 μm), its effect as a dust on the pulmonary tissue is weakened by the increase of solubility and the reduction of retention in the lungs, but the toxic effect is increased, as their chemical activity and sorption capacity increase.

As a rule, a disintegration aerosol has polydisperse properties, that is, dust particles of different sizes are contained in the air. Most often, dust particles with a size of 10 μm or more make up about 10%, from 9 to 2 μm – 15–20% and less than 2 μm – 60–80% in the structure of dust. At the same time the mass of dust particles of less than 2 μm does not exceed 1–2% of the total mass of the dust. Dispersion of condensation aerosols is more monotonic and is determined by conditions of the dust formation.

Dispersion of dust determines nature of such physiological processes as mucus secretion, activity of ciliary cells of bronchial epithelium, activity of phagocytes, and extent of elimination of particles from the respiratory tract.

In addition, it was found that degree of fibrogenic action of dust depends on the particle size. With increase in dispersion, degree of biological aggressiveness increases to a certain point, and then decreases. The greatest fibrogenic activity is observed in disintegration aerosols with the size of the dust particles from 1 to 5 μm, and condensation aerosols with the particle size of less than 0.3 μm.

At present, after implementation of nanotechnology in various industries, a significant number of workers can be exposed to nanoparticles sized from 1 to 100 μm.

Regardless of the way they are synthesized from individual atoms ("from the bottom up") or from the material ("top to the bottom"), nanoparticles can incur unique reactivity due to changes in physical, chemical and biological properties. The questions of impact of such structures on human health and safety require conduction of special studies in order to develop hygienic criteria and norms for assessing the level of occupational risk related.

Solubility of dust in water and tissue fluids depends on the chemical composition and can have both a positive and negative effects. If the dust is not toxic and its effect is limited to mechanical irritation of tissues, good solubility facilitates the rapid removal of it from the body. In case of toxic dust exposure, good solubility is accompanied by its more intense negative action (dust of lead, cadmium, copper, etc.). Moreover, highly disperse dust of certain substances (beryllium, nickel, ursol, etc.) causes more rapid specific manifestations and allergic reactions.

Dust particles morphology depends on the mechanism of their formation and can be different: spherical, plane, irregular. In condensation aerosols dust particles usually have "fused" round shapes in the form of a ball or cube, easily settle out of the air, but also penetrate easily into the lung tissue and better undergo phagocytosis.

Disintegration aerosols – irregularly shaped particles (flat, split, needle, radiant, fibrous, spiral, etc.) last longer in the air even at larger sizes and are more difficult to penetrate into the deep lungs. Getting on the mucous membranes of the upper respiratory tract and eyes, on the skin, the particles with sharp edges (asbestos, fiberglass, mica, charcoal) incur irritating and traumatic effect.

The adsorption properties of dust depend on the dispersion and total surface of the dust particles. Thus, for example, grinding of 1 cm^3 of solids to 0.1 μm particles increases its total surface from 6 to 600000 cm^2, that is, 100000 times.

On their own surface dust particles can sorb gases, vapors, radioactive substances, ions, as well as free radicals, which are formed during combustion, under the influence of radioactive radiation and as a result of the photochemical action of light.

So, coal dust sorbs molecules of carbon monoxide and carbon dioxide, methane; dust from blast furnace gas adsorbs carbon monoxide. Inhalation with dust of irritating and toxic substances intensifies the harmful effect of dust. In addition, dust can be a carrier of microbes, fungi, mites, helminth eggs. Pulmonary forms of anthrax are described in workers who inhale dust of wool. There is a well-known relationship between dustiness of the air and pulmonary tuberculosis, including so-called silicon-associated tuberculosis. Some types of dust (flour dust for example) can be nutrition medium for a number of bacteria.

Flammability and explosiveness of dust are directly related to the specific surface area of the substances dispersed and degree of their chemical activity. In order for explosion and ignition to occur, the dust cloud of sufficient concentration ("dust cluster") consisting of the dust particles, absorbing the air oxygen, and an open flame or even an accidental spark are required. Explosive properties are inherent for different types of dust (aluminum, zinc, etc.), but organic dust (coal, cork, sugar, flour, starch, powdered cocoa, powdered milk, etc.) can be especially explosive. Formation of the dust cluster can occur gradually as a result of accumulation of dust in the air and the raising of the dust settled.

Almost all dust particles have an electric charge, which they acquire as a result of friction of a substance with the surface of machines, friction and collision with each other, or absorption of the atmospheric ions. Disintegration aerosols have a larger charge than the condensation aerosols. A different charge of particles contributes to rapid conglomeration and precipitation from the air, and the same charge determines the stability of the aerosol. Dust of metals and basic oxides has a negative charge, and nonmetals and acid oxides – a positive one. It is established that electronegative particles more easily undergo phagocytosis, whereas in the respiratory organs positively charged particles (70%) are mostly retained.

Dust impact on human body. Not all dust particles entering the respiratory tract reach the lungs: some of it is retained in the upper respiratory tract, primarily in the nasal cavity. Hairs of the nasal mucosa, sinuous nasal passages, sticky mucus, covering the membrane, ciliated epithelium of the nasal mucosa are excellent barrier mechanisms that change the speed of the air stream along the airways and trap dust particles. Similar mechanisms work in the middle sections of the airways: glottis, bifurcation and bronchial peristalsis, phagocytosis on the surface of the mucous membranes. Normal functioning of these mechanisms provides retention of 50–90% of the dust inhaled, a significant part of which is released back during sneezing, coughing and expectoration.

However, for the upper respiratory tract, prolonged and constant inhalation of significant concentrations of dust does not pass without a trace. Acute inflammatory hypertrophic processes in them at initial stages of dust exposure (rhinitis, nasopharyngitis, tracheitis, etc.) are gradually replaced by sub-atrophic and atrophic pathological changes in the mucous membranes of the nose, pharynx, larynx, trachea, and bronchi. In this case, both the suction and excretory functions of the mucous membranes are disturbed, the sense of smell is reduced, etc. Workers in some industries (cement plants) may have stones in the nasal mucosa (rhinolites). In those contacting with chromium, fluoride, arsenic, necrotic processes can develop, manifested as ulceration, nose bleeding (epistaxis), and even nasal septum perforation.

Such pathological changes in the upper respiratory tract do not allow them to purify (filter) the air inhaled, and, having overcome these protective boundaries, a dust more easily reaches deeper sections – bronchi etc.

Regardless of the physical and chemical properties, all types of dust particles initially have mechanical effect on the lung tissue, which fights against these foreign bodies with a proliferative cell reaction, phagocytosis and subsequent removal of it from the lungs in various ways: with sputum, along the lymphatic ducts into the bronchial glands and towards the pleura.

A well phagocytosed dust (coal) is relatively easy to be removed from the lungs; quartz dust rapidly destroys phagocytes and accumulates in the lungs, both in the alveoli and in the interalveolar septa, in the places of bifurcation and bending of the lymphatic vessels, followed by lymphostasis and the formation of pathological connective tissue, i.e., lung fibrosis. Specific process develops – pneumoconiosis. Under the influence of dust of weak aggressiveness nonspecific diseases develop – pneumonia, alveolitis, bronchial asthma, tuberculosis, cancer, etc.

A harmful effect of industrial dust on the body depends on:

- Physical and chemical properties of the dust;
- Concentration of dust in the air of the working area;
- Simultaneous influence of other unfavorable factors of the working environment, of conditions and nature of work (microclimate, noise, heavy physical work, presence in the air of gas and vaporous harmful chemicals, bad habits, etc.);
- Exposure, both during the working shift and duration of the professional experience;
- Individual sensitivity, related to the filtering properties of the airways, immunological reactivity of the organism and its genetic predisposition.

Dust-associated professional respiratory diseases. The main dust-associated respiratory occupational diseases are pneumoconiosis and chronic dust bronchitis. Pneumoconiosis – polyetiologic disease that gradually develops due to long exposure to inhaling of various types of dust, containing either silicon dioxide or other substances such as coal, aluminum dust, plastics, etc. The term pneumoconiosis was introduced into the medical literature by Zenker in 1866 and is translated from the Greek language as "Dusting of the lungs". Pneumoconiosis is a chronic occupational dust disease of lungs, characterized by development of fibrotic changes as a result of prolonged inhalation of fibrogenic industrial aerosols.

According to etiology, 6 types of pneumoconiosis are distinguished:

1. *Silicosis* – pneumoconiosis caused by the inhalation of dust containing free crystalline or amorphous silica.
2. *Silicatosis* – pneumoconiosis, resulting from the inhalation of mineral dust containing silicon dioxide in a bound state with various elements in the form of salts, specifically of silicic acid (kaolinosis, asbestosis, talcose, cementosis, etc.).
3. *Carboconiosis* – pneumoconiosis, caused by inhalation of carbon-containing dusts: coal, soot, coke, graphite (anthracosis, graphitosis).
4. *Metalloconiosis* – pneumoconiosis due to metal dust and their oxides: iron, aluminum, barium, tin, manganese, beryllium, etc. (siderosis, aluminosis, baritosis, stanioses, manganoconiosis, berylliosis, etc.).
5. *Mixed dust pneumoconiosis* is due to dust with different content of quartz, silicates and other components (siderosilicosis, anthracosilicosis, etc.).
6. *Organic dust pneumoconiosis* results from organic dust of plant, animal and synthetic origin: bissinosis – from dust of cotton and flax; bagasse – from the dust of sugar cane; tobacco – from tobacco dust; amylose – from flour dust, farm light – from agricultural dust containing microscopic fungi.

For all types of pneumoconiosis fibrous process in the pulmonary tissue is inherent, but its localization and degree depend on the fibrogenic properties of the dust and dustiness intensity. With a significant concentration of quartz-containing dust, formation of silicic dust nodules occurs inside the alveoli and around them. With a decrease in dust concentration, fibrotic changes are more pronounced in the pulmonary parenchyma – in the region of peribronchial and perivascular lymphatic follicles.

A small amount of dust in the air (small concentrations) causes formation of silicic nodules in regional lymph nodes, whereas in the lungs diffuse sclerotic changes predominate.

Chronic dust bronchitis is a very common and serious disease from prognostic point of view. In the industrialized countries of Western Europe, it holds a leading place in the structure of occupational pathology (17–37% of workers); the mortality and complications rate in this disease are 2 times higher than those for lung cancer and 3 times higher than for tuberculosis.

Some pulmonary dust diseases (asbestosis, carboconiosis, graphitosis, etc.) are background for the subsequent development of malignant neoplasms in bronchi, pleura, and the lungs. For example, asbestosis is complicated by cancer in 15–20% of cases. In addition, some types of dust, including those containing carbon and hydrocarbons, are themselves carcinogens.

Dust, which has an irritating effect, can cause conjunctivitis, keratitis and professional cataracts, as well as dermatitis, folliculitis, eczema, asbestos warts, cancer, etc. Substances with photosensitizing action (coal tar dust, tar, asphalt) along with the solar action cause keratitis, conjunctivitis and photodermatitis.

Prevention of dust-associated diseases. Fighting against dust in industrial enterprises and prevention of harmful effects of aerosols on the health of workers are carried out through a complex of anti-dust and health-improving measures of legislative, technological, sanitary and medical preventive nature, as well as through the use of personal protective equipment.

Legislative measures regulate the hygienically valid allowable content of aerosols in the air of the working area (***tab. 2***) and hygienic control over the air pollution by dust. It should be emphasized that the *maximum permissible concentration (MPC)* for various types of dust in terms of chemical composition are established by the lowest threshold of the biological effect.

Under the labor law, persons under 20 years are not allowed to work underground (in mines). For miners, a reduced working day, additional off-days and retirement at the age of 50 years are established. The Order of the Ministry of Health of Russian Federation No. 90 of 1996 regulates the conduct of preliminary and periodic preventive medical examinations, timing of their conduct, participation of physicians of various profiles, mandatory laboratory and functional studies, including the radiological. In addition, the document contains a list of contraindications for admission to work associated with the dust factor: all forms of tuberculosis, chronic respiratory diseases, cardiovascular diseases, eyes and skin diseases.

Technological (engineering) activities are aimed at reducing the dustiness of the air in industrial areas, namely through:

- Introduction of continuous, including so-called “man-free” technology
- Automation and mechanization of industrial processes, at maximum eliminating manual labor

Table 2

The maximum permissible concentrations of aerosols predominantly fibrogenic

Substance name	Maximal permissible concentration, mg/m^3	Hazard class
Silicon dioxide crystallic when its content in dust: a) above 70% b) 10–70% c) from 2 to 10%	 1 2 4	 3 3 3
Silicon dioxide amorphous in the form of condensation aerosol: a) content in dust above 60% b) content in dust from 10 to 60%	 1 2	 3 4
Dust of vegetable and animal origin with an admixture of silicon dioxide of more than 10%	2	4
Silicates and silicate-containing dust asbestos asbestos cement, cement, apatite, clay talc, mica	2 6 4	4 4 3
Metal dust: cast iron aluminum oxide (condensation aerosol) aluminum oxide (disintegration aerosol)	6 2 6	4 3 4

Note: the MPC level for dust with a pronounced toxic effect is significantly less than 1 mg/m^3.

- Use of remote controls by the workers, spatially isolated from the sources of dust
- Sealing of equipment, places of grinding and transportation
- Interior improvement of technology – replacement of dry processes (drilling, grinding) with wet ones; toxic substances to non-toxic; powdered products on briquettes, granules, pastes, etc
- Use of irrigation devices and water curtains
- Transition from solid fuel to gaseous
- Replacement of quartz sand used for cleaning of casting with steel or cast-iron shot; of lead grated disks when processing diamonds and semiprecious stones with cast iron
- Dust sedimentation – use of special wet surfactants

- Sheltering of dust-generating equipment with special dustproof enclosures

Sanitary technical measures: removal of dust from the places of its formation by means of air sucking (exhaust ventilation) with obligatory preliminary cleaning of the air from dust before release into the atmosphere; regular cleaning (wet or pneumatic) of rooms and workplaces.

Medical preventive measures: preliminary and periodic medical examinations (see above); measures aimed at increasing reactivity of the body to the dust: UV irradiation, inhibiting sclerotic processes; inhalation (alkaline, oily, with mineral water, with a mixture of vitamins B1, B2, C and diphenhydramine, alkaline-saline iodide, with menthol oil, etc.) that promote the sanitation of the upper respiratory tract; respiratory gymnastics, improving external respiratory function; therapeutic nutrition, including a protein component enriched with methionine and vitamins; sanitary-educational work with employers and workers (creation of favorable conditions of work and rest, healthy lifestyle, etc.).

Use of personal protective equipment (PPE). Use of PPE chosen for specific work situations depends upon the nature and extent of the hazard, the circumstances of exposure, other protective equipment used. These may include: goggles (***fig. 1***), shields and masks to protect the eyes and face (***fig. 2***), dust protecting mask respirators (***fig. 3***); special clothes and shoes; suits, protective pastes and ointments for the skin. In cases where a reduction in dust concentration is technically unattainable, PPE usage is mandatory and explicit labels such as «*PPE MUST BE WORN AT ALL TIMES*» should be provided in the exposure areas.

The choice of PPE follows the state standards. Specifically, usage of anti-aerosol respirators in Russia is regulated by the GOST P 12.4.191-2011. The similar standards in European Union (EN-149) and other countries suggest mostly the same basic requirements. There are three classes of face masks: FFP1, FFP2 and FFP3 (*FFP – filtering face piece*) capable of filtering 80, 94 and 99% of aerosol particles, accordingly. The FFP1 masks are capable stopping a rough dust from silica, coal, iron ore, zinc, aluminum or cement. The FFP2 class is commonly used in glass, foundry and pharmaceutical industry, whereas the FFP3 masks are most filtering, capable to protect against very fine particles of ceramic, asbestos, etc.

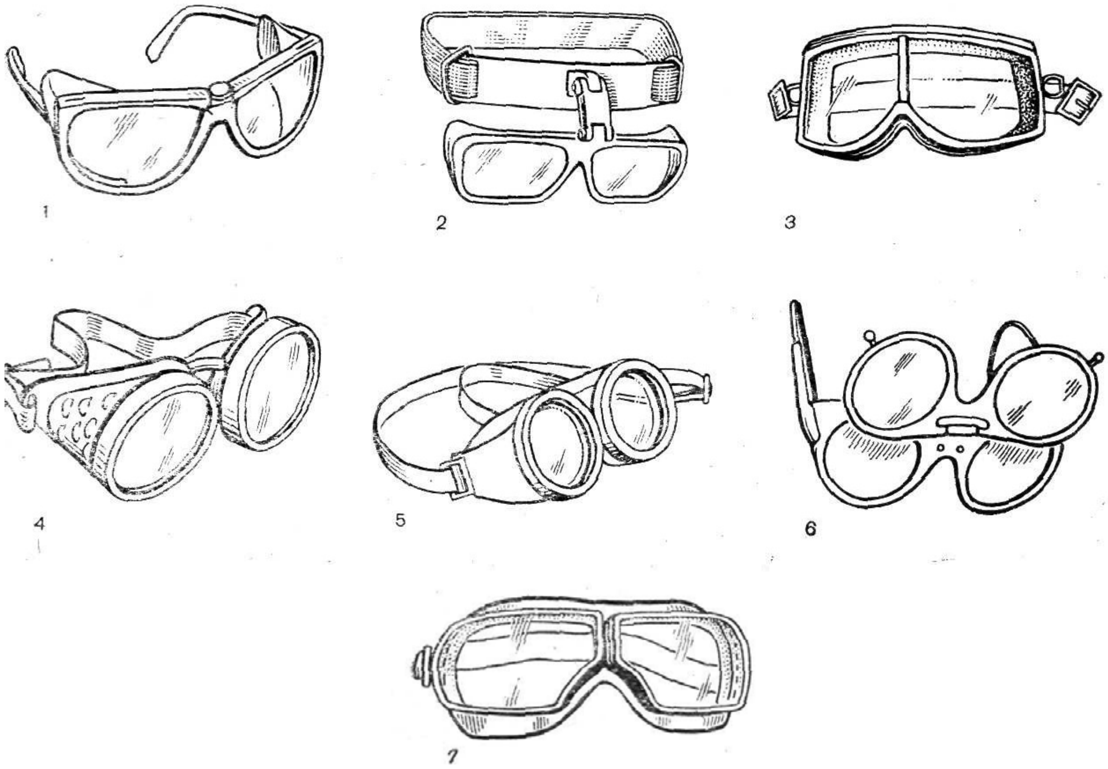


Figure 1. *Basic types of protecting glasses*

1 – open glasses; 2 – hinged open glasses; 3 – closed glasses with direct ventilation; 4 – closed glasses with indirect ventilation; 5 – closed sealed glasses; 6 – double open glasses; 7 – metallized glasses «ORZ-5»

Methods for hygienic evaluation of industrial dust

Sanitary and hygienic control over the presence and concentration of dust in the air of industrial premises includes the study of the technological process, equipment, raw materials, methods of processing and transportation. At the same time, it is must be established whether dust is constantly or periodically occurs in the air, and, depending on this, it is planned to take samples not only at different workplaces, but also at different periods of the shift, and sometimes at different times of year. In the case of variability of dust concentrations in the air, timing studies are carried out.

For the purpose of hygienic assessment of industrial dust, the following basic methods of its investigation are currently used:

- Weighting of the dust per unit volume of the air (gravimetric method);
- Analysis of the composition and morphology of dust particles;
- Analysis of the chemical composition of dust particles (content of free silicon dioxide).

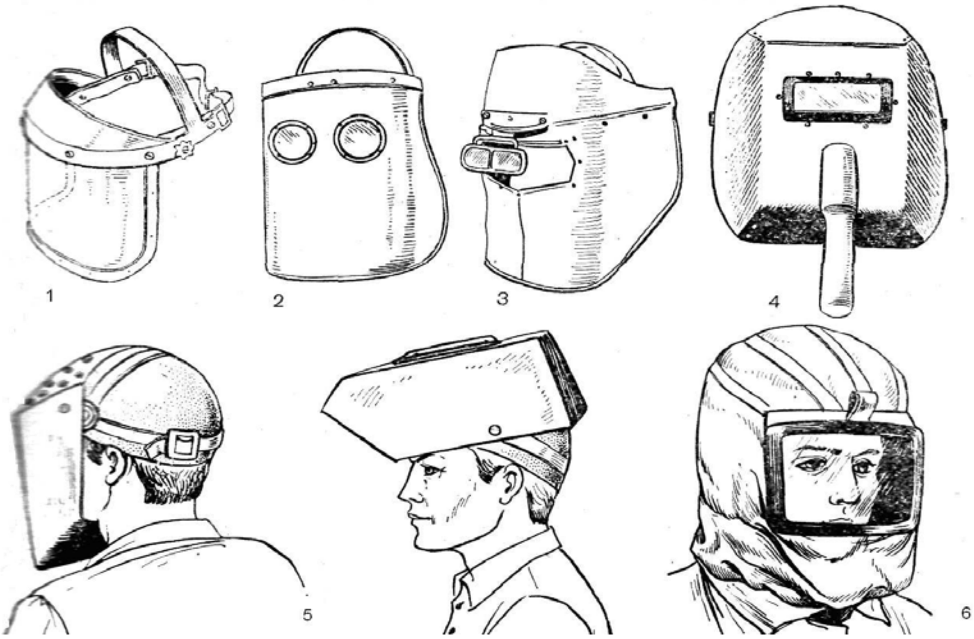


Figure 2. *Shields and masks to protect the eyes and face*

1 – head shield with colorless impact-resistant casing; 2 – head shield with a mesh body; 3 – head shield for distributors; 4 – manual cover with opaque casing; 5 – welder's head shield; 6 – TBIOT pneumatic scute

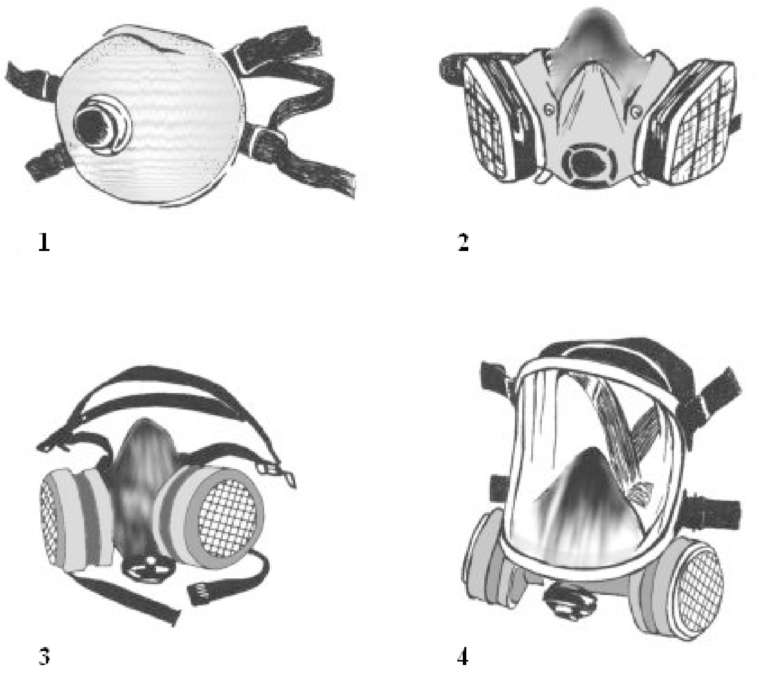


Figure 3. Basic *types of anti-dust respirators*

1 – half mask particulate; 2 – half mask dual cartridge disposable; 3 – half mask dual cartridge reusable; 4 – full face dual cartridge reusable

Weighting method. A content of dust particles in the air is determined by weighing of the dust, being deposited on the filter as result of forced passage of certain amount of the air through it.

Equipment, materials and methods of air sampling for evaluation of the dust content. Air samples are taken near the place of work, in the so-called breathing zone at the height of 1.5 m. To assess the propagation of dust through the room (shop), samples are taken at neutral points (at the distance of 1–3–5 m or more from the sites of formation), as well as in the aisles. During the air sampling period, the selection conditions must be recorded: air temperature and barometric pressure, time and duration of selection, air-drawing speed.

Under normal operation of the technological equipment, the quality characteristics (chemical composition, physical-chemical properties) and quantitative (dust mass in mg/m^3 of the air) are relatively constant; In case of malfunctions and accidents, these figures can vary quite significantly.

Sampling is carried out using electric aspirator (***fig. 4a***), which consists of a blower, exhaust air, electric motor and four rheometers, two of which are graduated from 0 to 20 liters per minute (l/min), and are intended for dust sampling, and the other two from 0 to 1 l/min, for sampling purposed for vapors and gases content definition. Before insertion into the network, the aspirator must be grounded. The procedure for working with it assumes constant monitoring of the rheometer readings (along the upper edge of the float), the time of continuous operation of the aspirator should not exceed 1 hour.

In case of a power line absence (in mines) or impossibility of using it (for the reason of explosion danger), ejector miner aspirator is used (AERA, ***fig. 4b***).

As a filtering material, most often a perchlorovinyl fabric is used. It allows air to be drawn at high speed (up to 100 l/min), has high filtering efficiency (detains up to 98% of the dust particles), is resistant to chemically aggressive media and practically does not require preliminary treatment (drying), except for cases of sampling under conditions of high relative humidity. Analytic aerosol filters made of this fabric represent disks with pressed edges, placed in protective rings of thick paper and laid in separate bags of tracing paper (***fig. 5***). The preparatory stage of the work consists in weighing the filters on the analytical balance in the laboratory, recording its number and mass in the journal. To get ready for sampling, the filter is fixed in the plastic or metal funnel-shaped fitting with the help

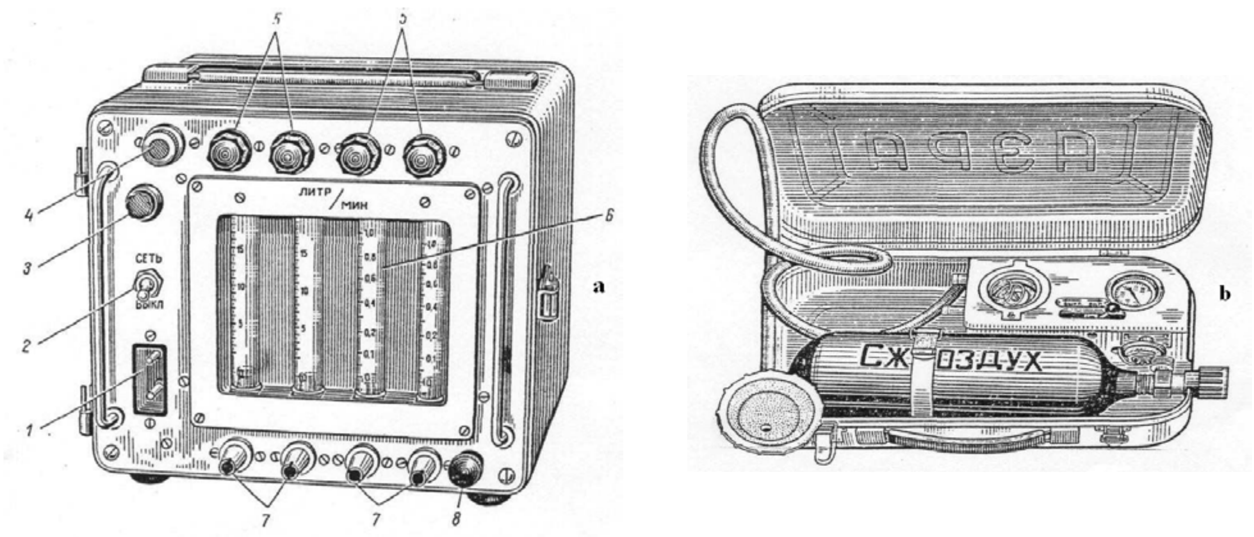


Figure 4. *a – Electric aspirator (model 822) portable with manual air flow control, b – explosion-protected aspirator AERA*

1 – plug for connection with electric cord; 2 – toggle switch for turning the device on and off; 3 – fuse socket; 4 – safety valve to prevent the motor from overloading when sampling air at low speeds and facilitating the launch of the device; 5 – handles of flow meter valves; 6 – flow meters; 7 – fittings for tube connecting; 8 – earth terminal

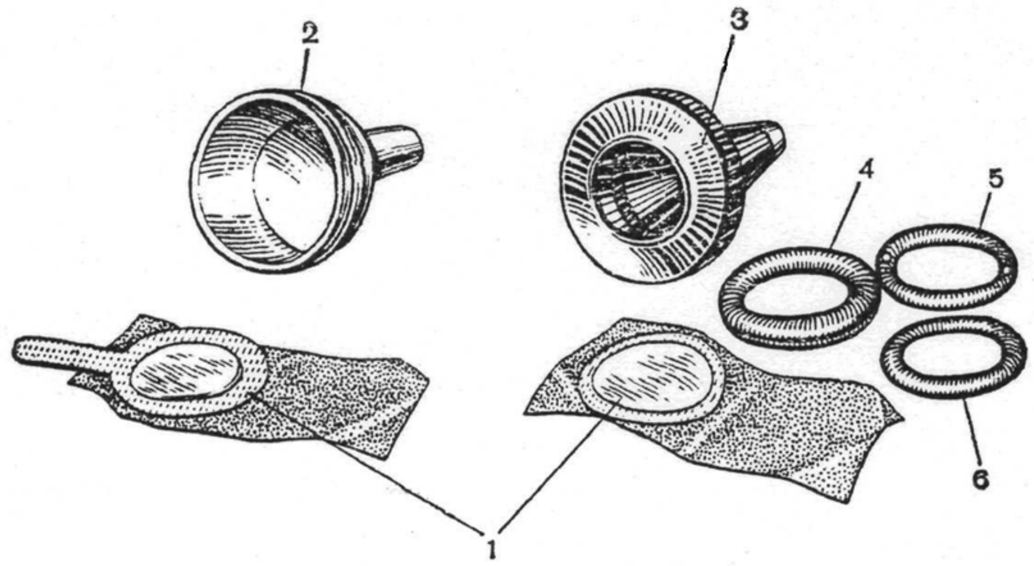


Figure 5. *Filters and the accessories for air sampling (explanation in the text)*
1 – disposable dust filters; 2 and 3 – filter fitting funnels; 4, 5 and 6 – sealing rings

of sealing rings; then one funnel with the filter fixed is inserted into the second one with the tips looking outward; the first funnel tip serves to absorb the sampling air, to the second funnel tip a pipe is attached by one end, by the other end the pipe is connected to the electric aspirator fitting.

AERA allows air to be withdrawn at a stable rate of 20 l/min due to opening of the valve of cylinder filled with compressed air. When you open the valve, kinetic energy of the air jet moving at high speed is transferred to the air surrounding. As result, the air of the working area passes (gets aspirated) through a funnel (alonge) with a filter connected by a rubber tube to the balloon. On the front panel of the AERA there are: on the right side – a stopwatch, for fixing the time of the air sampling; on the left side – manometer that shows how many liters of the air passed through the filter.

After the sampling is finished, the filter is removed, delivered to the laboratory, reweighed and the concentration of dust in the air is then calculated.

Calculation of dust concentration and evaluation of results. Calculation of dust concentration (mg/m^3) is carried out according to the formula:

$$P = \frac{(M2 - M1) \times 1000}{V_0}$$

where:

P – concentration of dust, mg/m^3; M^2 – the mass of the dirty filter, mg;
M1 is the mass of the clean filter, mg;
1000 – recalculation for 1 m^3 (1000 l) of the air;
V_0 is the volume of the air passed through in liters, reduced to normal conditions, i.e., atmospheric pressure equal to 760 mm Hg; and temperature of 0°C.
V_0 is calculated by the formula:

$$V_0 = \frac{V_t \times 273 \times P}{(273 + t) \times 760}$$

V_0 – the volume of air required at 0ºC and pressure 760 mm Hg, liters;
V_t is the volume of the air taken for investigation at a given temperature t and barometric pressure P, in liters;
273 – the coefficient of gas expansion;
(273 + t) is a temperature correction based on the Gay-Lussac law, according to which the volume of all true gases, and consequently of the air, when heated by 1°C expands to 1.273 part of its original volume;
B is a pressure correction based on the Boyle-Mariotte law: the volume of gases is inversely proportional to the pressure under which it is.

Example: The weight of the filter before sampling 400 mg, after air selection – 420 mg. When selecting 200 liters of the air, the air temperature was 27°C, the barometric pressure was 760 mm Hg.

We bring the volume of the air to normal conditions:

$$V_0 = 200 \times \frac{760}{760} \times \frac{273}{273 + 27} = 182\, liters;$$

$$P = \frac{(420 - 400) \times 1000}{182} = 109.8\, mg/m^3$$

The value obtained is compared with the MPC specific for this type of dust and hygienic assessment of its content in the air is thus given (specifically, less than MPC, corresponds to or exceeds the allowable limits).

Determination of dispersed composition of dust particles is made by microscopy of dust preparations made in various ways. Currently, their preparation is carried out by clarifying of the filters through which the investigated air was drawn. To do this, filters are placed by their filter surface on a clean defatted glass and kept for several minutes over acetone vapor. At the same time, the filter fabric quickly melts and a transparent film is formed on the glass, in which dust particles are clearly visible under the microscope. In case where dust particles are soluble in organic solvents, the dust preparation is prepared by the natural deposition of dust particles on the glass, greased with adhesive (glycerin, petrolatum, 2% solution of Canadian balsam in xylene). It is also possible to pass dusty air through 2–3 ml of vaseline oil or glycerin filled into the absorber of Polejaev, and then place a drop of this solution on a slide and microscopize.

The study of dust particles morphology is carried out for the same dust preparations, for which the dispersion was investigated. In the study of dust, in which ultramicroscopic particles predominate, an electron microscope is used. Describe the configuration of particles, the nature of the edges (regular or irregular shape). Examples of the morphology of various types of dust are shown in the figure 6.

Along with the classic method explained above, other technologies for dust concentration monitoring are increasingly used.

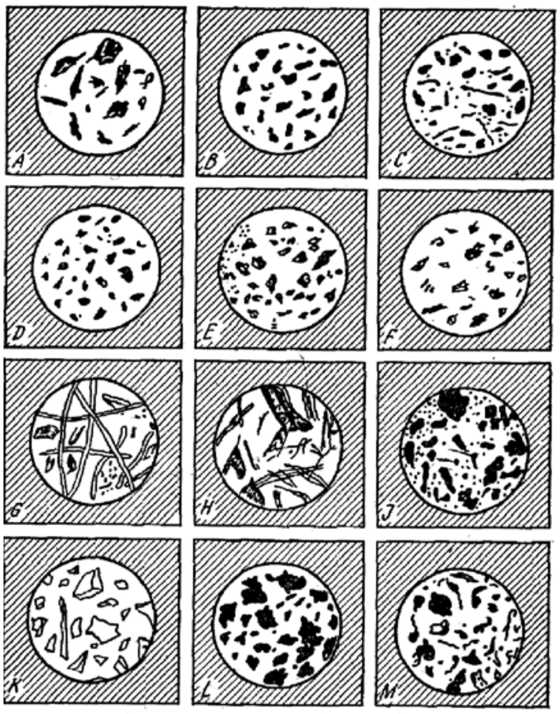


Figure 6. *Morphology of dust particles*

A and B – wood dust; C – dust of bristles; D – dust of chamotte (fire-resistant clay); E, F – silicon dust; G – hemp dust; H – the dust of coniferous tree; J – coal dust; K – glass dust; L is bronze dust; M – dust when cleaning casting

Photoelectric counter of aerosol particles (***fig. 7a***) is used to determine the amount of dust particles in the volume of the air as well as degree of the dust dispersion. The operation of the device is based on the principle of light scattering by separated aerosol particles. Due to quantitative relationship between the particle size and intensity of the scattered light, the particle size analysis is carried out. The device consists of the aspirator, optical sensor and electrical unit. It allows determining a concentration of aerosol particles (from 1 to 300000) in 1 liter of air and dispersed composition of aerosol particles with a size of 0.4 to 10 µm.

Portative dust meter AtMAS (***fig. 7b***) makes it possible to conduct continuous monitoring of concentration of dust of different types and chemical composition when monitoring maximum permissible concentrations in the air of a working area during technological control. The principle of operation of the dust meter is based on obtaining electric charge by the dust particles while being within the field of corona discharge, produced by a high-voltage electrode and their subsequent deposition on the surface of the dust sensor, consisting of quartz piezoelectric element. When dust particles settle on the sensor surface, the frequency of its oscillations changes to the extent, proportional to the mass of the settled dust.

a b

Figure 7. *a – Photoelectric aerosol particle counter AEROKON (Rus. «АЭРОКОН», modified from www.ccenter.msk.ru), b – Portable dust meter AtMAS (Rus. «АтМАС», modified from www.ndt-group.ru)*

PRACTICAL PART

1. Getting familiar with equipment intended for air sampling and its usage. Under instructor's supervision assemble the aspirating device for air sampling.
2. Determine dust content in the air, calculate the concentration of dust in the air based on situational problem data and give its hygienic assessment. Formulate conclusion and make a list of necessary preventive measures.

SITUATIONAL PROBLEM

In one of the glass factory shops air samples were taken for dust content examination. The air sampling conditions: air flow rate 20 l/min, sampling time – 25 min, barometric pressure 760 mm Hg. The air temperature is 20°C. After the procedure, overall 6 mg of dust was found in the air sample.

Give hygienic assessment of the dust content in the air of the workshop, since it is known that the dust sample contains more than 70% of free silica.

QUESTIONS FOR SELF-CONTROL

1. Industrial dust: its concept, sources of dust formation.
2. Classification of dust by origin, formation mechanism, dispersity.
3. Hygienic value of the basic physical and chemical properties of a dust.
4. Types of action of dust on the workers.
5. Adverse factors, aggravating the harmful effect of industrial dust.
6. Professional dust-associated respiratory diseases. Pneumoconiosis – concept, classification; chronic dust bronchitis, lung cancer.
7. Measures to control dust content in the workplace.
8. Dust-associated eye diseases.
9. Dust-associated skin diseases.
10. Methods of dust investigation.
11. Equipment: principle of action of electro-aspirator and AERA-device.
12. Principles of determining the morphology and dispersion composition of dust particles.

2. INDUSTRIAL POISONS.
PREVENTION OF PROFESSIONAL POISONING

Purpose of the lesson: is to familiarize students with the basics of industrial toxicology, impact of industrial poisons at work on the body and measures to prevent occupational diseases and poisoning; to review the sanitary and chemical methods for determining content of harmful chemicals in the air; to teach how to give hygienic assessment of chemical pollution of the air.

Practical skills:

1. To master the methodology of air sampling;
2. To master the express method of studying of the air for content of certain poisons (carbon monoxide, ammonia, gasoline, benzene, etc.);
3. To learn how to evaluate the results obtained by comparison with relevant regulations;
4. To learn how to develop recommendations for elimination of air pollution.

Relevance of the topic. Many types of professional activities related to receipt, processing of raw materials, manufacturing and use of industrial products are carried out under conditions of exposure of human body to industrial poisons.

At present, about 10 million chemical compounds are known to mankind; more than 60 thousand of them are widely used in everyday life, medicine, industry and agriculture. The number of them continues to increase from year to year, according to some data by about 1500 items annually.

Chemical factor is the main one in such industries as chemical, petrochemical, chemical-pharmaceutical, agricultural, etc. In the process of labor activity under unfavorable production conditions and violation of the technological process, chemical substances can have harmful action on the working capacity and health of workers, causing professional poisoning and diseases of chemical etiology.

A future doctor needs to have certain knowledge in the field of industrial toxicology. Understanding the role and importance of chemical pollutants as the etiological factors of many diseases is necessary for correct approach in collecting anamnesis, for diagnosing and treating of a patient.

Basic toxicological concepts and terms

Industrial poisons (IP) – chemicals that as raw, intermediate, by-, or end-products of industrial process enter human body and produce harmful effects to its function, resulting in disruption of health or progeny.

Toxicology is a science that studies mechanisms of action of chemical substances on human and animal organism, and develops methods for diagnosing, treating and prevention of poisoning.

Industrial toxicology is a section of occupational hygiene that studies effects of a chemical factor on human body from the point of view of creating harmless and safe working conditions.

Toxicity – ability of chemical substances to impact biological systems in such a non-mechanical way as to cause their damage or destruction. The same applied to the human body means **an ability to cause a malfunction, disease or death.** The less quantity of the substance is capable of causing damage to the body, the more toxic it is.

Theoretically, there are no substances that are devoid of toxicity. Under certain conditions, some biological object will eventually be found that responds with damage, dysfunction or death to chemical substance exposure in certain doses.

Toxicant is a concept used not only for substances that cause intoxication, but also for those provoking other forms of toxic process, and is not only applied to the organism, but also to biological systems having other levels of organization: cells (**cytotoxicant**), populations (**ecotoxicant**).

Poisonings and diseases arising from exposure to harmful substances during performing work at the workplace are called **occupational poisonings and diseases**. Under actual industrial conditions, the probability of developing intoxication with one or another substance is due not only to its toxicity, but also to the possibility of entering the body in life-threatening quantities.

Hazard – likelihood of harmful effects to health occurring under actual industrial conditions due to exposure to chemical products.

The physical and chemical properties that determine toxicity and hazard of chemically active substances include: aggregate state, dispersity, solubility in lipids and water. By degree of solubility in lipids and water (P o/w), all substances are divided into 9 classes (NV Lazarev's classification):

a) Electrolytes with high hydrophilic properties: 1–3 classes Po/w = (10^{-3}–10^{-1}); the most dangerous way through which these substances enter the body is inhalation: they dissolve quickly in the blood plasma and can cause acute poisoning;

b) Substances that are highly soluble in water and in fats: 4–5 classes (P o/w = 10–10^{2}); these can enter the body both by inhalation and by oral route, and also through intact skin;

c) Non-electrolytes with high hydrophobic properties: classes 6–9 (P o/w = 10^{3}–10^{6}); easily penetrate the skin; get deposited in lipid-rich organs.

Classification of industrial poisons

The compounds used in industry, depending on the objective they serve, can be distinguished using various classifications.

1. Chemical classification: organic, inorganic and organic-elemental;

2. By the way of entrance to the body: through inhalation, oral and percutaneous pathways.

3. By the nature of effect on human body: general toxic (acute, subacute, chronic); local irritating; sensitizing (industrial allergens); causing specific, including such long-term effects as mutagenic, gonadotropic, embryotropic, carcinogenic and others.

4. By degree of toxicity: extremely toxic, highly toxic, moderately toxic, little toxic.

5. By degree of the hazard:

1) Extremely dangerous (blastomogenic, mutagenic, gonadotropic and embryotropic substances);

2) Highly dangerous (substances of convulsive and neuromuscular paralytic action, drugs that affect parenchymatous organs and produce purely narcotic effect);

3) Moderately dangerous (substances that cause bone marrow activity depression or hemolytic action);

4) Low dangerous (substances that irritate mucous membranes of the eyes, upper respiratory tract, skin).

6. According to the aggregate state: can be in the form of gases, vapors, liquids, aerosols, solids, and mixtures.

The ways industrial poisons enter the body

In the air of industrial premises, harmful chemicals can be in various aggregate states and enter the body in three main ways: through the respiratory system, intact skin, gastrointestinal tract, and in some cases through the mucous membrane of the eyes.

In order for a chemical to enter the bloodstream, it must pass through one or more semipermeable membranes, such as the gastrointestinal or respiratory tract epithelium or the skin epidermis. Absorption of a chemical depends on its physical and chemical properties, the size of the molecule and its shape, the degree of ionization and solubility in lipids and water.

The respiratory way of getting poisons into the body. The pulmonary epithelium is a thin structure that has a large surface (more than 100 m^2) that is in close contact with a wide network of capillaries, so the absorption of foreign substances can occur here at high speed.

Absorption of vapors and gases occurs partly already in the upper respiratory tract and trachea. The patterns of sorption of poisons through the lungs for two groups of chemical substances are well established. The first group consists of so-called non-reacting vapors and gases, called so because of their low chemical activity; they do not change in the body or their conversion is slower than accumulation in the blood. These include vapors of all aromatic and fatty hydrocarbons and their derivatives.

Initially, a saturation of blood with gases or vapors occurs quickly due to a large difference in the partial pressure, then slows down, and finally, when the partial pressure of gases or vapors in the alveolar air and blood is equalized, the blood saturation stops. Removal of gases and vapors through the lungs also occur quickly on the basis of diffusion laws. If at a constant concentration of gases or vapors in the air for a short time there was no acute poisoning, then in the future it will not occur, because when inhaled, for example, harmful substances with narcotic effect of action (benzene, gasoline), equilibrium of concentrations in the blood and the alveolar air is established immediately.

The second group of chemicals consists of reacting vapors and gases. Quickly dissolving in body fluids, they easily enter into chemical reactions and turn into new compounds. These include water-reactive oxides of nitrogen and sulfur, ammonia and some other compounds.

The level and speed of blood saturation with gases and vapors in case of different compounds depends on the distribution coefficient (K), which is the ratio of the concentration of vapors in the arterial blood to their concentration in the alveolar air (K = blood/air). Non-reactive non-electrolytes with high K (alcohol, acetone) pass from the air to the blood for a long time. Compounds with a low K, for example hydrocarbons, quickly reach an equilibrium concentration between blood and air.

Knowing the distribution coefficient for each substance, there can be known in advance a risk of rapid and even fatal poisoning. Vapors of gasoline, for example (K = 2.1), at high concentrations can cause instant acute or fatal poisoning, since gasoline saturates the blood very quickly; in contrast, acetone vapor (K = 400) can not cause instantaneous, especially fatal poisoning, as it slowly saturates the blood. Therefore, when they are inhaled, by occurrence of symptoms, you can prevent possible acute poisoning by removing a person from the danger zone.

In practice, the solubility coefficient, that is, the distribution of the substance in water (Oswald's solubility coefficient), is approximately the same order of magnitude as the distribution coefficient, that is, the substance is highly soluble in water and dissolves well in the blood.

Trapped into the lungs, toxic and highly soluble aerosols pose a great danger, since their entrance into the blood can start over the entire area of the respiratory tract and lead to a rapid toxic effect to the body.

In case of low toxicity of the substance, its aerosol acts on the tissue mainly as a mechanical stimulus. In this case, good solubility is a favorable factor contributing to the rapid removal of the poison from all segments of the airway tract.

Suction of poisons through the skin. The structure of the skin allows rapid penetration through the epidermis of both fat and water-soluble substances. These properties are fully possessed by aromatic and fatty hydrocarbons, their derivatives, organophosphorus, organometallic compounds, etc. The combination of high toxicity of substances with good water and fat solubility contributes to a significant increase in the risk of poisoning when entering the skin. It’s known the possibility of salts of certain metals (copper, lead, bismuth, arsenic, mercury, thallium, etc.) to penetrate through the epidermis, when having combined with sebaceous gland secretions or fatty acids inside the stratum corneum, they become fat-soluble compounds. Zinc and cadmium, forming protein complexes, also penetrate through the skin.

Factors that affect the penetration of substances through the skin include: the degree of skin hydration, pH, temperature, the contact surface area, blood circulation, etc. Liquid organic substances with high volatility quickly evaporate from the surface of the skin, but if they enter the composition of ointments, pastes, glues, then stay for a long time on the skin and penetrate into the blood. Superficial damage to the skin contributes to increased penetration of toxic substances into the body.

Absorption of poisons through the gastrointestinal tract. The mechanism of penetration of poisons from the air into digestive organs is due to their dissolution in saliva and absorption in the oral cavity.

Poisons can enter digestive tract with food and drinking water. All lipid-soluble compounds, some salts, especially cyanides, phenols are absorbed in the oral cavity.

The resorption of poison from the stomach depends to large extent on pH of the gastric juice, state of mucus, nature of food, etc. Gastric secrets can significantly change poisons, but also can increase their solubility. For example, when metals are absorbed from the stomach, they can undergo change of their properties – iron goes from divalent to trivalent, insoluble lead salts – into more soluble one.

Due to the large surface and abundant blood supply, absorption is most intensive in the small intestine. Absorption of metals in the intestine occurs at different levels, usually in the upper sections (chromium, manganese), iron, copper, mercury, thallium, antimony are absorbed in the distal parts. Alkali metals (sodium, potassium, lithium, etc.) are resorbed quickly and completely. Alkaline earth metals are absorbed significantly less due to the formation of hardly soluble complexes with fatty acids. Reinforced intestinal peristalsis usually inhibits the absorption process in it.

Distribution of chemicals in the body

The nature of the distribution of industrial poisons in the body is largely determined by their ability to dissolve in water or lipids. Relatively uniform distribution pattern is inherent to lipophilic non-electrolytes. They penetrate through passive diffusion through cell membranes and are distributed both in extracellular and intracellular body fluids. For this group of chemicals, there are no barriers in the body: their distribution in the body is determined mainly by the conditions of the blood supply of organs and tissues – the higher it is the greater the content of the substance.

Hydrophilic electrolytes are distributed unevenly in the body. Most of them do not penetrate into cells, but are distributed mainly in blood plasma and interstitial fluid. The ability of electrolytes to penetrate the cell is severely limited and depends on the charge of its surface layer.

Certain obstacle to distribution of hydrophilic compounds in the body is produced by natural barriers, existing between some tissues and the blood, such as: blood-brain, hemato-ophthalmic, hematotesticular and placental.

The transport of chemical compounds along the vascular bed is possible in various ways. For example, organic compounds, which are mainly non-electrolytes, dissolving in the blood, can enter erythrocytes, and be sorbed on hemoglobin, or bind to albumins.

Metal salts dissociate into ions and neutral molecules, the rapidity of this process is determined by the dissociation constant.

Alkaline metals are quickly absorbed and quickly removed from the body – lithium, sodium, rubidium, potassium. Alkaline earth metals (calcium, strontium, barium) form poorly soluble hydroxides and complexes poorly bound with proteins, which makes their resorption and excretion difficult.

The affinity of certain metals to proteins and amino acids is noted. Amino acids are associated with mercury, silver, lead, copper, zinc, cobalt, mainly through sulfhydryl groups.

Heavy metals form hydroxides, phosphates, albumins, poorly soluble in water and therefore slowly absorbed from the gastrointestinal tract.

Arsenic and lead are mainly found in the red blood cells. With red blood cells, such elements as chromium, selenium, potassium, rubidium are distributed throughout the body.

Deposition of poisons

If excretion of a poison or its transformation goes slower than intake, then it can accumulate in the body and produce a long-term negative effect.

This process is called deposition. For lipid-soluble substances, fatty tissue and lipid rich organs (bone marrow, testes, etc.) have the greatest accumulative capacity. Benzene can stay in adipose tissue for up to 48 hours, some pesticides – up to several months. The distribution of electrolytes in tissues is very uneven. For example, chrome, nickel, selenium are evenly distributed across all organs. Other poisons can accumulate in those organs that have relatively higher metabolism (liver, kidneys, endocrine glands), and in those where they are present as trace elements or participate in the processes of hormone synthesis, etc. Manganese, molybdenum lingers in the pituitary, cadmium, zinc – in the testes, cobalt, cesium – in the pancreas.

The largest amount of lead accumulates in the bones, then in the liver, kidneys, muscles, and 16 days after cessation of its entry into the body, all lead passes into bone tissue. Fluorine compounds accumulate in the bones, teeth, in a small amount – in the liver and skin. Deposited compounds can be gradually released and enter the blood, producing toxic effects.

Transformation of chemicals in the body

Metabolic transformation of chemicals in the body, as a rule, leads to the formation of less toxic substances. However, some metabolites eventually have a higher toxicity than the initial substance. For example, as a result of fluorocarboxylic acids conversion in the body, fluoroacetates with higher biological activity is synthesized.

Metabolic transformation of chemicals is carried out, mainly, in the liver and is catalyzed by the mitochondrial and microsomal fractions of the enzymes. Biochemical transformations can be divided according to the types of reactions into four main groups: oxidative, reducing, hydrolysis and synthesis reactions. Metabolic pathways can consist of either one or several reactions in any combination. The final stage of this pathway is the addition reaction, which involves attachment of polar endogenous functional groups, which usually increase polarity of the molecule, reduce its fat solubility, and therefore facilitates its removal from the body.

Thus, knowledge of the poison transformations in the body allows you to influence them in order to speed up neutralization or to diagnose intoxication.

Excretion of chemicals from the body

Chemicals are excreted from the body either in the form of initial products or metabolites mainly with urine and bile, and to a lesser extent – with exhaled air, then, saliva, breast milk and feces.

More often toxic compounds and their metabolites are released at once in several ways, and one of them is of primary importance. An example can be ethyl alcohol, most of which is exposed in the body to transformations. The rest, about 10%, is excreted unchanged, through the lungs, then with urine and in small amounts with feces, saliva, etc.

Excretion from the body of both organic compounds and metals is usually three-phase: this is due to different forms of circulation and deposition of the poison. First of all, the compounds that are unchanged or insufficiently tightly bound to the biological components of the body (ligands) are first removed from the body, then a part of the poison that is in the cells in a more firmly connected form is released, and the poison leaves the permanent tissue stores. Such a phasic release from the body is proved for many non-electrolytes, their metabolites, and also for poison-metals.

To estimate the excretion time of a poison, the half-life indicator is used: this is a time during which half of the substance entered the body ($T_{1/2}$) gets excreted. Thus, the half-life of cesium is more than 70 days, of mercury – 100 days.

Release of harmful substances through the lungs. The release rate of harmful substances depends on the distribution coefficient (K): the smaller K, the faster the substance is released. Excretion begins immediately after cessation of the poison intake. This applies to many volatile organic solvents. Through the lungs, gasoline, benzene, chloroform, ethyl ether are quickly released; slow release is inherent to acetone, esters.

Elimination of solid aerosols from the lungs depends on their physical and chemical properties and goes due to interstitial drainage and phagocytosis. Some particles remain in the alveoli for a long time and gradually undergo dissolution and excretion with blood flow.

Elimination of harmful substances through gastrointestinal tract. Poorly soluble or insoluble substances are released through the gastrointestinal tract: lead, mercury, manganese, antimony, etc. Lead and mercury can be released together with saliva from the oral cavity. Poisons entering the body both through the lungs and through the skin, having a cycle of detoxification in the liver passed through, are released into the gastrointestinal tract with bile and enter the lumen of the intestine.

From intestinal lumen reabsorption of poison substances can occur, through the portal vein they enter the liver again and are partially released through the peripheral circulation of the kidneys, thus repeating the cycle. This mechanism was called liver-intestinal circulation, which can delay the foreign compounds in the body and increase the period of their half-elimination. Volatile non-electrolytes (hydrocarbons, alcohols, ethers, etc.) are practically not released through the gastrointestinal tract.

Excretion of poison substances with urine largely depends on the process of their reabsorption (reverse diffusion) from the tubules. Alien substances are reabsorbed by simple diffusion. This applies to lipophilic non-polar compounds that penetrate well through the biological membranes of the body, therefore fat-soluble substances can be reabsorbed from the tubules into the blood and thereby their presence in the body is prolonged. Ionized chemicals are reabsorbed poorly and are immediately eliminated from the body with urine. Weak acids or bases, being polar compounds, are poorly reabsorbed, so urine pH is important for their induction. Thus, with an alkaline reaction of urine, the excretion of acidic compounds increases, and vice versa.

Transported by the same transport system, chemical substances compete with each other, and the rate of elimination of one substance may decrease when another one is introduced into the body.

Alkaline metals (lithium, rubidium, cesium) are excreted exclusively with urine whatever way they enter the body. Complex compounds of beryllium, cadmium, lead are released much faster than the salts because of good solubility due to facilitating their penetration through the biological membranes of the kidneys. For this reason, the acceleration of excretion of metals with urine is facilitated by application of various complexing compounds used in the therapy of poisoning.

Release of harmful substances from the body in other ways. Some poisons can be excreted with breast milk, specifically non-electrolytes – chlorinated hydrocarbons; lipophilic compounds, for example, chloroform, benzene, etc. Releasing with milk is also known for many metals – mercury, selenium, arsenic, etc.

Through the skin, sebaceous glands secrete all the substances soluble in fats. Mercury, copper, arsenic, many non-electrolytes (hydrogen sulphide, ethyl alcohol, acetone, phenol), chlorinated hydrocarbons, etc. are released by the sweat glands. Presence of a poison substance in the sweat can lead to development of dermatitis. In the balance of excretion of toxic compounds from the body, these pathways do not play a significant role, but they can acquire higher significance in case of intoxication.

Dependence of toxic effect of substances on the chemical structure

The nature and strength of the toxic effect are closely related to the physical and chemical properties of the compounds, their structure and spatial composition. Knowledge of these interrelations allows predicting to some extent the nature of possible toxic effects, various toxicity parameters and indicative values of hygienic standards.

As the number of carbon atoms in the homologous series of hydrocarbons increases, their toxic narcotic effect increases. Therefore, the first fractions obtained during the distillation of oil are less poisonous than the subsequent fractions; light gasolines are less toxic than heavy; higher alcohols (butyl, amyl) are more toxic than ethyl and propyl, etc. This rule however turned out to be inapplicable to aromatic hydrocarbons.

When the chain of carbon atoms is branched, the strength of the narcotic effect weakens, so the long chain isomers are more toxic than the branched chain isomers, although the empirical formulas are identical. For example, isopropyl alcohol is less toxic than propyl alcohol due to having an unbranched carbon chain. Isoheptane is less toxic than heptane.

When the chain of carbon atoms is closed into the ring, the narcotic action of substance increases. Toxicity of cyclopropane, cyclopentane, cyclohexane and their homologues was found to be higher than that of the corresponding methane hydrocarbons.

Introduction of multiple bonds into the molecule makes it possible for the poison to enter into biological reactions more easily: all compounds of trivalent arsenic are more poisonous than pentavalent; compounds of bivalent sulfur are more toxic than trivalent; the compounds of trivalent phosphorus are more toxic than the pentavalent; sharply increases the toxicity in the series from ethane (CH_3-CH_3) through ethylene ($CH_2 = CH_2$) to acetylene (HC-CH).

Introduction of halogens into molecule of an organic compound (in fluorine, chlorine and bromine) significantly increases their toxicity and makes compounds capable of causing specific effects (fatty degeneration of parenchymal organs, damage to the kidneys, heart).

The halogen atom present in open chain is much more active than the halogen atom in the cyclic structure. Tear gases such as chloride, benzyl iodide and benzyl iodide with a halogen atom in the side chain (C_6H_5-CH_2Cl, etc.) have sharp irritant effect on the eye membranes. At the same time, chlorobenzene with a chlorine atom inside the benzene ring does not possess irritant properties.

Introduction into molecule of nitro- and amino groups. Introduction of amino or nitro groups into the benzene ring (aniline and nitrobenzene) leads to the appearance of their ability to methemoglobin formation due to conversion of bivalent iron of hemoglobin to trivalent iron.

Spatial location (isomerism of position). Isomeric forms of a compound sometimes have differences in the nature of the biological activity. Thus, p-phenylenediamine is a classic allergen, and the o-isomer does not possess allergic properties.

Biological activity of inorganic compounds can also be due to the chemical structure.

Thus, the elements whose atoms have a large number of electron shells and a large radius are more toxic. For example, cesium (6 shells) and rubidium (5 shells) is much more toxic than lithium (2 shells). This dependence holds true in various ways of poison entering the body, as well as entering in the form of salts.

Selective action of industrial poisons

Among industrial poisons, irritants, neurotropic, hepatotropic, nephrotoxic, cardiotoxic, blood poisoning, allergens, mutagens, carcinogens, teratogens and other toxic groups are distinguished. Accordingly, under their influence, any of the known pathological processes – inflammation, dystrophy, sensitization, pneumosclerosis, fibrosis, changes in the nervous, cardiovascular, endocrine systems, respiratory system damage, blood system, teratogenic, mutagenic and blastomogenic actions can develop.

Such a selective manifestation of the action can be noted both with the effect of minimal amounts of poison, and with exposure in higher doses, and with prolonged exposure. These kinds of effects can also manifest themselves as a part of general toxic reactions.

Skin. When skin contact occurs, the stimulating effect of poison can cause various disorders, from mild contact dermatitis to necrotic ulcers. Some substances can cause hyperpigmentation (oil refining products, hydrofluoric acid salts), coloring of the palm skin, feet and nails in yellow (trinitrotoluene, dinitrochlorobenzene), gray (silver). Nickel causes severe itching of the skin. Some compounds contribute to development of keratosis or hair loss (anthracene, chloroprene, trinitrotoluene, dinitrobenzene); specific epilating effect of thallium salts is noted.

Respiratory system. Well soluble chlorine, ammonia, sulfurous anhydride often cause rhinitis, laryngitis, tracheitis, bronchitis, thus affect mainly the upper and middle parts of the respiratory system.

Poorly soluble poisons (dimethyl sulphate, cadmium, manganese, vanadium, nitrogen oxides, phosgene, etc.) mainly affect the deep sections – bronchi, bronchioles, causing bronchiolitis and pulmonary edema. Prolonged professional inhalation of substances lead to atrophic or hypertrophic changes in the mucosa with impairment of its ciliaric motility. As manifestation of a long-term exposure to light ammonia, nitrogen oxides toxic pneumosclerosis can develop. Currently, out of 3000 substances known to operate in the air of the working zone, only about 9% of them are regulated in accordance with the presence of irritating inhalation action.

Cardiovascular system. Specific damage to the cardiovascular system is manifested when the substance affects both the myocardium and the vessels. Some substances have a specific effect on biochemical processes, causing disturbances in oxidative processes (glycolysis, conduction disorders and contractility of the myocardium), specifically mercury, organomercury compounds, lead and its compounds, chromium, sodium fluoride, phenols, etc.

Arsenic has a pronounced capillarotoxic effect. Dystrophic changes in the vessels of myocardium are caused by cadmium, cobalt and its compounds ("cobalt myocardiopathy").

Nervous system. Impact of chemicals on the nervous system manifests itself in short-term effects in the form of lung disorders of the type of autonomic dysfunction (pulse lability, red dermographism, thyroid gland hyperfunction); also as prolonged disorders such as asthenia, fatigue, drowsiness or encephalopathy (headaches, emotional instability, impaired intellect).

Long-term effects of chemical compounds on the body can lead to interstitial brain disease with inherent to it lack of coordination mechanisms for regulation of metabolic, endocrine, and vegetative processes. These disorders are typical for heavy intoxication with tetraethyl lead, chlorinated hydrocarbons, benzene, gasoline, cyanides. Neuritis, polyneuritis is characteristic of thallium, arsenic, bromoethyl, etc.

Lesion of blood and blood-forming organs. Three groups of substances were identified for which specific blood lesions were noted:

1) Substances that cause changes in hemoglobin: when ingested, affect porphyrin metabolism and, when combined with iron, inactivate hemoglobin due to the formation of carboxyhemoglobin. This leads to disruption of oxygenation processes and decrease in the transport function of hemoglobin, causing development of hemic hypoxia of tissues (carbon monoxide, nitro- and amino-derivatives of benzene and its metabolites, sodium nitrates and nitrates);

2) Substances that cause primary hemolysis of blood due to the damaging effect of poison on the erythrocyte membrane or interference with the enzymatic processes standing for integrity of red blood cells (arsenic hydrogen, phenylhydrazine, etc.);

3) Substances that cause primary inhibition of hemopoetic function. Specific depression in this respect is characteristic of chronic exposure to benzene. When it is exposed, decrease in the number of polipotent stem cells is noted. One of the manifestations of this is a decrease in the number

of cells in the bone marrow and spleen. With intensive and prolonged exposure to benzene and its derivatives, leuko-, thrombocyto- and erythrocytopenia develop. A similar but less pronounced effect is exerted by chlorobenzene, hexamethyleneamine.

Hepatotropic action of industrial poisons. Toxic damage of hepatic parenchyma under influence of hepatotropic poisons occurs due to the violation of intra-lobar circulation, and also due to the binding of the sulfhydryl groups of proteins. The consequence is impairment of protein-forming and detoxification function of the liver, and also change in carbohydrate metabolism.

At oral poisoning with mercury preparations, atrophic changes in the liver parenchyma predominate, and in case of poisoning with iron salts – liver necrosis and hepatic coma can develop.

Damage of the kidneys. More than 20 metals and their compounds (beryllium, boron, bismuth, silver, lead, thallium, chromium, etc.) cause nephrotoxic effects. Mercury, arsenic, cadmium produce selective effect. A direct effect on the epithelium of the renal tubules is due to necrotic effect of heavy metals excreted by the kidneys.

Aromatic amino compounds with chronic exposure induce benign tumors, and subsequently bladder cancer (benzidine, dianisidine, naphthylamine, aniline, etc.).

Changes in the digestive organs are typical for intoxication with virtually all compounds that enter the body in this way. They can have different localizations and severity. Dental lesions can cause fluoride and phosphorus compounds, salts of silver, bismuth, lead, mercury, antimony are deposited in the oral mucosa and on the gums. Disturbances in the gastrointestinal tract (gastritis, dyspeptic phenomena) are caused by selenium, organic solvents, zinc, oxides of nitrogen, chromium. Pronounced local irritant effect on intestinal mucosa and stomach is exerted by heavy metals, carbon disulfide, bromides, iodides, etc.

Long-term effects of poisons on the body

Study of various industrial factors impact on the state of reproductive function of the body showed high degree of its susceptibility to chemicals.

Toxicants can cause disorders in the sex glands (ovaries and testes), affect sex hormones production, both in the sex glands and in the pituitary gland, and also to disrupt embryogenesis.

Gonadotropic action of chemical substances. The nature of the action of chemical toxicants on gonads is closely related to development of germ cells, fertilization and embryogenesis.

Survey of female workers in chemical industry made it possible to reveal a violation of the menstrual cycle under the action of caprolactam, synthetic rubbers, phenol-formaldehyde resins, dimethylamine, carbon disulfide, benzene, phenol, etc. Increases in infertility rate were observed in those workers who were in contact with benzene, lead, arsenic, xylene, toluene, mercury.

Effect of poisons on spermatogenic epithelium can occur at all stages of its differentiation, which leads to a decrease in the number of mature spermatozoa (lead, vinyl chloride, fluoride, styrene, acetone, cadmium); decrease in their fertilizing capacity (chloroprene, chromium compounds) and as extreme case of harmful gonadotropic actions – infertility. It was noted in chemical industry workers exposed for more than 5 years to compounds of lead, arsenic, carbon disulphide, leaded gasoline.

Embryotropic action of industrial poisons. At early stages of pregnancy chemical compounds, entering woman's body under working conditions, can affect both the mother, disrupting the functioning of her organs and systems, and the fetus. These violations can manifest as termination of pregnancy, death of the fetus, formation of various developmental defects.

Teratogenic effect of chemicals (teratos – ugliness). It is known more than 600 chemical compounds that can penetrate placenta and disrupt development of the fetus. A manifestation of teratogenic effect of poisons largely depends on the stage of embryogenesis, with which this effect coincided. A definition of the most sensitive, so-called "critical periods" for effect of various substances is possible only when conducting experimental studies on animals.

Impact of a substance is determined by its dose and the period of exposure.

Disturbance of the placental barrier, inflammation and dystrophic changes in placenta are noted when exposed to dimethylformamide, formaldehyde, toluene, styrene, etc.

Long-term effects – development of pathological processes in individuals who have had contacts with environmental chemical pollutants later in their life, and also during the life of several consequent generations of their offspring. These include carcinogenesis and the genetic effect (genotoxic or mutagenic action).

Mutagenic action of chemical substances – ability of chemical substances to produce damaging effect on the genetic structure of the body. It is noted that 80% of genotoxicants penetrate the body with food, more than 10% – with water, and the rest – with the air and through the skin.

Dangerous in respect to mutagens are steelmaking, electrolytic production of aluminum, lead, copper, chromium, cadmium, beryllium, chloroprene, pesticides, epichlorohydrin, asbestos, rubber products, furniture, footwear.

Upon admission to the body genotoxicants can influence the chromosomal apparatus of both somatic and sex cells. The degree and nature of the damage depend on the target of the poison. Penetrating into cells, it can be inactivated or activated, can impact cell division, DNA synthesis, can interact with chromosomes, leading to chromosomal aberrations.

Disturbances (mutations) in somatic cells are not inherited by the offspring of a person in contact with the active poison, but can contribute to the development of acquired diseases, to be the cause of malignant tumors. An increase in the gene or chromosomal abnormalities in the reproductive cells affects the frequency of hereditary defects or diseases in the offspring. Chromosomal mutations in genital cells are accompanied by a decrease in the fetus viability in the form of spontaneous abortions, the birth of live children with anomalies (achondroplasia, congenital cataracts, polydactyly, etc.), mental retardation and possible sterility.

Types of action of industrial poisons

There are four types of action of industrial poisons: combined, intermittent, complex, combined.

The combined action of poisons is the simultaneous or sequential action of several poisons on the body through the same pathway. With a combined effect on the body, various effects can be observed. According to the classification, several types of joint action are distinguished:

a). **Summation** – when the joint effect is equal to the sum of the separate effects of the compounds. It is characteristic for substances of narcotic or suffocating action and substances that irritate the respiratory tract – mixtures of nitrogen oxides and carbon monoxide. Ethyl alcohol enhances the toxic effect of many IPs.

b). **Synergism or potentiation** – when one substance enhances the action of another substance. A clear example of synergism is an increase in the effect of nitroglycerin, arsenic, mercury and other substances with simultaneous exposure of the body to alcohol by increasing absorption through the gastrointestinal tract.

c). **Antagonism**, when one substance weakens the effect of another, so that the joint effect is less than the sum of the separate effects.

d). **Independent action** – the total combined effect does not differ from the isolated action of each poison. An independent action can be manifested with simultaneous action of irritating gases with benzene.

Intermittent action is associated with fluctuations in the concentration of the substance over time during the work shift – from extremely low to exceeding the maximum permissible, which can lead to disruption of adaptation processes.

For some poisonings metatoxic effect is possible – development of a pathological process after the poisoning has ended. For example, psychoses that arise after previously experienced carbon monoxide poisoning.

Complex effects of chemicals occur when the same substances are supplied in various ways with the air, water, food.

Combined action of chemical and physical factors

Actual working activity of a person proceeds under the influence not only of industrial poisons, but also of other unfavorable factors, such as high and low temperature, high and low humidity, vibration, noise, various kinds of radiation, etc. When there are combined effects of harmful substances with other factors (physical, chemical), the total effect may be more significant.

High temperature not only increases the volatility of poisons and increases their concentration in the air of the working area, but also disrupts the body's thermoregulation, which leads to loss of water, water-soluble vitamins, sodium chloride; also to acceleration of biochemical processes, increased respiration rate and increased blood circulation, increased body temperature. Expansion of vessels of skin and mucous membranes increases absorption rate of poisons through the skin and respiratory tract. Lowering the temperature also leads to increase of the toxic effect of many poisons (gasoline, benzene, carbon monoxide, carbon disulfide, etc.).

Increased air humidity increases the possibility and danger of poisoning, especially with irritating gases, due to their dissolution, formation of the smallest droplets, their retention on the surface of the mucous membranes, and the intensification of hydrolysis of the poison.

Barometric pressure, both increased and decreased, contribute to increase in the toxic effect of IP. At increased pressure, this occurs for two reasons: firstly, due to the increased intake of poison due to the increase in the partial pressure of gases and vapors in the alveolar air and accelerated passage into the blood; secondly, due to changes in the functions of respiration and circulation, the state of the central nervous system and analyzers.

Under reduced pressure conditions, the first cause is absent, but the influence of the second is still enhanced.

Noise and vibration enhance toxic effect of many poisons (carbon monoxide, benzene, carbon tetrachloride) due to functional changes in the body.

Radiant energy can reduce toxic effect of certain substances (ethyl alcohol, carbon monoxide) due to the intensification of oxidative processes in the body. In conditions of deficiency or excess of ultraviolet (UV) irradiation, the degree of toxic effect of chemicals increases, but UV radiation also improve resistance to chemical carcinogens.

Physical activity most often increases toxic effects of poisons due to increased blood supply to working organs.

Factors affecting the toxic effects of chemicals

Species differences. There are significant species differences in the sensitivity to chemical compounds, in particular, aromatic amines, nitro compounds, alkaloids, etc. For example, barium carbonate is 10 times more toxic for mice than for humans; Methanol is 30 times more toxic to humans than to mice. Species differences are determined by the speed and nature of metabolic processes, primarily by differences in the activity of metabolic liver enzymes. Different sensitivity to the poisons is possessed by separate animal lines even within one species (ordinary white mice and linear ones). The questions of assessing the sensitivity of species to chemicals are relevant in connection with the fact that for hygienic regulation we have to extrapolate the experimental data from animals to humans. To increase the reliability of extrapolation, special safety coefficients are introduced.

Sexual sensitivity. The opinion that a female organism is more sensitive to the action of poisons than the male one is not uniform, but females are surely more resistant to the toxic effects of a number of substances, not only with a single, but also with repeated exposure. This is noted specifically when studying the long-term exposure to small doses of mercury, ethyl alcohol.

Age sensitivity. Young organisms has increased sensitivity to the action of lead, carbon disulphide, benzene, acetone and other solvents. In a number of experiments, it was found that, regardless of the species of the animal (mouse, rat, rabbit, dog), newborns were more sensitive to the action of toxic substances than the young animals, and still more than adult animals. However, to such compounds as adrenaline, histamine and some narcotic substances, young and even newborn animals were less sensitive than adults.

Individual sensitivity. Persons with impaired metabolism, liver and kidney diseases are more prone to poisoning, since they have impaired excretory and detoxification functions. With severe anemia, disorders of hematopoietic function particularly strong reaction to hematolitic poisons is observed.

Persons with lesions of the upper respiratory tract are more predisposed to the action of irritating gases. Also, the state of the vegetative nervous system, various chronic diseases, has a great influence as to degree of individual susceptibility to industrial poisons.

Adaptation to poisons

Under low intensity influence of a chemical factor there may be no signs of toxic effects inherent and it can be regarded as adaptive or compensatory reactions of the organism. Reaction of the adaptive systems of the body is a multi-stage process and is characterized by a regular phase change.

The phase of primary reaction is short-term, lasting from several hours to two weeks. During this period there is increase in sympathetic nervous system activity, activation of pituitary-adrenal system and thyroid gland function, as well as the liver, where the main biotransformation of poisons occurs. Sometimes no shifts are observed at all.

The primary decompensation phase. This phase is characterized by impairment of homeostasis – resistance to extreme loads (blood loss, trauma, intoxication, physical activity) decreases. Duration and degree of expression of this phase depend on the amount of active poison and exposure.

The phase of nonspecifically increased resistance is formed when the poisonous action is continued, but the amount of active poison is not large enough to produce pronounced pathological changes. According to

N.V. Lazarev, this condition is called “nonspecifically increased resistance”, in which the functioning of the hypothalamus-pituitary-adrenal cortex system is up-regulated, adrenocorticotropic and secretory activity of the hypothalamic nuclei increase, and oxygen content in the brain tissue increases. This contributes to the adaptation and enhancement of the body's resistance to chemicals. The period of such habituation to the poison can be stretched for many years without pathological manifestations, it depends on the nature of the action of the poison, its ability to cumulate, on the mode of action (monotonous or intermittent), on the individual characteristics of the workers, and on impact of other environmental factors.

The habituation phase is interrupted by periods of intoxication. This is due to the weakening of the compensatory and protective mechanisms, with diseases or due to over-fatigue. In this regard, the body undergoes profound functional rearrangements. For example, in animals after the action of acetone, muscle strength decreased compared to the control group, and then, as the substance continued its exposure, it increased.

The most obvious sign of habituation to a harmful substance is disappearance of reaction to its repeated exposure, and it is needed to increase the dose to obtain the former effect. Weakening the reaction on the part of any system or organ can also indicate habituation. The presence of habituation to organic (hydrocarbons, amino and nitrocompounds, alcohols, organophosphorus compounds, etc.), inorganic (metal oxides, carbon monoxide, hydrogen sulphide), narcotic substances and irritating gases has been revealed. The presence of cross-adaptation to active poisons was also noted.

The phase of decompensation. The last period of intoxication is characterized by the presence of symptoms specific for the active poison; there is a definite decrease in the level of homeostasis. The organism becomes very sensitive to the action of the poison.

Thus, the adaptation to poisons represents a phase of poisoning masked by signs of adaptation, and this stage only temporarily slows down the pathological process.

When in the air of the working zone there is a sharp fluctuation in the concentrations of substances, habituation to them is unlikely, and nonspecifically resistance phase may not occur, which leads to appearance of severe intoxication. Activation of regulatory system of habituation to industrial poisons can increase overall resistance of the body to the effects of other factors or infections, which is usually seen in workers.

Acute, subacute and chronic forms of intoxication

Acute intoxication develops at a short-term (7–8 h) intake of relatively large amounts of toxic substances into the body and have a short latent period. Under industrial conditions acute poisoning can occur most often in case of accidents, depressurization of equipment or when using an unexplored substance that does not comply with the technological regulations. Cases are described when acute poisoning with gasoline came almost instantly (during the cleaning of tanks) and was characterized by excitation, weakness, trembling of hands and feet; sometimes there can be vomiting, tachycardia, chills and even a quick death from paralysis of the respiratory center. Very high concentrations of hydrogen sulphide also cause a instant form of poisoning with lethal outcome as a result of tissue anoxia.

Sometimes manifestations of acute poisoning are not immediately apparent (poisoning with arsenic hydrogen, nitrogen oxides), and after some latent (asymptomatic) period, when there are no specific manifestations of poisoning, and only nonspecific symptoms are observed – dizziness, nausea, general weakness, easy fatigue. There are cases of poisoning with zinc, which is essentially not a poison, but the finest zinc particles that are formed during melting can cause the so-called "cast fever".

The outcome of acute intoxication may be death, recovery or in case of repeated exposure – chronic development of the lesion, often with disability.

Subacute intoxications, in a similar way with the acute ones, occur due to a single intake of poison into the body, but in smaller quantities, and are usually characterized by less pronounced disorders.

As a result of modernizing of technological processes and implementation of hygienic regulations, air pollution with low concentrations of poisons is currently taking place in the work area. This can lead to development of chronic intoxications characterized by a gradual increase in functional and organic disorders with prolonged, long-term exposure.

The threshold of acute (LIM_{ac}) and chronic (LIM_{ch}) action of chemicals is considered to be the minimum concentration, a single or long-term action of which causes statistically significant deviations from the norm of a number of functional or biochemical health indicators.

The degree of hazard of acute poisoning development is determined by the inhalation poisoning possibility coefficient (IPPC), equal to the ratio of the volatility of the substance to toxicity during inhalation under standard conditions: 20°C, exposure for 2 hours (mice). Another indicator is the zone of acute action (Z_{ac}). The substance is all the more dangerous for development of acute poisoning, the smaller the gap between the concentrations that cause the initial signs of poisoning and the concentrations that cause death. For example, amyl alcohol has a very narrow zone of acute action (Z_{ac}=3). This is a dangerous substance in terms of the possibility of developing acute poisoning.

To assess the risk of developing chronic poisoning, Z_{ch} (zone of chronic effect) is used, the magnitude of which is directly proportional to the risk of chronic poisoning and K_{cum} (cumulation coefficient). K_{cum} is the ratio of the total average lethal dose of ΣDL_{50}, obtained in the experiment with repeated administration of the substance, to the same for a single administration. There can be **material cumulation** of a substance (accumulation of matter in the body) and **functional cumulation** (gradual enhancement of toxic effect at repeated exposures). The criteria for assessing the hazard degree are shown in the table 3.

Chronic poisoning is more often the result of functional cumulation under the influence of chlorinated hydrocarbons, benzene, gasoline and many gases and vapors, which are very easily excreted from the body with exhaled air. In metal poisoning, there is usually material cumulation.

Table 3

Classes of danger of development of acute and chronic poisoning by chemical substances

Indicators of hazard of acute and chronic poisoning	Norms for the hazard class of poisoning			
	I extremely dangerous	II highly dangerous	III moderately dangerous	IV low dangerous
IPPC	> 300	300 – 30	29 – 3	<3
Z_{ac} (Cl_{50}/Lim_{ac})	< 6	6 – 18	18 – 54	>54
Z_{ch} (Lim_{ac}/Lim_{ch})	> 10	10 – 5	4.9 – 2.5	<2.5
K_{cum}	<1	1 – 2.2	2.3 – 5	>5

In acute and chronic poisoning, some poisons affect the same organs and systems, while others act in different specific directions. For example, in acute poisoning benzene affects mainly the central nervous system, whereas in case of the chronic it causes leukopenia and parenchymal organs lesion.

Prevention of harmful effects of chemicals on the body

Legislative measures:

- Sanitary and hygienic regulations (MPC) limiting the content of harmful chemicals in the air of the working area;
- Hygienic standardization of raw materials, intermediate and final industrial products;
- Rational organization of working and rest conditions for workers occupied in hazardous chemical industries (reduced working hours, additional leave, early retirement).

Technological measures:

- Introduction of continuous technology that excludes an ingress of poisonous substances into the air of the working area;
- Elimination of poison from the technological process or use of new technologies aimed at replacing of highly toxic substances with non-toxic ones; complex automation and mechanization of production processes;
- Application of remote control of technological processes;
- Use of pneumatic transport;
- Use of automatically operating alarms, signaling when exceeding of the concentrations beyond established levels of MPC for hazardous aerosols, gases and vapors occurs.

Sanitary and technical measures:

- Arrangement of local mechanical exhaust ventilation in areas of possible toxic emissions in the form of hoods, side suctions, umbrellas with the speed of air movement in the range from 0.25 to 1.5 m/s or general ventilation with negative air balance.
- If sanitary and technical measures do not eliminate the effects of toxic compounds on the body, especially when working in enclosed spaces, during repair work, sampling, personal protective equipment (PPE) – gas masks, respirators, clothing, goggles, pastes, ointments, creams and other protective devices should be used.

Curative and preventive measures:

- Conducting of preliminary (when hiring) and periodic medical examinations of persons working under influence of chemical factors;
- Organization of rational, curative and preventive nutrition;

- Sanitary and educational work at enterprises – promotion of knowledge on the prevention of occupational diseases, promotion of knowledge in the field of personal and public hygiene.

Features and principles of hygienic regulation of harmful chemicals in the air of the working area

Up to 95% of all occupational poisoning is caused by inhalation of volatile harmful chemicals (HC). Therefore, knowledge of methodology for determining air pollution in industrial premises is necessary for physician, including the workshop therapist, for the hygienic assessment of working conditions and for investigating the causes of poisoning in the workplace.

Working area is a space up to 2 m high above the floor or a platform on which there are workers permanently or most of the working time – more than 50% or 2 hours continuously; when working in different locations – the entire work area. HC can enter the air during a wide range of production processes: thermal, chemical, mechanical, transport, etc., so systematic monitoring of compliance with MPC of toxic substances contained in the air is carried out at enterprises. Hygienic regulation of HC in the air of the working area is characterized by a number of features due to their level, regime and duration of impact on the population of working age. For chemical air pollutants in the work area, two types of MPCs are developed and regulated: the maximum one-time and the shift average. MPC – the maximum permissible concentration of harmful substance in the air of the working area is the concentration that for a period of 8 hours (but not more than 41 hours per week) during the whole period of work activity does not cause disease or abnormalities in the health state of the worker and his offspring, detected by modern methods of analysis during work or in the long term of life.

The maximum one-time MPC is the concentration of HC in the breathing zone of workers, averaged by a period of short-term sampling of the air (15 min).

The shift average MPC is the average concentration of HC obtained with continuous or intermittent sampling of the air for a period of not less than 75% of the shift time, or the weighted average of the entire working shift in the breathing zone of those working in the places of permanent or temporary residence; it is established along with the maximum one-time MPC, regulated for substances with pronounced cumulative properties (copper, mercury, lead, etc.)

When establishing the MPC for HC in the air of the working area in our country they are guided by the following principles:

1. The principle of advancing of development and implementation of preventive measures relative to the time of initiation of the substance use in the wide practice.

2. The principle of the stage-wise development of toxicological research, which is conducted synchronously with the stages of chemical and technological development of production of a new product.

3. The principle of priority of medical and biological indications for establishment of sanitary regulations before considering of other approaches (technical feasibility, economic requirements).

4. The threshold principle for all types of action of chemical compounds (including mutagenic and carcinogenic).

5. The principle of the unity of the organism with environ, unity of the organism as a biological system.

Hygienic rationing of HC is currently carried out in 3 stages:

1. Justification of the roughly safe level of impact as a temporary hygienic standard for content of harmful substances in the air of the working area, established by calculation methods.

2. Justification of MPC is based on the toxicometry indicators obtained in animal experiments through the threshold of chronic impact and the safety factor.

3. Adjustment of MPC by comparing the working conditions of workers and their health status, while the value of MPC can be revised taking into account the data on the health of workers or in connection with accumulation of new information on the toxicological characteristics of the compound or substances close to it.

When MPC is established in the air of the working area, it is necessary to investigate the effects of HC on the skin, and for substances having a skin-resorptive effect, to justify the **maximum permissible level** of skin contamination (**MPL**, mg/cm^2).

Development of MPC, MPL and hygienic assessment of the air pollution of industrial premises is carried out using methods of sanitary-chemical analysis, as well as physical and chemical methods.

Determination of harmful chemicals in the air of the working area: general principles and methods

The direct objective of sanitary and chemical study of air pollution in the working area is their qualitative detection and quantification. Since most often it is necessary to determine very small amounts of a substance, measured in milligrams or their fractions, the methods of determination must be highly sensitive and accurate. However, it is often necessary to give a quick answer about the presence and concentration of poisons in the air, in such cases, less accurate express methods are irreplaceable. In addition, if working with substances of the first and second hazard classes, monitoring is carried out – automatic continuous gas monitoring, giving information on trends and dynamics of the contamination degree in time, with the help of stationary gas analyzers.

Sanitary and chemical analysis of the air of industrial premises consists of the following stages:

- Thorough study of the technological process and equipment to determine the cause of air pollution with HC (to specify the problematic stage of the process when the poison occurs and to specify at what periods it enters the air)
- Familiarization with the physical and chemical properties of the substances to be determined (specific gravity, volatility, solubility, dispersity, the ability to change its aggregate state, etc.)
- Choice of the informative sampling points (place and period), taking into account the technology, equipment and working areas; drawing up a map of the plan of the shop (factory) with application of selection points on it
- The air sampling procedure
- Analysis of the air sample
- Evaluation of results

Methods for the air sampling. Equipment

Air samples are taken in the breathing zone of the workers – in the working area, also at the places of their temporary residence and in the so-called neutral points. The level of sampling from the floor and working areas is determined taking into account the physical and chemical properties of these substances and the directions of the currents of the air movement. The mandatory parameters to be measured at all times are the air temperature (t) and barometric pressure (P) at the time of sample collection. These are needed to bring the volume of the air sampled to the so-called "normal conditions" ($t=0^{\circ}C$, $P=760$ mm Hg), for which the MPC is established, according to the following formula:

$$V_0 = \frac{V_t \times 273 \times P}{(273 + t) \times 760}$$

where:

V_0 – is the volume of the air under normal conditions;

V_t – is the volume of the air taken for the study at given t and P;

273 – is the coefficient of gas expansion;

Aspiration method is used in those cases where it is difficult to determine a micro-quantity of a substance in a small volume but whose presence already has a hygienic significance. It is based on the principle of drawing air through absorbing media (liquid or solid), which retard and concentrate the substance desired. The result of the sample analysis in this case reflects the average concentrations of the substance during the sampling time, which can take up to 30–60 minutes to accumulate the poison.

For air sampling, air driving devices are required, which may include pumps, vacuum cleaners, but the best way to do this by using electric aspirators (***Fig. 4a, p. 19***). They allow regulating easily the speed of the air drawing – along the upper edge of the float rheometers, two of which are graduated from 0 to 20 l/min, and the other two – from 0 to 1 l/min; The latter are used to determine gases and vapors. The device requires a mandatory grounding and is used only in explosion-proof conditions. In those cases where production processes are explosive, AERA – an automatic ejector mine aspirator (***Fig. 4b, p. 19***) can be used. In this device the air being sampled is taken in thanks to the vacuum effect, simultaneously created by the rapid movement of air out from the compressed air cylinder at a speed of 20 l/min.

To absorb harmful vapors and gases for analysis the air sample should pass through adsorption solutions or solid sorbents contained in absorbers (absorbing devices). These are glass products of different design, filled with solution. Specific device construction ensures maximum contact of the air drawn with the absorption solution. This is achieved by the fact that by narrowing the lower part of the absorber, the height of the column of liquid through which the analyzed air passes increases. To further increase the contact of the air with the solution in some absorbers, a glass porous plate is soldered into the lower part of the tube. The upper part of the absorber is usually expanded to reduce the speed of the air movement, prevent foaming of the liquid and its ejection.

Constructions of the absorption devices are diverse (***fig. 8***), they are often called by the name of the author or institution, having implemented

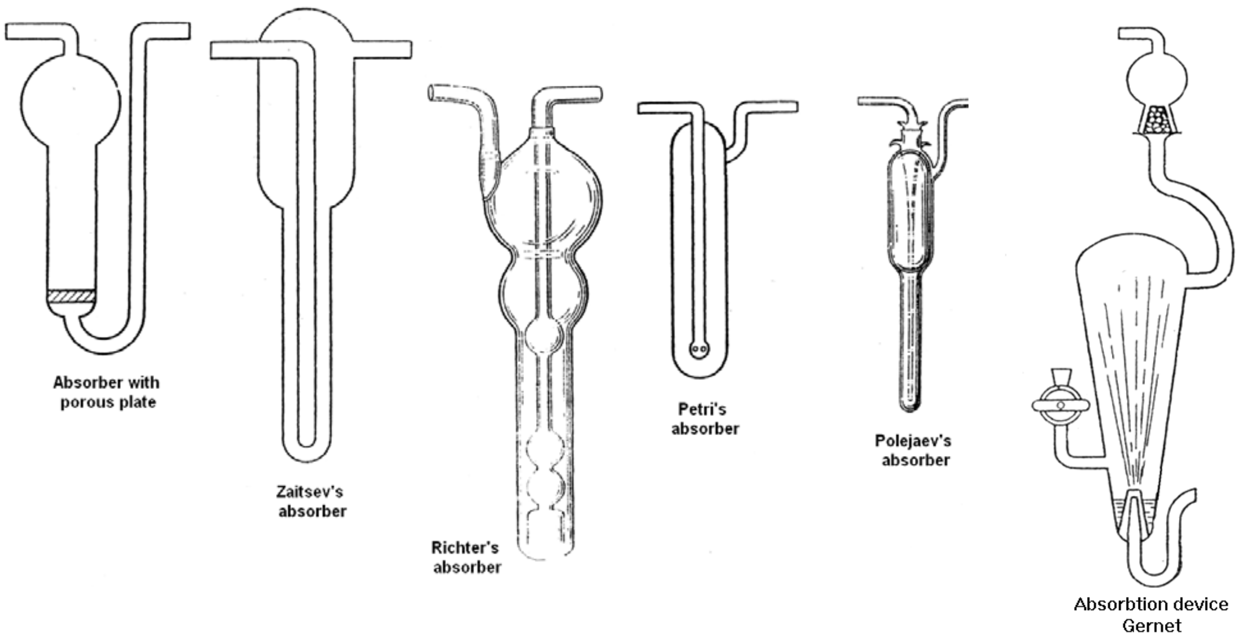


Figure 8. *Absorbing devices*

them for the first time (absorbers of Polezhaev, Zaitsev, Petri, Richter, Gernet, etc.). To be used as absorbing media, liquids that dissolve the detectable substances or react quickly with them are preferred. Under conditions of high and low temperatures, when evaporation or freezing of the solution in absorbers is possible, solid grained sorbents, such as – silica gel and activated carbon are used in tubes or special containers, from which the absorbed substances are subsequently desorbed with the help of suitable solvents.

One-shot sampling is performed at high concentrations of HC in the air and application of highly sensitive methods of assay.

The air smpling procedure can be conducted in several ways:

1. The method of pouring liquid from a vessel (bottle), which leads to its filling with the air being examined;

2. The air exchange method is when through a dry vessel into which a sample is taken, the volume of the air to be examined is blown 10 times (in relation to the volume of the vessel).

3. The vacuum method of filling the vessel is the fastest and most convenient: in the vessel intended for sampling, the air is vacuumed by a pump and the vessel is opened at the point of collection.

After the air sampling (in a bottle of known capacity, gas pipettes) by any of the methods the samples are sent to the laboratory for analysis.

Methods for sanitary-chemical analysis of the air samples

Air samples taken by the aspiration method in liquid absorption media are solutions and can be immediately analyzed.

In samples taken in containers (vessels) by a single-step method, the substance is found in the air and either it is transferred to a solution or the air is distilled by an aspirator through appropriate absorbing solutions, and the content of absorbers is then analyzed.

For air analysis in industrial enterprises, the methods most often used are those that determine small amounts of toxic substances. Along with traditional chemical (titrimetric, etc.), photometric, chromatographic, luminescent, spectroscopic and other methods of investigation are used. Based on results of the analysis, a hygienic assessment of the HC content in the air of the working area is made.

Example. In the electrochemical plant's electroplating shop air sample was taken for the chromic anhydride content for 10 minutes at the rate of 10 liters per minute. The air temperature in the shop at the time of sampling was 20°C, atmospheric pressure 760 mm Hg. When analyzing the absorption solution 30.0 μg of chromic anhydride was found in it.

Solution. We bring the volume of the air to normal conditions:

$$V_0 = \frac{V_t \times 273 \times P}{(273 + t) \times 760}$$

where:

V_0 is the air volume required at 0°C and the pressure of 760 mm Hg;

V_t is the volume of the air taken for analysis at the temperature t and barometric pressure P;

273 is the coefficient of gas expansion;

In this problem:

$$V_0 = \frac{(10 \times 10 \times 273) \times 760}{(273 + 20) \times 760} = 93\,liters$$

The content of chromic anhydride – (X) in 1 m^3 of the air is determined by the formula:

$$X = \frac{30 \times 1000}{93} = 0.322\,mg/m^3$$

which exceeds the MPC for CrO_3 (0.1 mg/m^3) more than 3 times.

Express methods of harmful chemicals determining. Equipment

There are 3 groups of express methods for HC determining:

- The methods of visual colorimetry – comparison of the color of the absorbing solution that appears after drawing the test air, with a standard scale;
- The methods, using reactive paper, allow for qualitative and quantitative analysis of HC content: the presence of a substance is judged by the appearance of a characteristic color, and concentration of the substance is judged by its intensity;
- The linear color methods with the use of indicator tubes.

Currently, for determining of many HCs the linear-color method is mainly used, based on change in the color of the indicator powder enclosed in a testing glass tube. Determination of HC in the air is carried out with the help of special instruments – universal gas analyzer (UG-2), chemical gas determiners, and some others.

The universal gas analyzer (UG-2, ***fig. 9a***) is designed for rapid quantitative determination of various vapor and gaseous HC (vapor of gasoline, benzene, toluene, nitrogen oxide, ammonia, acetone, carbon monoxide, etc.).

The principle of UG-2 operation is based on measuring the colored column length of the indicator powder placed inside the indicator tube. The length of the indicator powder column as a result of reaction with absorbed HC is proportional to their concentration in the air; it is measured by the scales applied to the instrument, graduated in mg/l (mg/m^3).

The construction of UG-2 includes:

- Air inlet – rubber chamber (bellows), inside of which a spring is placed;
- Indicator tubes;
- Measuring scales;
- Set of rods allowing selecting different volumes of HC.

On the top panel of the device there is a fixed bushing, where rod is inserted, by means of which the bellows is compressed. On the bushing there is a stopper, fixing the rod for air sucking through the indicator tube. The latter is connected with a rubber tube, which is put on the bellows terminal.

The indicator tube is a glass tube (length 90 mm, internal diameter 2.5 mm) filled with a powder – silica gel or porcelain, which are treated with

a b

Figure 9. *Universal gas analyzers*

a – UG-2 (Rus. УГ-2); b – Microsence M3 (Rus. Микросенс М3, modified from www.igm-pribor.ru)

reagents that change color when in contact with the HC detected. The composition of the indicator powders is different for different substances:

for gasoline determination it will be silica gel impregnated with a solution of potassium iodate in concentrated sulfuric acid; for determination of ammonia – the porcelain powder treated with an alcoholic solution of bromophenol blue; for determination of hydrogen sulphide, silica gel, treated with a solution of fluorescein and potassium bromide (yellow turns pink), etc. The white indicator powder for the determination of gasoline when passing through a gasoline vapor tube acquires a brown color, pairs of ammonia stain the orange-brick powder in blue color, etc.

Indicator tubes with a special micro-funnel are filled with the indicator powder, which is in sealed ampoules. The powder in the tube is held on both sides by means of two cotton woolen cloths, and its ends are poured with sealing wax. Prepare the tubes immediately before analysis (ex tempore!).

The order of work with UG-2 device. On the site of the analysis, open the lid of the device and perform the following operations:

1. Pulling the stopper;
2. Insertion of the rod into the guide bush;
3. Purging the bellows with the air investigated (10-fold);

4. Fitting the rod to the required depth indicated on the groove of the rod;
5. Securing the rod with a stopper;
6. Connection to the bellows of the indicator tube fitting;
7. Retraction of the stopper;

When retracting the stopper under spring pressure, the bellows expands and sucks in the test air through the indicator tube. The air stretching continues until the tip of the stopper enters the bottom hole of the rod (at this time, a click is heard). After this, keep pause (5–7 minutes), because sucking of the air through the tube because of the negative pressure formed in the bellows, is still going on.

At the end of the air pulling, the indicator tube is released and set on the appropriate measuring scale; then determine the concentration of the test substance in the air (mg/m^3).

The blurring of the interfaces between the colors of the layers of the initial and reacted powder should not exceed 2 mm. The measurement result is taken from the middle of the blur. If the boundary is blurred, exceeding 2 mm, the measurement must be repeated.

Portable universal gas-detector «Microsence M3» (***fig. 9b***) uses optical, electrochemical and photo-ionizing methods, allowing detection of pre-explosive concentrations of combustible gases, oxygen volume fraction, hydrogen, carbon dioxide, harmful gases and vapors of volatile potential compounds in the air of a working area. Once maximum permissible concentration of a gas is reached, alarm sound is produced. The device can be used in wide spectrum of working environments, including underground mines, characterized by exposure to explosive hazardous gas and dust.

INDEPENDENT WORK OF STUDENTS

1. Prepare and assemble air sampling device (using an aspirating method) with the assistance of the teacher.

2. Determine content of benzene, ammonia and carbon monoxide in the air (pollution simulation) by means of UG-2. Give a hygienic assessment of the air quality, comparing the data obtained with the MPC for these substances (***tab. 4***).

Table 4

Maximum permissible concentrations for common chemicals in the air of the work area

	Substance name	MPC value, mg/m^3	Primary aggregate state	Hazard class under industrial conditions
1	Ammonia	20	Vapor	IY
2	Benzene +	15/5	Vapor	II
3	Carbon monoxide	20	Gas	IY

Note: + – Danger when entering the skin.

SITUATIONAL PROBLEMS

Problem 1. As a result of the planned air study, benzene at the concentration of 27 mg/m^3 was found in one of the shops of electric wire plant.

1. Give hygienic assessment of the air quality in the plant shop.
2. What preventive measures should be taken in the shop of the plant: tactics of the shop doctor.

Problem 2. In the air of electric lamp factory shop insignificantly high content of beryllium (0.0015–0.0019 mg/m^3) is found during 3 weeks. The maximum permissible concentration of beryllium for the air in the working area is 0.001 mg/m^3, the substance belongs to the I hazard class.

What preventive measures should be taken in the shop of the plant? Tactics of the shop doctor (full program of his actions, their sequence), forecasting of the sanitary situation. Discussion of the results.

QUESTIONS FOR SELF-CONTROL

1. Industrial poisons: definition of the concept.
2. Classification of industrial poisons.
3. Ways of IP entering into the body. The term "distribution coefficient".
4. Ways of excretion of chemicals from the body.
5. Dependence of toxic effect of substances on the chemical structure.

6. Specific action of chemicals on the organs and systems.
7. Long-term effects of poisons on the body.
8. Combined action of chemicals.
9. Factors affecting the toxic effects of chemicals.
10. Adaptation to poisons. Phases. The concept of nonspecifically increased resistance.
11. Acute, subacute and chronic intoxication. Thresholds of acute and chronic effects of chemicals. The concept of inhalation poisoning possibility coefficient.
12. Measures to prevent harmful effects of chemicals on the body.
13. The concept of MPC, the maximum one-time and shift-average MPC.
14. Principles of establishing MPC in the air of the working area.
15. Stages of sanitary-chemical study of the air in the working area.
16. Aspiration method of air sampling.
17. Methods of air sampling for harmful chemicals.
18. Principle of operation of electric aspirator and automatic ejector mine aspirator (AERA).
19. Methods of sanitary-chemical analysis of the air samples.
20. Express methods for the determination of harmful chemicals.
21. Principle of UG-2 device operation.

3. NOISE AS A HARMFUL INDUSTRIAL FACTOR

Purpose of the lesson: is to introduce students to the problem of industrial noise, its impact on the body, regulations, efforts to prevent exposure of the workers; noise-measuring equipment; methods for studying the effect of noise on the body.

Practical skills: is to master the technique of measuring and hygienic assessment of industrial noise.

Task for students:

1. With the help of this tutorial to obtain theoretical knowledge of noise as a harmful industrial factor.
2. To familiarize yourselves with equipment for definition of intensity of industrial noise.
3. To measure the background noise level in the training room with the sound level meter. As well measure the level of production noise sample recorded on the magnetic tape.
4. To use physiological methods to assess the short-term effect of industrial noise on the body of a volunteer student.

Theoretical part

At present, noise is one of the most dangerous and harmful environmental factors. Acoustic discomfort accompanies a modern person at home, at work, in transport, on the street. In one of A. Bell's figurative expressions, noise became "a public calamity and a danger to the physical and mental health of the population". According to WHO, in 2002 there were 250 million people with hearing impairment, which is 4.2% of the world's population. In Russia, over 240000 of people with hearing impairment have been registered and more than 13 million people with socially significant hearing impairments. More than 30% of residents of large cities of Russia live in the high-level noise zones.

The effect of noise on the body is often combined with other harmful industrial factors – vibration, ultrasound and infrasound, toxic substances, an unfavorable microclimate. The effect of high levels of noise on the body leads to development of premature fatigue, reduced efficiency, increased morbidity, disability and other adverse consequences. Noise and vibration as harmful industrial factors account for about 40% of all occupational pathology.

Noise concept definition

Sound vibrations affect a person permanently; their sources can be of natural and artificial (anthropogenic). Natural sounds can be as little intensity as the rustle of leaves, the voices of birds and animals, the noise of a stream; and of enormous power – the noise of a hurricane, a waterfall, a volcano during its eruption.

Evolutionary sound was used by living organisms as a means of biological communication. Absolute silence is not physiological for a human body. Sound is essential component of environment, psychological stimulus, a source of information. It is noted that harmonious, ordered sound vibrations – speech, music, verses, can have a beneficial effect on the psycho-emotional sphere, hide unwanted noise and contribute to labor productivity and even acceleration of recovery in a number of diseases. In modern conditions hygienists attach great importance to the noise from acoustic systems at concerts and discotheques, due to which high risk of development of diseases of both the auditory analyzer and other organs and systems is established. Damaging effect of noise on the body of adolescents is established when using players whose sound pressure level reaches 105 dBA. When using electromechanical children's toys with sound signals, noise can reach 115 dBA, which in children of school age lead to dip in hearing at the frequency of 4000 Hz.

Noise is a collection of sounds of different frequency and intensity, randomly combining and changing in time, having adverse effects on the body, hindering work and rest.

Mechanism of noise generation

According to the physical point of view, noise is the mechanical vibrations of particles of an elastic medium (gas, liquid or solid) that arise under the influence of some perturbing force. In this case, sound is called regular periodic oscillations, and noise – non-periodic, random oscillatory processes.

Noise occurs as a result of oscillations during collision, friction, sliding of solids (mechanical); flow of fluids (hydrodynamic); movement of gases during the operation of injectors, compressors, pneumatic conveying system (aerodynamic); when propagating impact noise on the structure of the building (structural).

Noise is one of the most widespread occupational hazards in foundries, metalworking, pharmaceuticals, forestry and construction, mining, textile, woodworking and other industries.

In production conditions, noise sources are operating machines, manual power tools (electric and pneumatic saws, jackhammers, perforators), electric machines (generators, electric motors, turbines), compressors, press-forging and handling equipment, ventilation systems, air conditioners and etc. In the pharmaceutical industry, the sources of intensive noise are tablet machines and granulators in the production of tablets, the gearboxes for the production of pellets, crushers, sieves, conveyors in galenic shops. For example, ball mills generate noise greater than 90 dB, jaw crusher 100–125 dB.

Noise inside the treatment and preventive and pharmacy establishments is created by the operation of ventilation installations, water supply and sewerage, vacuum pumps, in suction of liquids, electromotors of devices for artificial circulation and ventilation, washing machines and other equipment.

Fundamental acoustic concepts and measurement units

A sound is a wave process propagating in an elastic medium in the form of alternating waves of condensation and rarefaction of the particles of this medium. The source of sound can be any vibrating body. When this body comes into contact with the environment, sound waves are formed. Condensation waves cause an increase, and rarefaction waves – a decrease in the pressure in an elastic medium. So there is a sound pressure – variable pressure from passage of sound waves in addition to atmospheric pressure.

Sound pressure is measured in pascals (Pa), equal to one newton (N) per meter square (1 Pa = 1 N/m^2). The person's ear senses sound pressures in the range from 2×10^{-5} (threshold of sound perception) up to 2×10^2 N/m^2 (pain threshold).

Sound waves are energy carriers. Sound energy, which accounts for 1 m^2 of surface area, located perpendicular to propagating sound waves, is called the sound power or sound energy and is measured in W/m^2.

A sound wave is an oscillatory process, which is characterized by such concepts as the period of oscillation (T) – the time during which one complete oscillation takes place; frequency of oscillations (f) – number of complete oscillations per 1 sec (measured in Hertz – Hz); the amplitude of the oscillations is the greatest deviation from the point of stable equilibrium – the sound wave amplitude. The frequency composition of the noise is characterized by its spectrum, i.e. the set of frequencies it is made of.

The amplitude of the oscillations determines the magnitude of the sound pressure, and the frequency of the oscillations is the pitch of the sound: the higher the frequency of oscillations, the higher the sound and the shorter the wavelength. The wavelength (λ) is equal to the velocity of sound propagation (334 m/s) divided by the oscillation frequency: $\lambda = 334/f$.

By frequency, all the fluctuations are divided into three ranges:

- Infrasonic – up to 20 Hz;
- Audible – the sound frequency range, perceived by the human hearing organ as a sound, from 20 to 20000 Hz;
- Ultrasonic – above 20000 Hz;

The voice of a person has a sound frequency within 80–350 Hz (bass) and 260–1300 Hz (soprano). The human ear is most sensitive to sound vibrations in the range of 1000–4000 Hz (***fig. 10***).

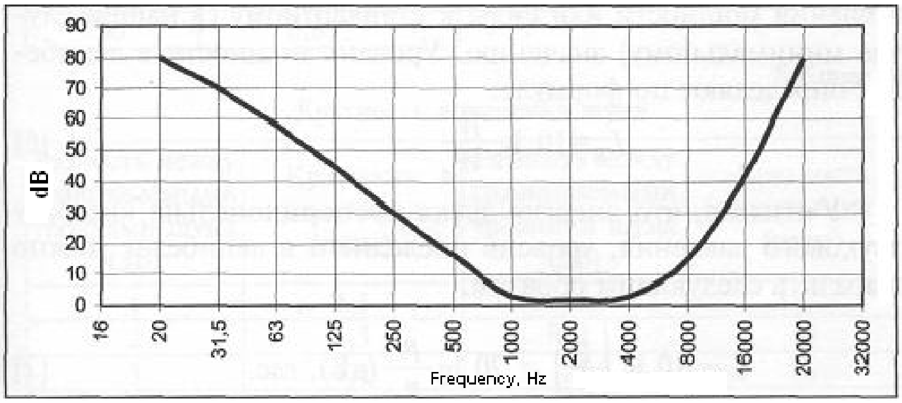


Figure 10. *Audible frequency range*

The frequency range that a person hears, even in the absence of organic lesions decreases with age, which is associated with a natural (physiologic) change in the body. To a greater extent, hearing loss occurs in the high frequency range.

A frequency characteristic of noise is of great importance in evaluating its effect on the body, since sounds of the same intensity but of different frequencies are perceived unequally. The high frequency sounds are perceived as louder and, consequently, they have a more pronounced effect on the auditory analyzer. In terms of production environs most often there are noises in the range from 45 to 11000 Hz. This range is divided into 9 octaves with the average geometric values of the frequencies: 31.5; 63; 125; 250; 500; 1000; 2000; 4000; 8000 Hz. Octave is an interval frequency, in which the upper limit is twice as large as the lower limit, for example, 45–90 Hz. The average geometric frequency is the square root of the product of frequencies that are boundary for a given octave ($\sqrt{45 \times 90} = 63$).

According to the frequency of vibration, a noise is divided into low-frequency – up to 400 Hz; mid-frequency – from 400 to 1000 Hz; high-frequency – over 1000 Hz.

For hygienic characteristics of noise, not absolute physical quantities (sound pressure, sound energy) are used, but relative, taking into account the subjective perception of sound – bell, decibel. The organ of hearing distinguishes not the difference (absolute increase), but the multiplicity of the change in sound pressures. For example, if the intensity of one sound is 10, 100, 1000 times higher than another, then according to the logarithmic scale it corresponds to an increase by 1, 2, 3 units (log 10=1; log 100=2, etc.).

In the range from the threshold of sound perception to the pain threshold, the ratio of sound pressure changes by a factor of a million, so to reduce the measurement scale, the sound pressure levels are expressed in logarithmic units. A logarithmic unit that reflects a tenfold increase in the intensity of sound over another's level is called bell (B). The decibel (dB) is 1/10 of bell. Zero dB corresponds to a sound pressure of 2×10^{-5} N/m^2, approximately equal to the threshold of audibility of a tone with a frequency of 1000 Hz. The sound power or sound energy taken for 0 decibels is 10–12 W/m^2. The decibel scale is within the range from 0 to 140 dB: 0 dB – the threshold of audibility; 85 dB – the beginning of the danger zone; 140 dB – the pain threshold.

Classification of noise

Sanitary standards establish a classification of noise; characteristics and permissible noise levels at the workplace; general requirements for the measurement of standard values; main efforts to prevent adverse effects of noise on the workers.

Noise is classified according to two principles – the nature of the spectrum and time characteristics.

The nature of the spectrum (the totality of the sounds that make up the noise) is divided into:

- Broadband noise, with a continuous spectrum, a width of more than one octave;

- Tonal noise, in the spectrum of which there are audible discrete tones, i.e., sounds of a certain height. The tonal character of the noise is established by measuring in 1/3 octave frequency bands by exceeding the level in one band over neighboring ones by at least 10 dB.

According to time characteristics, noise is divided into:

- Constant noise – such a noise, whose level for an 8-hour day changes in time by no more than 5 dBA;
- Variable noise is whose sound level changes by more than 5 dBA over an 8-hour day.

The **variable noise** is further divided into:

- Oscillating in time, the sound level of which continuously changes in time;
- Intermittent, the sound level of which changes step by step by 5 dBA or more, and the duration of intervals during which the level remains constant is 1 sec or more;
- Pulse, consisting of one or several audio signals, each lasting less than 1 second.

Effect of noise on the human body

The hearing organ performs two functions: it provides the body with sensory information that allows it to adapt to the surrounding environment and provides self-preservation, i.e., it counteracts the damaging effect of the acoustic signal. Under noise, these functions are in conflict: the hearing should have a high resolving sensitivity to information signals on the one hand, and on the other hand, in order to adapt to noise, the auditory sensitivity should decrease. In this regard, the body takes a compromise solution – a decrease in auditory sensitivity, a temporary shift in the hearing threshold, i.e., internal adaptation of the hearing organ, and a simultaneous decrease in the adaptive capacity of the organism as a whole.

It may be distinguished specific (aural) and nonspecific (extraaural) effect of noise. The first is associated with a disruption of the auditory analyzer function due to the prolonged spasm of the vessels of the sound receiving apparatus, mechanical injury of the auditory receptors, and disturbance of metabolic processes. This leads to degenerative changes in precochlear nerve and cells of the spiral (Corti) organ, to their atrophy.

As result, professional deafness or neuritis of the auditory nerve (cochlear neuritis) develops. In the early stages of the process, maximum hearing loss is noted at the frequency of about 4000 Hz; further development of professional hearing loss is characterized by a decrease in sound perception throughout the range of sound waves. Professional hearing loss develops slowly, gradually progresses with increasing age of workers and the length of their work experience. In this regard, the main method of early diagnosis of hearing impairment in workers of noisy industries is tonal audiometry, which makes it possible to determine the minimal intensity of tones of different frequencies perceived by each ear separately.

The professional pathology of the hearing organ is also a sound trauma. It is caused by impact of intense impulse noise and consists in mechanical damage to the tympanic membrane and middle ear.

The main role in the development of noise damage to the hearing organ belongs to the noise intensity. Changes in the central nervous system occur much earlier than violations in the sound analyzer. At the same time, noise, acting as a stress factor, causes a change in the reactivity of the central nervous system, resulting in disorders of relevant functions of the organs and systems.

In addition to noise intensity, its biological effect is influenced by the nature of the spectrum. A more unfavorable effect is caused by high-frequency noise (above 1000 Hz) compared to low frequencies (31.5–125 Hz). Biologically aggressive noise includes impulse noise arising from hit processes (riveting, stubbing, forging, stamping, etc.), as well as noise, in the spectrum of which there are audible discrete tones. It is believed that a constant noise is relatively favorable compared to the non-constant noise due to the time-varying sound pressure level of the latter.

The nonspecific effect of noise on the human body is associated with impact on the cerebral cortex, hypothalamus and spinal cord. In the cortex at initial stages of the noise exposure, inhibition develops, which is manifested by a violation of the equilibrium of excitation and inhibition processes. At the same time, nerve cells are depleted, which is manifested by symptoms such as irritability, emotional imbalance, decreased memory and attention, disability.

From hypothalamus excitation is transferred to the pituitary gland, then to the cortical substance of the adrenal glands. The body's response is realized by the type of stress reaction. When the excitation enters the spinal cord, switching it to the centers of the autonomic nervous system, which causes disruption of the functions of many internal organs, depresses the immune responses of the body. As a result, a noise disease develops – a symptomatic complex of functional and organic changes with a predominant lesion of the ear, central nervous system, circulatory and digestive system.

There may be complaints of headache, fatigue, sleep disturbance, memory loss, irritability. Objectively, prolongation of the latent period of reflexes, changes in dermographism, pulse liability, increase in blood pressure are observed. There may be respiratory depression, disturbances in the visual analyzer function (decrease in cornea sensitivity, decrease in the clear vision time and critical flicker frequency, deterioration of color vision), vestibular disorders (dizziness), gastrointestinal disorders (motor and secretory function).

After a long exposure to noise, the workers have a rhythm of breathing, pulse altered; the vascular system tone increases, which leads to an increase in systolic and diastolic pressure; the motor and secretory function of gastrointestinal tract undergo changes; hypersecretion of individual glands of internal secretion, vegetative disorders are manifested as increased sweating of feet and brushes; lipid metabolism is altered and accelerates atherosclerosis development.

Pathological process with noise exposure develops gradually and begins with nonspecific manifestations as vegetative vascular dysfunction (autonomic dysfunction). Later neurotic changes develop, manifested as vegetative asthenia syndrome. For workers with experience of more than 10 years, such changes become permanent.

Hygienic assessment of noise

For approximate estimation of the constant noise at the workplace, one determines its level in dB, measured on the "A" scale of a sound level meter (dBA), which approximately corresponds to the frequency response of the noise, physiologically adjusted, well perceived by human ear. In the spectral estimation, a constant noise is characterized by sound pressure levels (dB) in octave frequency bands. This method of evaluation is fundamental.

An unstable noise is estimated by the **equivalent sound level** in dBA. Equivalent level of a variable noise is the level of constant broadband noise sound, which exerts the same effect on a person as the investigated variable noise.

In case of a pulsed noise, the peak level is what we take and, if it does not exceed 125 dBA, then minus 5 dBA correction is introduced into the standard established for constant noise for this workplace. The value obtained in this way is the norm.

The **permissible sound pressure levels** (dB) in octave bands, **equivalent and maximum sound level** (dB) at workplaces are given in the table 5. (Extract from the "Construction Norms and Regulations of Russian Federation, Protection Against Noise", SNiP 23–03–2003, put into effect on 1.01.2004).

Measurement and analysis of production noise

To estimate noise levels at workplaces in industrial premises, the measurement must be made in at least three locations. The microphone that takes the noise should be placed 1.5 m above the floor or a work platform level, or at the height of the head of a person sitting. It should be directed towards the source of noise and removed at least 0.5 m from the person making the measurement.

When measuring, general sound pressure levels, the spectral composition of noise in octave bands, and equivalent sound levels in dBA can be determined. The advantage of measuring noise in dBA is that it allows determining the increase in the permissible noise level without spectral analysis of it in octave bands.

Sound level meter and noise analyzer are used to measure noise levels. The principle of operation of instruments measuring the noise level consists in converting the parameters of the electric current generated in them under the influence of sound energy and recording of these current changes on the scale graduated in decibels.

For hygienic assessment of noise at workplaces or in industrial premises, the intensity level and the spectral composition of the noise are measured. For this purpose, noise meters, filters, recorders, tape recorders are used to record and reproduce the noise being investigated.

Spectral noise analysis is performed using a noise analyzer or bandpass filter. As noise analyzers, octave filters are used that measure the sound pressure levels in each octave of the noise under investigation.

Sound level meter consists of three main units: microphone, amplifier and measuring scheme. The sound level meter has frequency (A, B, C) and time ("Fast", "Slowly") switchers. When measuring sound levels (dBA), “A” frequency setting is applied. On the "Slowly" setting the device is used when measuring the constant and other types of noise for the purpose of their averaging, the "Fast" setting is used to measure a noise oscillating in time.

Table 5

Maximum permissible noise levels

Appointment of premises or territories	Time of day, hours	Sound pressure level (equivalent sound pressure level), dB, in octave bands with average geometric frequencies, Hz									Equivalent sound level, dBA	Maximum sound level, dBA
		31.5	63	125	250	500	1000	2000	4000	8000		
1	2	3	4	5	6	7	8	9	10	11	12	13
1. Workplaces of administrative and managerial personnel of manufacturing enterprises, laboratories, premises for measuring and analytical work	-	93	79	70	63	58	55	52	50	49	60	70
2. Work premises of dispatching services, observation and remote control cabins with voice communications over the telephone, precise assembly areas, telephone and telegraph stations, computer information processing rooms	-	96	83	74	68	63	60	57	55	54	65	75
3. Premises of laboratories for carrying out experimental works, observation booths and remote control without voice communication by telephone	-	103	91	83	77	73	70	68	66	64	75	90

Table 5 (continued)

4. Premises with permanent workplaces of production enterprises, territories of enterprises with permanent workplaces (with the exception of the works listed in items 1–3)	-	107	95	87	82	78	75	73	71	69	80	95
5. Chambers of hospitals and sanatoria	7–23	76	59	48	40	34	30	27	25	23	35	50
	23–7	69	51	39	31	24	20	17	14	13	25	40
6. Operational rooms in hospitals, doctors' offices of hospitals, polyclinics, sanatoriums	-	76	59	48	40	34	30	27	25	23	35	50
7. Classrooms, classrooms, auditoriums of educational institutions, conference halls, library reading rooms, auditoriums of clubs and cinemas, courtrooms, religious buildings	-	79	63	52	45	39	35	32	30	28	40	55
8. Residential apartments:												
- in houses of category A	7–23	76	59	48	40	34	30	27	25	23	35	50
	23–7	69	51	39	31	24	20	17	14	13	25	40
- in houses of category B and C	7–23	79	63	52	45	39	35	32	30	28	40	55
	23–7	72	55	44	35	29	25	22	20	18	30	45
9. Living rooms of hostels	7–23	83	67	57	49	44	40	37	35	33	45	60
	23–7	76	59	48	40	34	30	27	25	23	35	50

Table 5 (continued)

10. Hotel rooms:												
category A	7–23	76	59	48	40	34	30	27	25	23	35	50
	23–7	69	51	39	41	24	20	17	14	13	25	40
category B	7–23	79	63	52	45	39	35	32	30	28	40	55
	23–7	72	55	44	35	29	25	22	20	18	30	45
category C	7–23	83	67	57	49	44	40	37	35	33	45	60
	23–7	76	59	48	40	34	30	27	25	23	35	50
11. Residential premises of holiday homes, boarding houses, boarding houses for the elderly and disabled, sleeping rooms for children's pre-school and school educational organizations	7–23	79	63	52	45	39	35	32	30	28	40	55
	23–7	72	55	44	35	29	25	22	20	18	30	45
12. Premises of offices, working premises and offices of administrative buildings, design and research organizations:												
category A	-	83	67	57	49	44	40	37	35	33	45	60
categories B and C	-	86	71	61	54	49	45	42	40	38	50	65
13. Halls of cafes, restaurants, foyer of theaters and cinemas:												
category A	-	86	71	61	54	49	45	42	40	38	50	60
categories B, C	-	89	75	66	59	54	50	47	45	43	55	65

Table 5 (continued)

14. Trade halls of shops, passenger halls of railway stations, air terminals, sport halls	-	93	79	70	63	58	55	52	50	49	60	70
15. Territories directly adjacent to the buildings of hospitals and sanatoriums	7–23	86	71	61	54	49	45	42	40	38	50	65
	23–7	79	63	52	45	39	35	32	30	28	40	55
16. Territories directly adjacent to residential buildings, holiday homes, boarding homes for the elderly and disabled	7–23	90	75	66	59	54	50	47	45	44	55	70
	23–7	83	67	57	49	44	40	37	35	33	45	60
17. Territories directly adjacent to outpatient clinics, schools, educational institutions, pre-school areas, recreational areas of dwelling houses	-	90	75	66	59	54	50	47	45	44	55	70

Notes:

1. The permissible noise levels in the rooms, given in positions 1, 5–13, refer only to the noise penetrating from other premises and from outside.

2. Permissible noise levels from external sources in the rooms, given in pos. 5–12, are installed under the condition of ensuring the normative air exchange, i.e. in the absence of a forced ventilation system or air conditioning, there should be carried out under the condition of open air vents or other devices that provide airflow. In the presence of forced ventilation or air conditioning systems providing normative air exchange, the permissible levels of external noise in buildings (items 15–17) can be increased by calculating the permissible levels in rooms with closed windows.

3. For tonal and (or) impulse noise, allowable levels should be taken by 5 dB (dBA) below the values indicated in table 4.

4. The permissible noise levels from ventilation, air conditioning and air heating equipment, as well as from pumps for heating and water supply systems and refrigeration systems, built-in (attached) trading and catering establishments should be taken by 5 dB (dBA) below the values specified in the table 5. In this case, correction for the tonality of noise is not taken into account.

5. Permitted noise levels from vehicles (items 5, 7–10, 12) may be taken by 5 dB (dBA) below the values indicated in the table 5.

Sound level meters are equipped also with filters B and C, in varying degrees reducing the intensity of low-frequency signals. The sound levels measured on these scales are used for finding out an approximate frequency response of the noise. If the sound levels measured on the A-scale (dBA), B-scale (dBB), C-scale (dBC), are equal to each other, then such a noise can be attributed to high frequency type, above 1000 Hz. If the sound level on B- and C-scale is greater than on the A-scale by 2–5 dB, then such a noise is called mid-range type (400–1000 Hz); if by 5 and more dB – low-frequency type, accordingly.

Working with «Noise-M1» sound meter device. Before you start, insert two batteries for power supply and set the switch "Fast-Slow" to the "Fast" position. The power supply switch is to be set at the "Battery" position. The sound level meter should be on the black sector of the dB scale above the "Bat" label. Then set the operating mode switch to the "Calibration" position and rotate relevant knob so that the arrow meets "0" of the dB scale (***fig. 11a***).

When measuring the sound level in dBA, the operating mode switch is transferred to A position relative to the arrow on the device.

When using external analyzers for measuring sound pressure, the required mode (B or C) is selected.

With the "Range" switch, one step of which is equal to 10 dB, it is necessary to achieve such an arrow position when on the scale it is between 0 and 10 dB. Then the noise level measured will be equal to the sum of the "Range" switch scale and the scale with the arrow. For example, if operating mode switch is in “A” position, the Range switch is at 70 and the arrow is at 6 to the right of zero, then the noise level measured would be 76 dBA.

Professional sound-meter «Assistent SIU V1» (***fig. 11b***) offers even greater possibilities and can measure intensity of sound, infrasound, ultrasound and vibration in variety of working environments.

Hygienic estimation of noise is carried out by comparing the actually measured noise level to the maximum permissible level. For example, we give a situational problem.

In the health center of the plant, the total noise level was measured in octave bands. The data obtained in comparison with the maximum permissible levels are presented in the table 6.

a b

Figure 11. *a – Professional sound-meter «Noise-1M»; b – Professional sound, infrasound, ultrasound and vibration meter «Assistent SIU V1» (Rus. «Ассистент SIU V1», from www.eksis.ru)*

Figure 12 shows a noise spectrogram compiled from the data in the table 6, which shows that there is excess of both the overall noise level and the sound pressure levels in the frequency range from 250 to 2000 Hz.

Table 6

The noise levels in octave bands (dB)

Noise level	Noise intensity: Total	In octave bands with mean geometric frequencies, Hz: 63	125	250	500	1000	2000	4000	8000
Factual	65	70	60	60	65	60	48	40	35
Maximum permissible	50	71	61	54	49	45	42	40	38

Efforts to combat noise at the workplace

Activities to combat noise are divided into technical, architectural and planning, organizational and medical-preventive.

Technical measures are aimed, first, to eliminate the causes of noise or reduce its level in the source; secondly, to reduce noise on transmission paths; third, to directly protect the worker or a group of workers exposed to noise.

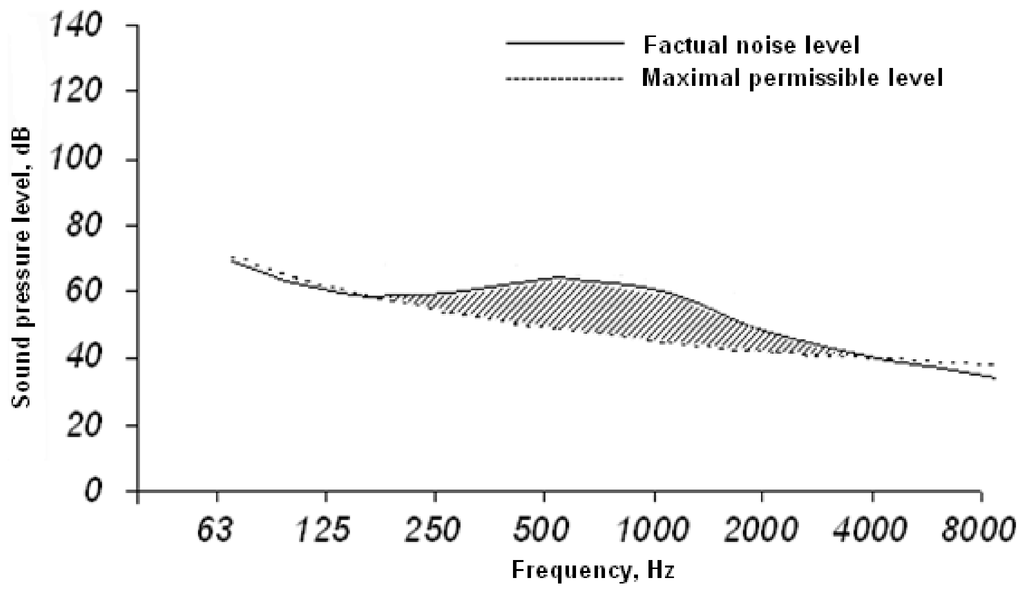


Figure 12. *Noise spectrogram*

The most effective means of noise reduction is the replacement of noisy technological operations with low noise or noiseless ones. For example, the replacement of riveting, made with the help of riveting hand machines, for welding or hydraulic joining of parts; replacement of manual editing of metal sheets by rolling, etc.

If this way of noise control is not possible, then reduce the noise level in the source by improving the design or layout of the machines producing noise, or use materials with reduced acoustic properties, for example, textolite, nylon or plastic parts of gears, bushings, etc. The noise sound source is further equipped with additional soundproofing devices or enclosures that are best to be placed as close as possible to the source of noise.

The simplest technical means of dealing with noise in the way it is transmitted is a soundproof enclosure that covers a separate noisy machine unit (for example, a gear box) or the entire unit as a whole. Covering of the line with metal sheet having inner surface layer made of absorbing material can reduce noise by 20–30 dB.

Increasing the sound insulation of the cover is achieved by applying to its surface of mastic possessing damping properties, which reduces its vibration at resonant frequencies and ensures rapid attenuation of the sound waves.

To reduce aerodynamic noise generated by compressors, ventilation systems, pneumatic conveying systems, use silencers.

To place the most noisy equipment use soundproofing cameras. With large dimensions of machines or in large service area, special cabin for operators is equipped, if possible, remote control is provided.

To reduce noise level, usage of acoustic screens fencing off a noisy mechanism or noise source from the workplace or the machine service area is effective. Screens are installed both near the source and at the workplace. The protective action of the acoustic screen is based on the reflection of sound waves and the formation behind the screen of the sound shadow region. The effect of screen protection is most pronounced in the region of high and medium frequencies and to a lesser extent in the low frequency region due to the large diffraction (wave bending of obstacles) of long waves that are commensurate with or larger than the linear dimensions of the screen. In noisy shops suspended sound-absorbing cubes, cones, mats, reduce noise by 5–12 dB.

Acoustic finishing of noisy rooms can provide noise reduction in the area of the reflected sound field by 10–12 dB, in the propagation zone of direct sound – up to 4–5 dB in separate octave bands. Use of sound-absorbing claddings for the decoration of walls and ceiling of noisy rooms leads to a change in the noise spectrum towards lower frequencies, which, even with a slight decrease in the noise level, significantly improves working conditions. Use porous materials, felt, perforated cardboard, cotton wool, etc.

In multi-floor industrial buildings, it is important to protect the premises from structural (impact) noise, which spreads through the structure of the building. The source of structural noise can be the production equipment, which has a rigid connection with the enclosing structures. The attenuation of transmission of this type of noise is achieved by vibration isolation and absorption, in particular, by application of "floating" floor constructs.

Architectural and planning activities are aimed at localizing the sound and reducing its propagation from a room with a source of noise to others.

A noisy shop building should be dislocated terminally relatively to other noiseless premises. Around it a strip of broad-leaved trees, absorbing noise, is planted. Noisy shop is recommended to be located on the 1st floor of a multifloor industrial building; if it is placed on 2–3 floors, then there will be secondary structural noise.

The noise regime of industrial premises is due to their size and shape, density and type of arrangement of machines and equipment, the presence of a sound-absorbing background, etc. In large-volume rooms, the number of sound waves reflected from the enclosing structures per unit time is much smaller in comparison with small-volume rooms. From the acoustic viewpoint, an elongated form of a large production room is preferable to a square one; the optimum height of the workshop is 6–7 m.

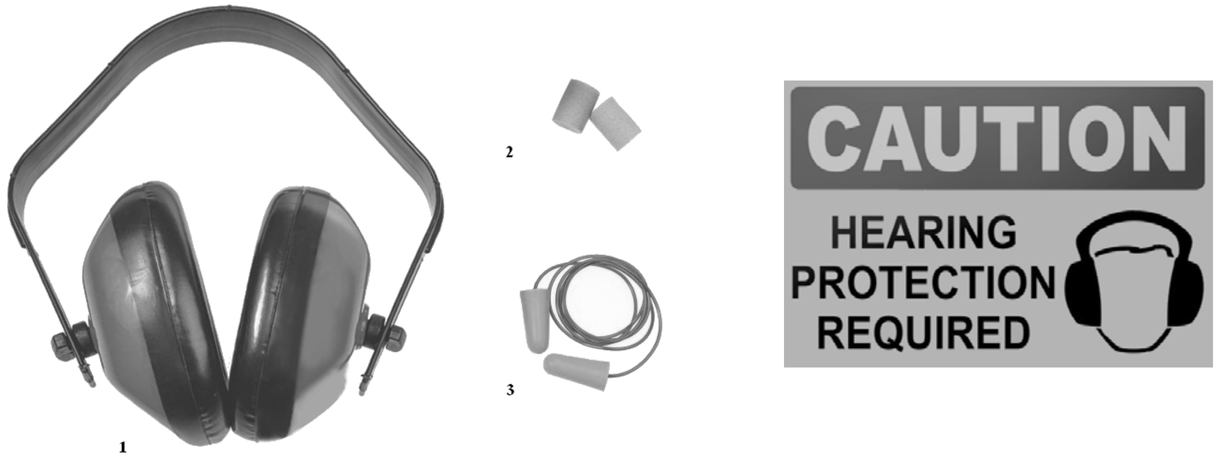
Premises with a high level of noise should be grouped in one area of the building adjacent to the warehouse and ancillary facilities, and separated by corridors or utility rooms with a short stay of workers.

Organizational measures. If technical measures do not ensure compliance with hygiene standards, then useful idea is to limit the duration of noise exposure of workers: every hour of work is followed by 10 minutes break, which must be spent in a specially equipped room (acoustic unload room), which positively affects a person's emotional status. As well reduced working hours, additional leave, early retirement is applied.

Personal protective equipment. Individual ears protection means are special noise-absorbing devices. By designation and design, they are divided into three basic types: (1) headphones covering the ears, (2) ear plugs made of rubber, plastics, cotton wool – all serve for blocking of external auditory canal from noise (***fig. 13a***) and (3) helmets and balaclava covering the ears and part of the head (not shown). Explicit warning labels should be provided in any unsafe noisy working areas of industrial environment (***fig. 13b***).

Medical-preventive measures include pre-employment and periodic medical examinations in accordance with Order No. 90 of the Ministry of Health of Russian Federation of 14.03.1996. The main objective of preliminary medical examinations is to assess the state of health for deciding on individual suitability for work in noisy environment. Periodic medical examinations provide dynamic monitoring of the health of workers in noisy environment in order to timely diagnose initial signs of occupational pathology. The order contains a list of general medical contraindications for admission to work related to hazardous, noxious substances and adverse occupational factors (***sup. 1, p. 171***). For working under conditions of industrial noise exceeding 80 dBA, the contraindications are:

- Decreased hearing for at least one ear of any etiology;
- Otosclerosis and other chronic ear diseases with unfavorable prognosis;
- Dysfunction of the vestibular apparatus of any etiology, including Meniere's disease (labyrinthopathy).



a b

Figure 13. *a – Basic types of ear protecting means:1 – headphones, 2 and 3 – ear plugs; b – Warning label for noisy working areas*

Periodic medical examinations are conducted once in 2 years if the maximum permissible noise level is exceeded in the range 81 to 99 dBA; 1 time per year if 100 dBA and higher, accordingly – with participation of a therapist, an otolaryngologist and a neurologist. Laboratory and functional studies include audiometry, according to indications – examination of the vestibular apparatus.

In order to exclude the risk of damaging effects of noise on the hearing organ for the purpose of rational professional selection, it is not recommended to hire persons under the age of 18 and over 30 years of age to work in "noisy" workshops.

To increase the body's resistance to adverse effects of noise, daily intake of vitamin B1 (2 mg) and ascorbic acid (50 mg) is recommended for two weeks followed by one-week break.

Significant positive effect may be achieved with sanatorium treatment, periodic rest in variety of recreation centers.

The legislative measures to prevent the effect of noise on the body include hygienic regulating of its parameters (***tab. 5***).

INDEPENDENT WORK OF STUDENTS

1. Get acquainted with equipment for determining of industrial noise intensity.

2. Measure the background noise level in the classroom with the sound level meter, as well as the level of industrial noise sample recorded on the magnetic tape.

3. Use the physiological methods to assess the short-term impact of industrial noise on the body of a volunteer student.

After acquaintance with "Noise-1M" sound level meter device students under the teacher's supervision measure the background noise level in the classroom.

To demonstrate an impact of industrial noise on the body, the following situation is modeled: a volunteer student before the noise load experiment undergoes determination of blood pressure, pulse and respiration rate, and audition acuity (acumetry). These indicators characterize state of the cardiovascular, respiratory, nervous systems.

The simplest method of acumetry is to study individual whispered speech perception. The volunteer is removed by 6–7 m from the experimenter, stands sidewise with the ear looking directly to the whisper source. The experimenter in whisper-wise manner (at the level of 30 dBA) alternately pronounces 20 two-digit (from 21 to 99) numbers, and each number should be instantly repeated loudly by the volunteer. Then number of errors – incorrectly reproduced numbers is recorded.

Then the noise load is given: for 5 minutes magnetic tape recording with industrial noise sample is switched on (the sound of a boiler units operating at the power plant) and the noise level of 85 dBA is set with the help of the volume control. After the noise load, all the tests are repeated and the results are tabulated:

Indicators	Before the noise load	After the noise load
Arterial pressure		
Heart Rate		
Breathing rate		
Whisper speech (number of errors)		

Comparison of physiological parameters before and after exposure to noise makes it possible to assess the degree of changes occurring in the body under the influence of noise corresponding to the beginning of the danger zone (85 dBA), and to draw conclusions about the effect of noise on the body.

QUESTIONS FOR SELF-CONTROL

1. How does noise differ from the sound of speech, melody?
2. How is noise classified by the mechanism of origination?
3. Classification of noise by the nature of the spectrum.
4. What frequencies are related to the audible range?
5. How is noise classified by time characteristics?
6. On which factors does the maximum permissible level of industrial noise depend on?
7. Symptoms of noise disease.
8. In what absolute and relative units is the noise intensity measured?
9. What sound pressure is taken at 0 dB?
10. List the technological measures to combat noise at the workplace.
11. List contra-indications for employment in noise-related workshops.
12. What is the frequency range of ultrasound?
13. Which frequency range is the most sensitive to human auditory analyzer?
14. What is an octave?
15. Kinds of medical examinations of persons contacting with harmful industrial factors.

4. INFRASOUND, ULTRASOUND AND VIBRATION AS HARMFUL INDUSTRIAL FACTORS

Influence of infrasound on a human body

Infrasound (from the Latin ***infra*** – "below, under") – elastic waves, similar to sound, but having frequencies below the audible range. It represents low-frequency sound oscillations with the frequencies below 20 Hz. The level of infrasound intensity is expressed in decibels. It can be either of mechanical (mechanical oscillations generated by machines) or aerodynamic (resulting from large turbulent flows of gases or liquids) origin. As a physical phenomenon infrasound is subject to the general properties inherent for sound waves, but it has a number of features specifically related to the low frequency oscillations:

- Infrasound has many times larger oscillation amplitude than acoustic waves, with the same power of the sound source;
- Infrasound propagates well in the air over long distances with little energy loss, as its absorption in the atmosphere is insignificant and is 8×10^{-6} dB/km;
- A longer wavelength makes the diffraction phenomenon inherent for infrasound. Due to this infrasound easily penetrate premises and envelop the obstacles that detain audible sounds;
- Infrasonic vibrations can cause large objects to vibrate due to resonance phenomena.

These features of infrasonic waves make it difficult to combat them, since the classical methods used to reduce noise (sound absorption and sound insulation), as well as removal from the source in this case are ineffective.

Sources of infrasound in the workplace

In modern industry and transport, infrasound sources are compressors, air conditioners, turbines, industrial fans, oil injectors, vibrating platforms, blast furnaces and open hearth furnaces, heavy machines with rotating parts, aircraft and helicopter engines, diesel engines for ships and submarines, as well as ground transport (***tab. 7***).

Industrial infrasound is a part of the mechanical energy generated by different equipment, and it arises when large surfaces, powerful turbulent flows of liquids and gases move, with shock excitation of structures, rota-

Table 7

Classification of workplaces with vehicles and technological equipment according to the noise characteristics of the infrasonic-frequency range

The nature of the spectrum	Octave bands with maximum sound pressure levels, Hz/dB	An example of the main type of machinery and equipment
Infrasound	2, 4, 8, 16/82–133	Motor transport, blast-furnace and oxygen-converter furnaces, river and sea ships, railway transport, compressors
Infra-and-low frequency	2–125/84–112	Marten furnaces, sinter machines, certain types of vehicles, self-propelled and semi-stationary machines
Low-frequency	31,5; 63; 125/84–116	Electric arc furnaces, tractors, crawler tractors, port cranes, turbine units, forklift trucks, excavators

tional and reciprocating motion of large masses with a repetition of cycles of at least 20 times per second.

Currently, the maximum levels of low-frequency acoustic oscillations from industrial and transport sources reach 100–110 dB.

In an industrial environment, infrasound, as a rule, does not act alone, but together with noise and also with low-frequency vibration.

Effects of infrasound on a human body

The key pathogenetic mechanism of the damaging effect of infrasound is the liquor-hemodynamic and microcirculatory disorders that cause development of cerebral hypoxia and consequently pathological changes in the nerve cells of the brain structures.

When studying a negative impact of infrasound it is very important assessment of subjective feelings of discomfort, which can be characterized as complains of sensory and somatic discomfort. At the same time, people complain of dizziness, nausea, a feeling of pressure on the eardrums, stuffiness of the ears, a shivering tremor of the body, movement in the intestine, headache, choking, coughing, fear, anxiety and others. Particular mention should be made of the transient numbness of the palate and skin of the face, of apparently sensory-cortical genesis. In general, the nature of complaints occurring due to infrasound effects allows one to postulate the idea of an infrasonic hypothalamic crisis (diencephalic syndrome) running with sensory, somatic, vegetative and visceral symptoms.

Table 8

A priori signs of infrasound presence in the sound source

Types of symptoms	Characteristic features
Construction-related	• Large areas of ceilings or fences of noise sources (for example, adjacent location of administrative premises with production facilities). • Large dimensions of engines and working mechanisms of machines (for example, mining excavators). • Presence of closed volumes that are dynamically excited (for example, the cabins for watching over moving equipment). • Suspension of self-propelled and transport-technological machines. Use of materials for sound attenuation and sound insulation effective at the audible frequencies of noise in the source of its formation (for example, when the operating frequency of the vibratory pad is reduced) or along the path of its propagation (mufflers, cladding, observation booths)
Technological	• Powerful single machines with a relatively low operating speed, steps or strokes (for example, reciprocating compressors with an operating frequency of 1200 rpm or less; vibrating platforms). • Heterogeneity or cyclicity of large-scale technological processes, when processing large parts or large quantities of raw materials (for example, open-hearth furnaces and converters of metallurgical production, in the mining industry). • Fluctuations of powerful flows of gases or liquids (for example, gas-dynamic or chemical installations). • Traffic on terrain, roads, highways, bridges, tunnels (for example, traffic streams, road construction machines)

Significant psychotropic effects are produced at the frequency of 7 Hz, consonant with the α-rhythm of natural brain vibrations. And any mental work in this case becomes impossible, because it seems that the head is about to burst into small pieces. The sound of low intensity causes nausea and ringing in the ears, as well as visual impairment and unaccountable fear. The sound of medium intensity upsets the digestive organs and the brain, giving rise to paralysis, general weakness, and sometimes blindness. Elastic, powerful infrasound can damage and even completely stop the heart. Usually a discomfort begins with 120 dB, traumatic effect – with 130 dB. Infrared frequencies of about 12 Hz with strength of 85–110 dB induce seasickness attacks and dizziness, and fluctuations of 15–18 Hz at the same intensity inspire feelings of anxiety, uncertainty and, finally, panic fear. With more intense infrasound, in addition to dizziness and abdominal pain, there are feelings of anxiety, dry mouth and scratching in the throat, coughing, choking, and increased irritability. With objective examination, note inhibition, lethargy, apathy, bad mood, increased fatigue, irritability. Prolonged exposure to infrasound intensity of more than 150 dB can cause symptoms of myocardial dystrophy, which is characterized by subdued cardiac tones and reduced heart rate. Hearing organs are especially affected. It is possible to detect hyperemia of the tympanic membrane, raising the thresholds of hearing. There is a feeling of pressure in the ears.

As a result of long-acting infrasound exposures with the levels close to the industrial (90–120 dB), asthenia develops, mental capacity decreases, vegetative and neurotic disorder symptoms appear: irritability, nausea, nervousness. Despite the fact that the frequency range of infrasound is below the threshold of audibility, according to most scientists, infrasonic fluctuations in the upper infrasonic range are perceived by the hearing organ.

A decrease in auditory sensitivity within the low speech frequencies has been established in persons long time working under an infrasound influence. The vestibular and not auditory receptors are more suitable for infrasound perception. The effects caused by infrasonic stimulation of the labyrinth are similar to the symptoms that develop during motion sickness. Under infrasound influence, the pressure in the middle ear is changed and transmitted to the perilymph and then to the semicircular canals. As a result, the labyrinth fluid shifts, producing mechanical stimulation of the semicircular canal receptors. The energy of low-frequency acoustic vibrations can be transmitted not only to the perilymph of the cochlea, but also to the otoliths through the endolymphatic sac, which has a great mechanical resistance – the feature, allowing transmitting of exclusively infrasonic waves.

Body balance disorders were noted in those working with compressors and drivers of the passenger motor transport, working with influence of infrasound.

In cardiovascular system due to infrasound there can be deviations of the heart rate, mostly bradycardia, and also increase of the diastolic blood pressure.

Regulation of infrasound

The current sanitary norms establish a classification, standardized parameter values and maximum permissible infrasound levels in the workplace. The infrasound parameters being regulated are the **equivalent sound pressure levels** in the octave frequency bands 2, 4, 8, 16 Hz and the **equivalent total sound pressure level** of infrasound during the monitoring period, as well as the **maximum total sound pressure level** of infrasound.

The actual standards for infrasound in the workplace are specified taking into account severity and intensity of the work:

- For jobs of varying severity in production facilities and on the territory of enterprises, the equivalent total sound pressure level of infrasound is 100 dB;
- For works of varying degrees of intellectual and emotional tension – 95 dB;
- For time-oscillating and intermittent infrasound, sound pressure levels should not exceed 120 dB.

Measures to prevent impact of infrasound on workers

Due to insignificant absorption in the atmosphere and ability to skip obstacles, infrasound spreads over considerable distances. Therefore, for the organization of protection against infrasound, a comprehensive approach should be used, including constructive measures to reduce infrasound in the source of its originating (infrasound absorption, silencers of infrasound), planning decisions, use of organizational, administrative, medical preventive measures and usage of personal protective equipment.

In working conditions, when infrasound levels exceed the normative, it is necessary to apply the work and rest modalities, assuming 20-minute breaks every 2 hours of work, which should be clearly stated in the technological regulations, instructions, etc.

To prevent unfavorable functional consequences occurred due to intense exposure to infrasound, rooms for psychological recreation should be provided.

To protect the hearing system in cases of noise and infrasound exposure above the norm exceeding levels, personal protective equipment is recommended. Selection of personal protective equipment under the influence of low-frequency noise and infrasound is performed taking into account the spectral characteristics. To increase the effectiveness of such a protection, it is recommended to use a combination of several types of personal protective equipment against noise, for example, noise-free earphones and inserts, as well as special belts that reduce fluctuations in the internal organs.

Those working under the influence of infrasound should undergo preliminary (at hiring) and periodic medical examinations once every 24 months by the following specialists: otorhinolaryngologist (with the obligatory audiometry and impedance-audiometry at times), neurologist and therapist. Additional medical contraindications for employment to the infrasound-related work:

- Persistent hearing decrease, at least with one ear, of any etiology;
- Otosclerosis and other chronic ear diseases with unfavorable prognosis expected;
- Vestibular dysfunction of any etiology, including Meniere's disease;
- Drug addiction, substance abuse, chronic alcoholism;
- Arterial hypertension, ischemic heart disease, myocardial dystrophy.

When carrying out medical examinations of the infrasound exposed workers, one should take into account the specificity of its effect on the hearing organ: if is there a damage of both the sound-receiving and sound-conducting apparatus. As a screening test of infrasound impact on the body one should check a presence of complaints of itching and unpleasant sensations in the ear canal in the absence of dermatitis.

Influence of ultrasound on a human body

Ultrasound is an elastic wave of high frequency. The human ear perceives the elastic waves propagating in the medium with a frequency of up to about 16000 oscillations per second (Hz). Oscillations with a higher frequency are beyond the limits of audibility for the most. Usually the ultrasonic range is considered the frequency band 20000 Hz and higher.

Sources of ultrasound in the workplace. The technogenic sources of ultrasound include all types of technological ultrasonic equipment used for industrial, medical, and household purposes and generating ultrasonic vibrations in the frequency range from 20 kHz to 100 MHz and higher. The source of ultrasound can also be equipment, producing ultrasound as a by-product.

The main elements of ultrasonic technology are ultrasonic transducers and generators. Ultrasonic transducers are divided into mechanical (ultrasonic whistles, sirens) and electromechanical (magnetic, piezoelectric, electrodynamic) depending on the type of energy consumed. Mechanical and magnetic transducers are used to generate low-frequency ultrasound, and piezoelectric transducers can produce high-frequency ultrasounds – up to 10^9 Hz.

Ultrasonic generators are designed to convert the industrial frequency current into a high frequency current as well as to supply electric-acoustic systems – converters of both piezoelectric and magnetic.

At present, ultrasound is widely used in machine building, metallurgy, radio electronics, construction, geology, light and food industries, fisheries, medicine, etc.

The basic features of ultrasound affecting an operator are given in the table 9. From the standpoint of possible adverse effects of ultrasound on the body, it is expedient to note the two main directions:

1. Application of low-frequency (up to 100 kHz) ultrasonic vibrations, propagating by contact and air paths, for active influence on substances and technological processes – cleaning, disinfection, welding, soldering, mechanical and thermal treatment of materials (super hard alloys, diamonds, ceramics); in medicine – ultrasound surgical instruments, facilities for sterilizing the hands of medical personnel, various items, etc.

2. Application of high-frequency (100 kHz – 100 MHz and higher) ultrasonic vibrations, propagating exclusively by contact, for non-destructive testing and measurements; in medicine – diagnosis and treatment of various diseases.

Those working with technological and medical ultrasonic sources are exposed to a complex of unfavorable factors, the leading one of which is ultrasound with a frequency of 20 kHz to 20.0 MHz and the intensity of 50–160 dB.

So, stationary cleaning, welding, and cutting plants generate permanent ultrasonic vibrations with frequencies of 22.0–24.0 kHz, propagating by contact and through the air (25–30% of the working shift).

Table 9

Hygienic classification of ultrasound affecting an operator

Classified attribute	Characteristic of the trait classified
1. Method of propagation of ultrasonic vibrations	Contact (when the hands or other parts of a human body contact the ultrasound source). Air (acoustic)
2. Type of ultrasonic oscillation source	Manual source. Stationary source
3. Frequency response of ultrasonic vibrations	Low-frequency ultrasound 16–63 kHz (the average geometric frequencies of octave bands are indicated). The mid-frequency ultrasound is 125–250 kHz. High-frequency ultrasound of 1.0–31.5 MHz
4. Mode of generating of ultrasonic vibrations	Constant. Pulse.
5. Method of radiation of ultrasonic oscillations	Magnetic. Piezoelectric.

The intensity of ultrasound in the contact zone with the operators of cleaning, grinding and welding aggregates is 0.03–1.4 watts per centimeter square (W/cm^2), i.e. the levels range from values of practically normative to 14-fold excess of the MPC. Sound pressure levels in the audible and ultrasonic frequency bands at workplaces reach 80–110 dB with a maximum at the operating frequencies of the installations, which corresponds to the norm.

The diagnostic facilities used in medical institutions operate in the frequency range 0.8–20.0 MHz, the pulse repetition frequency is 50–100 Hz. Diagnostic scanning is performed by a manual ultrasonic transducer. The duration of one study ranges from 15–20 minutes to 1–1.5 hours. The levels of high-frequency contact with ultrasound affecting the hands of the doctor are from 0.5–40.0 mW/cm^2 to 1.0 W/cm^2 with diagnostic studies, occupying about 70% of the working time.

In ultrasonic surgical equipment, the oscillation frequency is 26.6–44.0–66.0–88.0 kHz. At work of surgeons the contact transfer of ultrasound on hands is noted; duration of ultrasound does not exceed 14% of the working time. The intensity of the ultrasound contact is in the range of 0.07–1.5 W/cm^2, the air ultrasound levels at the surgical sites below the permissible levels are 80–89 dB.

Ultrasonic physiotherapeutic equipment generates oscillations with frequencies of 0.88 and 2.64 MHz. The levels of the permanent and pulsed ultrasound contact affecting the hand of the medical personnel, spreading through the side surface of the hand radiator, are 0.02–1.5 W/cm^2. The duration of one procedure does not exceed 15 minutes, the contact time with ultrasound is about 33% per shift.

Depending on the intensity of the ultrasound contact, there are three main types of its action:

1) **Low intensity ultrasound** (up to 1.5 W/cm^2) promotes acceleration of metabolic processes in the body, easy heating of tissues, micro massage, etc. Low intensities do not lead to morphological changes inside cells, since variable sound pressure causes only a certain acceleration of biophysical processes, therefore small exposures to ultrasound are considered as a physiological catalyst;

2) **Medium intensity ultrasound** (1.5–3.0 W/cm^2) due to the increase in the variable sound pressure causes reversible reactions of inhibition, in particular, of nervous tissue. The rate of function recovery depends on the intensity and time of ultrasound irradiation;

3) **High intensity ultrasound** (3.0–10.0 W/cm^2) causes irreversible inhibitions, which turn into the process of complete destruction of tissues.

The data available indicate that ultrasonic oscillations generated in the pulsed regime exert a somewhat different biological effect than constant oscillations. The peculiarity of the physiological effect of pulsed ultrasound is less pronounced, but greater softness and duration of manifestation of effects are noted. The softness of the pulsed ultrasound action is associated with predominance of physical-chemical effects over the thermal and mechanical.

The effect of ultrasound on biological structures is due to a number of factors. Effects caused by ultrasound are conventionally subdivided to:

- Mechanical, caused by an alternating displacement of the medium, radiation pressure, etc. Thus, at low intensities (up to 2–3 W/cm^2 at frequencies about 105–106 Hz), the vibrations of the particles of the biological medium produce a peculiar micro-massage of the tissue elements, which promotes better metabolism;
- Physical-chemical, associated with the acceleration of diffusion through biological membranes and the change in the rate of biological reactions;

- Thermal, which are consequence of heat generation: when ultrasound energy is absorbed by tissues, the temperature rise at the boundaries of tissue structures, heating on gas bubbles;
- Effects associated with ultrasonic cavitation (due to slamming of vapor-gas bubbles in the medium under the action of ultrasound) appearing in the tissue. Cavitation leads to the rupture of molecular bonds. For example, water molecules break down into free radicals OH^- and H^+, which is the primary cause of the oxidizing action of ultrasound. In a similar way, high-molecular compounds are broken down under the action of ultrasound in biological objects, for example, nucleic acids, protein substances.

The changes occurring under the influence of ultrasound (air and contact) are subject to a general pattern: small intensities stimulate, activate; medium and high inhibit and can completely suppress functions, respectively.

High-frequency ultrasound contact due to a short wavelength is practically not spread in the air and affects a worker only when the ultrasound source is in contact to the body surface. Changes caused by the action of contact ultrasound are usually more pronounced in the contact zone, more often they are fingers, hands, although the possibility of distal manifestations due to reflex, neural and glandular effects is not ruled out.

Specific features of the impact of contact ultrasound on workers due to its high biophysical activity are manifested as sensory, vegetative-vascular disorders and changes in the muscular-skeletal system of the hands.

In addition to changes in the neural and muscular systems, changes in bone structure in the form of osteoporosis, osteosclerosis of distal arm phalanges, and also some other changes of degenerative-dystrophic character are revealed in persons working with sources of contact ultrasound.

The skin is the "input gate" for a contact ultrasound, since when performing work with various ultrasonic sources, the skin of hands is exposed first. Intensity of ultrasonic vibrations on the skin of hands is nearly the same that on the surfaces of the radiator.

The skin in different areas of human body has a different sensitivity: the skin of the face is more sensitive than the skin of the abdomen; the abdominal skin in turn is more sensitive than the skin of the extremities. Ultrasound with intensity of 0.6 W/cm^2 (frequency of 2.5 MHz) causes flushing of the skin and a mild edema.

The effect of ultrasound with intensity of 0.4 W/cm^2 (1–2 MHz) is accompanied by a regular decrease in pH value of the skin surface, which indicates the predominant use for the energy metabolism of carbohydrates, because with their enhanced transformations, acidic metabolic products accumulate in the tissues. Perhaps the change in pH of the skin surface under the influence of ultrasound is associated with increase in the functional activity of the sebaceous glands. With the action of ultrasound, the number of active sweat glands increases, and, correspondingly, the excretion of chlorides increases.

Clinical and laboratory examination in defectoscopists reveals the following skin diseases: palmar and plantar hyperhydrosis or dyshydrosis; dysfunction of the feet and hands, seborrhea of the scalp, etc. The majority of patients with hyperhydrosis, dyshydrosis, showed a correlation with concomitant diseases, in particular with neuro-vascular disorders, manifested in the form of autonomic polyneuritis of the hands, vegetative-vascular dysfunctions. This made it possible to connect skin pathology with ultrasound exposure.

When ultrasound of low intensity – 20–35 mW/cm^2 (frequency 1 MHz) is applied, the permeability of skin vessels increases. At the same time a local exposure to heat, which leads to the same increase in skin temperature by 0.8–1.0°C, does not have any effect on the vascular permeability of the skin. Consequently, in the processes of changing the vascular permeability of the skin under the influence of ultrasonic waves, a large role is played not by the thermal factor, but by the mechanical effect. At high ultrasound intensities, vascular permeability can also be altered through reflex mechanisms.

Another important effect of ultrasound is its analgesic effect. That’s because in addition to lowering pH of the medium, local accumulation of histamine occurs, which contributes to inhibition of impulses in the synapses of sympathetic ganglia.

Regularities in the change in cardiovascular activity under the influence of contact ultrasound are revealed. Thus, when patients are sonicated with therapeutic doses of ultrasound (2.46 MHz, 1 W/cm^2), the heart rate increases more rapidly, ECG changes. An increase in the intensity of ultrasound leads to bradycardia, arrhythmia. Similar reactions are observed when not only the heart region is scanned, but also the adjacent areas.

The study of vascular responses of the body to ultrasound exposure during contact transfer showed that small doses of high-frequency ultrasound (0.2–1.0 W/cm^2) caused vessel dilating effect, whereas large doses (3 W/cm^2 and higher) constrictive effect, respectively.

Decrease in vascular tone and vessel dilatation are noted not only in the area exposed to ultrasound, but also in symmetrical areas, which allows us to speak of the important role of neural-reflex mechanisms in the formation of a response to the action of ultrasound.

Periodic medical examinations are carried out once a year. Therapist and neurologist should participate in the examination. In addition to conventional measures to prevent the adverse effects of ultrasound on the body of workers (professional selection, periodic medical examinations), an important role belongs to individual protective equipment (special gloves, screens, etc.), which defectoscopists and medical workers are often neglected. Additional medical contraindications for work in contact with ultrasound are chronic diseases of the peripheral nervous system, obliterating endarteritis, Raynaud's disease, peripheral vessel spasms.

Measures to prevent influence of ultrasound on workers

Measures to protect workers from the adverse effects of contact ultrasound include the following.

1. Medical and biological screening when hiring, taking into account subjective (individual) and objective (occupational) risk factors.
2. Organizational and technical.
3. Adoption of flexible work regimes.
4. Hygienic and clinical monitoring.
5. Measures directed to health improvement of workers.

It is advisable to carry out medical screening at hiring in several stages:

Stage 1 – social selection. According to the current hygienic norms and rules, the main contraindication for working with ultrasound exposure is the age under 18 years.

Stage 2 – medical selection, including preliminary medical examination and conducting of functional studies, taking into account the specific effects of contact ultrasound and risk factors (both the known individual and specific vocational, established as result of the specific working conditions assessment).

Preliminary medical examination is conducted in accordance with the actual official order. When conducting preliminary medical examinations, contraindications for work in ultrasound-related professions should be taken into account. Among them, along with the general medical contraindications for admission to work relating to harmful, dangerous substances and industrial factors, chronic diseases of the peripheral nervous system, obliterating arterial diseases and peripheral angiospasm are included.

In addition to medical contraindications, individual and objective risk factors are identified that can exacerbate effects of contact ultrasound. Individual risk factors include family history of vascular diseases, asthenic constitution, cold allergy, traumas of limbs, vegetative volatility, specifically sympathetic nervous tone predominance, long work experience in the profession, etc.

Objective occupational risk factors are high levels of contact and air ultrasound, transmission of ultrasonic vibrations through the liquid medium, a large area of contact with the source, hand contamination with contact lubricants, cool hands, high ultrasound source index, static load on the muscles of the fingers and hands, forced posture, cooling microclimate, etc.

Organizational and technical measures attempting to increase quality of the workplace environment dealing with ultrasound sources in order to reduce the risk of disrupting the health of workers:

- Development and implementation of new, improved equipment with better ultrasonic characteristics;
- Creation of automatic ultrasound equipment, for example, for cleaning of parts, defectoscopy, mechanical processing of materials, etc; creation of installations with remote control; use of low-power ultrasonic generators in equipment, which does not contradict the requirements of technological processes; design of ultrasonic devices with operating frequencies as far as possible from the audible frequency range (not lower than 22 kHz) in order to avoid the effect of pronounced high-frequency noise;
- Blocking, i.e. automatic disconnection of equipment, devices when performing auxiliary operations for loading and unloading products, applying contact lubricants, etc;
- Design of hand held sensors, taking into account the need to ensure minimum tension of the muscles of the hand;
- Use of grids supplied with handles and various devices for loading and unloading parts from ultrasonic waves or special devices (clamps, tripods, hooks, etc.) to hold the parts or an ultrasound source; lining the operator's hands to the source (scanning devices of flaw detectors and

diagnostic equipment, handles of a hand-held ultrasound instrument, etc.) with insulating material;

- Monitoring the timeliness of preventive and routine maintenance of ultrasonic equipment;
- Equipment of ultrasonic installations with soundproofing devices (casings, shields) made of sheet steel or duralumin, coating with rubber, anti-noise mastic or other materials; the arrangement of soundproofing cabins, boxes; shielding of feeder lines; equipment for effective ventilation.

Of great importance in the prevention of ultrasound exposure are rational working regimes established for a particular workplace. When developing labor regimes, the following principles should be guided:

- Reduction of the total work time and decrease in the exposure time if norms are exceeded;
- Work with regularly interrupted ultrasonic effects;
- Organization of two regulated breaks, the first – duration of 10 minutes, the second – 15 minutes for active recreation, a special complex of industrial gymnastics, physical and preventive procedures, etc. The first break should be rationally arranged 1.5–2 hours after the start of the shift, the second after 1.5 hours of the afternoon break;
- Lunch break of at least 30 min. In addition to shift work regimes, it is advisable to introduce flexible (sliding) working modes – weekly, decade, monthly, quarterly. These modern forms of work regimes are most acceptable for medical workers, when the ultrasound load on the workers, exceeding the allowable, can be evenly spaced in time.

The measures aimed at increasing the body's resistance, when exposed to contact ultrasound, include various types of preventive procedures – reflex-prevention, gymnastics, rational and balanced nutrition, vitaminization, psychic-physiological recreation.

Individual protection means. When working with low-frequency sources of contact ultrasound it is recommended to use:

- To decrease propagation of vibrations in a solid medium – 2 pairs of dense cotton gloves;
- To decrease propagation of vibrations in a liquid medium – 2 pairs of gloves: the lower ones – cotton and the upper ones – dense rubber gloves.

When working with high-frequency sources of contact ultrasound it is recommended to use:

- To reduce vibrations in a solid environment – 1 pair of cotton gloves, or cotton gloves with a waterproof palmar surface (made, for example, from waterproof synthetic materials), or cotton fingertips;
- To reduce propagation of vibrations in a liquid medium – 2 pairs of gloves: the lower ones – cotton and the upper ones – rubber gloves.

As a means of individual protection against the effects of noise and air ultrasound, workers should use anti-noise means – ear buds, headphones.

Among the measures to protect workers from ultrasound exposure, an important place is attributed to training the working personal with respect to the principles of labor protection legislation, safety regulations and preventive measures when working with contact ultrasound sources; health education among workers, promotion of a healthy lifestyle.

Industrial vibration

In the physical sense, a vibration represents a mechanical oscillatory motion that repeats itself through certain periods of time. The main parameters characterizing vibration are the **oscillation frequency** and **velocity**. The oscillation frequency is measured in hertz (Hz), and the vibration velocity – in meters per second (m/s), respectively.

The magnitude of vibration impact on the body depends on the amount of energy absorbed, the most adequate expression of which are the **vibration velocity** (cm/s) and the derivative of vibration velocity – **vibration acceleration** (m/s^2). In production conditions, vibration is an oscillatory process with a wide frequency range of up to 8–10 octaves. Measurements of technological vibration are conducted within octave bands with the help of special devices – vibration meters or universal noise and vibration meters (***fig. 11b, p.73***)

Classification

By frequency composition:

- **Low-frequency** vibrations (1–4 Hz for general vibrations; 8–16 Hz for local vibrations).
- **Medium-frequency** vibrations (8–16 Hz for general vibrations; 31.5–63.0 Hz for local vibrations).
- **High-frequency** vibrations (31.5–63.0 Hz for general vibrations; 125–1000 Hz – for local vibrations).

By time characteristics:

- **Constant vibrations**, are those for which the parameters being regulated change by less than 2 times (by 6 dB) during the observation time.
- **Unstable vibrations**, are those for which the parameters being regulated change 2 or more times (by 6 dB) during the observation time of at least 10 min when measured with a time constant of 1 s, including:
- **Vibrations oscillating** in time, for which the value of the parameters being regulated vary continuously in time;
- **Intermittent vibrations,** when contact of the worker with vibration is interrupted, and the duration of the intervals during which the contact occurs is more than 1 second;
- **Pulsed vibrations** consisting of one or more vibration episodes, each lasting less than 1 second.

By the source of occurrence:

- **Local vibration**, which is transmitted to the worker from a manual mechanized tool (with engines), bodies of manual control of machinery and equipment.
- **Local vibration** transmitted to a person from a manual non-mechanized tool (without engines), for example, straightening hammers of different models.
- **General vibration** of the 1st category is transport, affecting people in workplaces due to self-propelled and trailed machines, vehicles when driving on terrain and roads (including during their construction). The sources of transport vibration include agricultural and industrial tractors, self-propelled agricultural machines (including combines), trucks (including tractors, rollers, etc.); snow-plow, self-propelled mining rail transport.
- **General vibration** of the 2nd category is transport-technological, affecting the person due to workplace machines, which move through specially prepared surfaces of industrial premises, industrial sites, and mine workings. The sources of transport-technological vibration include excavators, industrial and construction cranes, machines for loading open-hearth furnaces in metallurgical production, mountain combines, mine loading and track machines, concrete pavers, floor industrial transport.
- **General vibration** of the 3rd category – technological, affecting the person in the workplace due to stationary machines located at or when

vibration is transmitted to the workplace by itself not having sources of vibration.

The sources of technological vibration include metal and woodworking machines, forging and pressing equipment, foundry and electrical machines, pump units and fans, equipment for drilling wells, drilling machines, livestock machinery, grain cleaning and sorting (including dryers), plants chemical and petrochemical industry, etc.

A prolonged impact of vibration can be the exposure for those working with a manual mechanized devices or rotary tool. They include metal casting choppers, metal scrapers, riveters, moulders, drillers, stone cutters, grinders, polishers, abrasives, sharpeners, fitters. The disease can occur in fellers and wood crosscutters when working with motor and electric saws, straighteners, working on dynamic hardening machines, concrete moulders with vibrocompaction of concrete.

Vibration disease is occupational disease characterized by the polymorphism of the clinical symptoms and the peculiarity of the course. ICD-10 code: T75.2. The impact of vibration.

Pathogenesis. The complexity of vibration disease pathogenesis is explained by diversity of its clinical signs. As a rule, abnormalities in the cardiovascular, nervous and muscular-skeletal system as also metabolic disorders are observed in this disease. The cornerstone of the pathology development is the complex of mechanisms interfering with neural, glandular and neural-reflex disorders. Vibration has a general biological effect on any cell, tissue and organ. Immediately after vibration exposure, deep, irreversible changes can develop. With prolonged action on the specific vibration receptors conditions for increase of excitability of the corresponding overlying centers occur. Under the influence of afferent impulses reflexes arise in the neurons of the spinal cord, sympathetic ganglia, the reticular formation of the brain stem, including at different levels of the vegetative vasomotor centers. Thus, along with decrease in the vibration perception, pain, tactile and temperature sensitivity are disturbed. This is explained by the fact that the spinal, thalamic and cortical centers of vibration sensitivity in humans are close to the vasomotor, as well as to the centers of pain and those of temperature sensitivity.

As a result of the violation of the regulatory effects of the central nervous system with respect to vascular tone, in particular to the regional blood circulation, specific angiospastic symptoms are observed. The greater extent the vibration sensitivity is changed to, the more expressed the vasospasm is. First of all, reflex disorders of vegetative vascular regulation are developed, associated with the state of the spinal ganglia and vegetative centers located both in the lateral horns of the spinal cord and at the higher levels. In this case, the disturbance of the activity of the reticular formation of the intermediate brain and the mechanisms of the regulation of homeostasis are important.

Clinical picture of vibration disease is characterized by polymorphism, in some cases the symptoms are nonspecific.

In the classification of vibration disease, three forms of the disease were identified (by E. Andreeva-Galanina, V.G. Artamonova):

- Due to local vibration;
- Due to combined vibration effects – local and general;
- Due to general vibration;

In terms of **severity** of the pathological process, four stages were conventionally identified:

- Stage I – initial (signs are rare);
- Stage II – moderately expressed;
- Stage III – severe;
- Stage IV – generalized (extremely rare);

In addition to the stages, it is suggested to note the most typical syndromes of the disease depending on the dominant vibration factor.

Classification of vibration disease dependent on the effects of local vibration:

Initial signs (1 degree):

- Peripheral vascular syndrome of the upper extremities, including rare cases of finger ischemia due to vascular spasm.
- Sensory (vegetative-sensory) polyneuropathy of the upper extremities.

Moderate signs (2 degree):

- Peripheral vascular syndrome of the upper extremities with partial angiospasm of the fingers.
- Syndrome of vegetative-sensory polyneuropathy of the upper extremities:
- With frequent angiospasm of fingers;
- Resistant vegetative and trophic disorders on the hands;
- Dystrophic disorders of the muscular-skeletal system of the hands and shoulder girdle (myopathosis, myofibrosis, periarthrosis, arthrosis);

- Cervical-brachial plexopathy;
- Cerebral vascular syndrome;

Severe signs (3 degree):

- Syndrome of the sensor-motor polyneuropathy of the upper extremities;
- Syndrome of the encephalopathy;
- Syndrome of the polyneuropathy with generalized vascular spasms.

In the clinical course of vibration disease, three degrees of severity are distinguished due to local vibration impact.

The first degree of the disease – is a little symptomatic. The state of the body is compensated. The process is completely reversible. Patients complain of mild pains in the hands, a feeling of numbness, paresthesia. At an objective examination, there are mild sensory disorders on the distal phalanges (hyper- or hypalgesia), uneven changes in the tone of the capillaries. Attacks of whitening of the fingers are extremely rare and only after a sharp cooling. **The second degree** is of moderately expressed signs. The number of complaints usually increases. The frequency and duration of vascular spasms grows. Painful phenomena and paresthesias become more persistent. Observe changes in the vascular tone of both the large vessels and capillaries. More expressed are sensitivity disorders, which can be of a segmental nature. Define vegetative dysfunction and signs of asthenia. The syndrome of vegetative-sensory polyneuropathy in combination with dystrophic disorders of the muscular-skeletal system is more pronounced. When conducting treatment and prevention activities, the process is reversible. **The third degree** is manifested with severe symptoms. Attacks of vascular spasms become frequent. Significant sensitivity disorders. There is a sharp decrease, and sometimes complete loss of vibration sensitivity. Vascular, trophic and sensitive disorders are sharply expressed up to development of osteopenia. There may be micro-focal symptomatology of the central nervous system, diencephalic crises, muscle atrophy and contracture often expressed. Angiodystonic crises cover the coronary, cerebral and peripheral vessels of the extremities.

Classification of vibration disease due to general vibration effects:

Initial signs (1 degree):

- Angiodystonic syndrome (cerebral or peripheral).
- Vegetative-vestibular syndrome.
- Sensory (vegetative-sensory) polyneuropathy of the lower extremities.

Moderate signs (2 degree):

- Cerebral-peripheral angiodystonic syndrome.
- Sensory (vegetative-sensory) polyneuropathy in combination with:
- Polyradicular disorders (a syndrome of polyradiculoneuropathy);
- Secondary lumbal-sacral radicular syndrome (due to lumbar spine affection);
- Functional disorders of the nervous system (neurasthenia syndrome).

Severe signs (3 degree):

- Syndrome of sensor-motor polyneuropathy;
- Syndrome of discirculatory encephalopathy in combination with peripheral polyneuropathy (encephalo-polyneuropathy syndrome).

In the classification of vibration disease due to general vibration, 3 degrees of its severity are distinguished: initial, moderately expressed and severe.

At the first degree of severity motor functions do not suffer. As manifestation of the angiodystonic syndrome, predominantly perivascular disorders are noted. The disease has functionally reversible character. The angiodystonic syndrome can be cerebral or peripheral.

At the second degree of severity beyond effects of general vibration, decrease in the adaptive capacity of the organism, the clearer symptoms of cerebral-peripheral angiodystonic and vegetative-sensory polyneuritis with possible polyradicular disorders are noted.

At the severe form of disease – III degree (is observed extremely seldom) they distinguish the dyscirculatory encephalopathy symptoms, most often in the form of the syndrome of encephalopolyneuropathy.

Diagnostics. When examining the patient pay attention to the color of the skin of the hands, movements in the fingers, hands and generally the limbs. Particular attention should be given to the state of vibration and pain sensitivity, as well as the osteoarticular apparatus, the muscular and cardiovascular system.

- Measure skin temperature
- Cold test, dynamometry, palesthesiometry, pitchfork test, algesiometry, capillaroscopy, thermography and electroneuromyography.

Risk factors. Effects of vibration and the likelihood of developing vibration-associated disorders depend on many production and non-production factors called "risk factors", including: characteristics of the vibration, environmental production factors, individual factors. The most significant factors are:

- Frequency composition of vibration, level, impulse, total duration of exposure per shift, presence of interruptions in work, including micro-pauses;
- Physical load (the weight that falls on the hands during the work with the vibration tool, the pressing and gripping forces of the handles, the working posture, the area and location of the parts of the hands exposed to vibration), since the vibration is transmitted to the operator in the process of power interaction with the vibration tool, hands exposed to vibration;
- Type and technical condition of the equipment, tools and accessories, the material of the handles and the insertion tool used, the thermal conductivity of the material;
- Environmental production factors, exacerbating the effect of vibration and affecting peripheral circulation (general and local cooling, blowing and wetting of hands, noise, harmful chemicals);
- Individual factors that affect peripheral blood circulation, such as nicotine, certain medicines, illnesses that can affect the blood circulation, and other individual characteristics (for example, the age of less than 18 or over 45 years old; morphologic or constitutional criteria);
- Non-industrial exposure to vibration and cold (home occupations with vibration tools, hobbies)

Organizational and technical preventive measures

Elimination of direct contact with vibrating equipment by using remote control, industrial robots, mechanization and automation of processes, replacement of technological operations; decrease in the intensity of vibration directly in the source (due to constructive improvements); application of resilient damping materials and devices placed between the source of vibration and the human operator. For example, the protection of transport and transport technology operators can be achieved by improving the amortization of the workplace – the chair.

Time protection – modes of work that must provide a general limitation of the time of exposure to vibration during the work shift; rational distribution of work with vibrating tools during the working shift (modes of work with the introduction of regularly recurring breaks); as well as limiting the duration of a continuous single exposure to vibration, the rational use of regulated breaks (during winter and transitional periods of the year breaks should also be used to heat workers). It is not recommended to perform overtime work with vibration tools.

Collective protection measures (protection from hypothermia). When working in open areas during the cold period of the year, it is necessary to equip the premises for heating, rest and shelter from unfavorable meteorological conditions. The air temperature in these rooms should be within 22–24°C. In the cold season, workers should be transported to a place of work in warm transport. In the lunchtime and other breaks for workers should be organized hot meals.

Personal protective equipment. Anti-vibration gauntlets and gloves, noise-absorbing headphones, special warm clothing, waterproof clothing, mittens and shoes when watering and cooling the water – are known to reduce negative impacts of industrial vibration and often – of other harmful physical factors associated on the health of workers.

Administrative measures to reduce the risk of developing occupational diseases when working with vibrating tools imply the fulfillment by employers of their duties towards the workers (allowing only working with vibration using suitable vibration-proof instruments, with handles coated with a heat-insulating material; periodic monitoring of the levels of vibration, noise, etc: development of labor regimes, providing employees with effective individual and collective protective equipment, sanitary facilities, preventive nutrition, training of workers in the correct ways about working with vibration tools that reduce the risk of developing vibration disease, ensuring the passage of regular medical examinations by employees.

Medical-preventive measures include: conducting of preliminary and periodic medical examinations; early diagnostics of diseases, carrying out of rehabilitation measures, and also fortifying measures: gymnastics; UV irradiation; vitamins, oxygen cocktails, use of rooms of psychological relief, physiotherapy measures; sanatorium treatment, etc.

QUESTIONS FOR SELF-CONTROL:

1. Frequency characteristics of infrasound, properties of infrasonic waves.
2. Industrial sources of infrasound.
3. Influence of infrasound on the human body.
4. Measures to prevent the adverse impact of infrasound on the workers.

5. Frequency range of ultrasound.
6. Sources of ultrasound.
7. Influence of ultrasound on the human body.
8. Technical measures that reduce impact of ultrasound transmitted by contact.
9. Preventive measures to reduce impact of the air ultrasound in a workplace.
10. Definition of industrial vibration.
11. Classification of vibration by the frequency composition.
12. Classification of vibration by time characteristics.
13. Classification of vibration by the source of its origin.
14. Definition of vibration disease.
15. Biologic effect of vibration.
16. Classification of vibration disease.
17. Risk factors for vibration disease.
18. Organizational, technical and medical-preventive measures aimed at reducing the pathological effect of industrial vibration.

5. BASICS OF RADIATION HYGIENE

Humanity has recognized existence of ionizing radiation (IR) at the turn of the 20th century thanks to discovery of X-ray by Wilhelm Roentgen in 1895. In 1896 the French physicist Antoine Henri Becquerel discovered the phenomenon of radioactivity of uranium salts, and Pierre and Marie Curie in 1898 revealed to the world the radioactive properties of polonium and radium. Along with excellent methods of diagnosis and treatment of many diseases existing thanks to IR, it is deadly to humans from the other side. Almost all the first radiation researchers – Maria, Irene, Frederic Joliot-Curie died of radiation disease, as did many physicians who worked with IR sources without due precaution. A powerful impetus for studying impact of IR on the human body was the testing of nuclear weapons and its direct application in 1945 to the Japanese cities of Hiroshima and Nagasaki by United States of America.

Prevention of the harmful effect of IR on people and general population is the objective of radiation hygiene. The urgency of radiation hygiene is determined by the widest use of IR sources in different industries, as well as by the huge number of people exposed to the radiation factor and the underestimation of the health risks due to it. Radiation hygiene represents a special hygienic discipline, comprehensively studying effects of IR on the health and at the same time is a part of all the sections of hygiene as of nutrition, children and adolescents, labor, water supply, etc.

Basic concepts of radiation hygiene

Radioactivity – spontaneous transformation of unstable nuclei of atoms of some elements into others, accompanied by emission of particles (corpuscular component) and gamma quanta (photons) – (electromagnetic component).

Ionizing radiation is radiation, the interaction of which with the medium leads to its ionization, that is, to the formation of charges of both signs. Ultraviolet, infrared radiation and visible light are capable of causing ionization of the medium under certain conditions (for example, in gas-discharge lamps), but they do not refer to IR. These types of radiation are associated with rearrangement of the outer electron shells of the atom, whereas IR is associated with rearrangement of the inner electron shells.

Radionuclides are any kind of atoms, regardless of whether they belong to the same element. There are isotopes and isobars.

Isotopes are varieties of one chemical element that occupy one place in the periodic system of elements, but differ in the mass of atoms. The chemical properties of atoms, that is, the belonging of an atom to any chemical element, depend on the number of electrons and their location in the electron shell of the atom. The place of an element in the periodic system is determined by its serial number Z, equal to the number of electrons in the shell of the atom, or to the number of protons contained in the atomic nucleus, which is the same thing.

The mass number of the atom A = Z + N, where Z is the number of protons, N is the number of neutrons. Stability of the nucleus, the type of decay, depends on the ratio of protons and neutrons in the nucleus. Isotopes – atoms that have nuclei with the same number of protons, but with different numbers of neutrons; have identical chemical properties, but have different masses and different nuclear properties. Example: ^{238}U contains 92 protons and 146 neutrons, and ^{235}U also has 92 protons, but 143 neutrons.

Isobars are atoms of different chemical elements with the same mass number A. The nuclei of isobars contain an equal number of nucleons (protons + neutrons), but different numbers of protons and neutrons. For example, the atoms of beryllium, boron and carbon are 3 isobars with the mass number of 10.

The basic law of radioactive decay is the exponential law of decrease in time of the average number of active nuclei. Some percents of nuclei of a radioactive element (for example, 1%) decays in a unit of time. This constant for each radioactive substance characterizes the probability of decay, it is called the **decay constant** (λ).

The **half-life** (T) is the time for which half of the original number of radioactive nuclei decays.

$$\mathbf{T = 0.693\ \lambda}$$

Depending on the half-life period, the following types of isotopes are known:

- Short-lived, half-life of which is calculated in fractions of seconds, minutes, hours, days (^{214}Ro, ^{210}Ro, ^{222}Ro);
- Long-lived – with a half-life of several months to billions of years (^{238}U, ^{234}U).

The absolute rate of radioactive decay is characterized by activity, that is, by the number of atoms decaying per unit of time. Activity is a measure of the radioactivity of any amount of a radionuclide that is in a given energy state at a given time. In the international system of units (SI), the unit of activity is **Becquerel (Bq)**, equal to 1 decay per second. Specific activity is the ratio of activity of the radionuclide to the mass or volume of the substance (Bq/kg, Bq/m^3, Bq/l).

Previously, an off-system activity unit – **Curie (Ku)** was used, it corresponds to the activity of 1 g of radium in equilibrium with the products of its decay.

$$\mathbf{1\ Ku = 3.7 \times 1010\ Bq;\ 1\ Bq = 2.7 \times 10^{-11}\ Ku}$$

There is a definite relationship between the activity in curie units and the weight of radioactive substances in grams: with a decrease in the decay constant (λ) or an increase in the half-life (T), the weight of the radioactive material increases with the same activity. So, for iodine-131, for which the half-life is 8.06 days, the weight of 1 curie is 0.008 mg, for uranium-238, for which the half-life is 4.5 billion years, about 3 tons.

Types of ionizing radiation

All types of IR are conventionally divided into electromagnetic, wave or photon (x-ray, gamma-radiation) and corpuscular (alpha, beta, neutron, proton, meson radiation). At the same time, any particle has a wave nature, and any wave has properties of quantization, i.e. the properties of the particle. The classification of IR is carried out both by the type of ionization and by the physical state (***fig. 14***).

Photon radiation is indirectly ionizing. It is a stream of electromagnetic oscillations (quanta) with a specific wavelength and energy, propagating rectilinearly and uniformly in all directions from the source at a constant speed close to the speed of light. By formation conditions, the following types of photonic IR are distinguished: Gamma, X-ray, Braking (Decelerating) and Characteristic.

Corpuscular radiation is a stream of elementary particles possessing a definite energy and rest mass different from zero. Particles that have an electric charge (alpha particles, electrons, positrons, protons) and kinetic energy sufficient for the ionization of the atoms of the medium refer to the ionizing radiation itself.

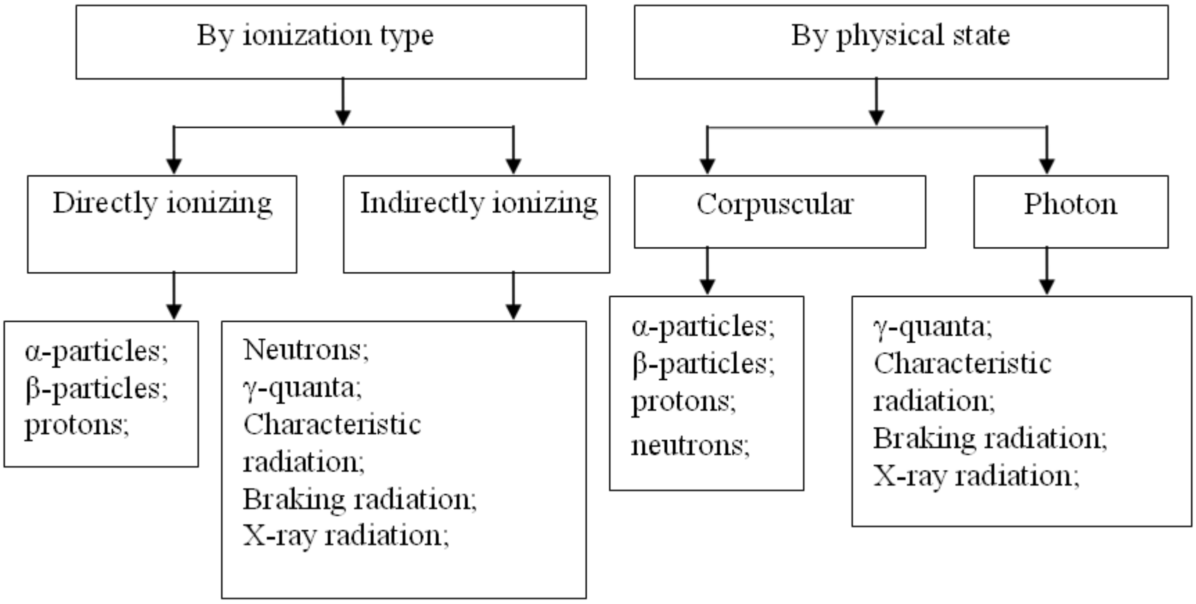


Figure 14. *Types of ionizing radiation*

Neutral elementary particles (neutrons with different energies), due to the absence of an electric charge, do not themselves cause ionization, but in the process of their interaction with the medium, formation of charged particles capable of creating an ionization effect occurs. Therefore neutral particles are referred to as **indirectly ionizing.**

Corpuscular radiation

Alpha-particle is a stream of positively charged helium atoms. Alpha decay is inherent for heavy (trans-uranium) natural and artificial radionuclides. The length of the run in the air is several centimeters, in biological tissues – up to 50 microns, thus are retained by the skin. The energy of alpha particles is mainly spent on the ionization of the medium, in which a high ionization density is created. For example, at the energy of 3 MeV per 1 mm of alpha run, 40000 ion pairs are formed. A substance that has alpha decay is dangerous for internal irradiation, in particular, for incorporation, because huge doses of irradiation at a small distance are created. Alpha-decay is inherent for natural radioactive elements with large ordinal numbers, hence, with low binding energies. Alpha-decay leads to a decrease in the ordinal number of the element by two units and the mass number by four units, in comparison with the "parent" nuclide:

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

Beta-particles are a stream of negatively charged electrons or positively charged positrons (antiparticles of electrons). The length of the run in the air is several meters, in biological tissues – up to 1–4 cm. The density of ionization of the medium at the energy of 3 MeV is 4 pairs of ions per 1 mm of the run. Dangerous is both with external and internal irradiation. The half-life of beta-active nuclei varies from 10^{-2} s to 10^{18} years.

There are three types of beta decay: **electron, positron and K-capture.**

1. **Electronic** beta decay is inherent for both natural and artificial radioactive elements. At the same time, the nucleus of a new radionuclide arises with a constant mass number of "maternal", for example:

$$^{40}_{19}K \longrightarrow e^{-1} + {}^{40}_{20}Ca$$

2. **Positron** beta decay is observed in some artificial radioactive isotopes. In this case, the ordinal number of the decaying element decreases by one, and the mass does not change, for example:

$$^{32}_{15}P \longrightarrow e^{-1} + {}^{32}_{14}Si$$

3. **K-capture** – capture of the orbital electron of the K shell by a nucleus. There is a transformation of the nucleus, similar to positron beta decay. Positron decay and K-capture are competing processes. In the case of K-capture, the neutrino emits from the nucleus and **characteristic X-ray radiation** arises.

Neutron radiation is a flux of heavy particles without a charge. The length of the run in the air is hundreds of meters; biological tissues permeate, dangerous for external irradiation, and also for internal radiation due to induced radiation. The sources of neutrons are: a nuclear reactor, an atomic bomb.

Photon radiation

Gamma radiation is formed as a result of energetic changes in the nuclei in the process of radioactive decay, as well as during annihilation (destruction, disappearance) of particles, for example, a positron and electron, when a particle and its corresponding antiparticle are converted into electromagnetic radiation – photons or quanta. The length of the run in the air is hundreds of meters, biological tissues permeate. It is dangerous for external exposure.

Braking radiation (Deceleration radiation; or German term – "Bremsstrahlung" is widely used) – electromagnetic radiation with a continuous energy spectrum, emitted by charged particles when braking in the electric field of the atomic nucleus. The intensity of bremsstrahlung is proportional to the square of the acceleration of the charged particle, and the acceleration, in turn, is inversely proportional to the mass of the particle. Therefore, in the same field, bremsstrahlung of the smallest particle of an electron will be millions of times stronger than the radiation of a proton. In practice, bremsstrahlung, occurring when electrons are scattered in the electric field of atomic nuclei, is most often used. This is the nature of X-rays in X-ray tubes and of gamma radiation emitted by fast electrons as they pass through matter.

Characteristic radiation with a discrete energy spectrum is formed when the energy state of an atom changes in connection with the rearrangement of its internal electron shells.

X-ray radiation is a combination of the braking and characteristic radiation. There are rigid (wavelength less than 2 angstroms (A°)) and soft (more than 2A°) X-ray radiation. One A° = 10^{-10} m. The length of the run in the air is tens of meters, biological tissues permeate, it is dangerous only with external irradiation.

Figure 15 shows the penetrating power of the main IR types.

Doses of radiation and units of its measurement

A biological effect due to IR influence is determined by the amount of absorbed energy per unit mass, i.e. absorbed dose (D). The absorbed dose is a fundamental dosimetric concept. In the international system of units, it is measured in **Gray (Gy)**. This is 1 joule of energy absorbed by 1 kg of matter. The non-systemic unit of the absorbed dose is **rad** (is the first letters of the English word combination radiation absorbed dose). 1 Gy = 100 rad.

Effect of radiation exposure on the body depends not only on the dose absorbed and its fractionation in time, but also on the specific ionization of this type of radiation. With the same absorbed dose, biological effects can be different for different types of IR, therefore hygienic assessment of the exposure effects; the relative biological effectiveness of different types of

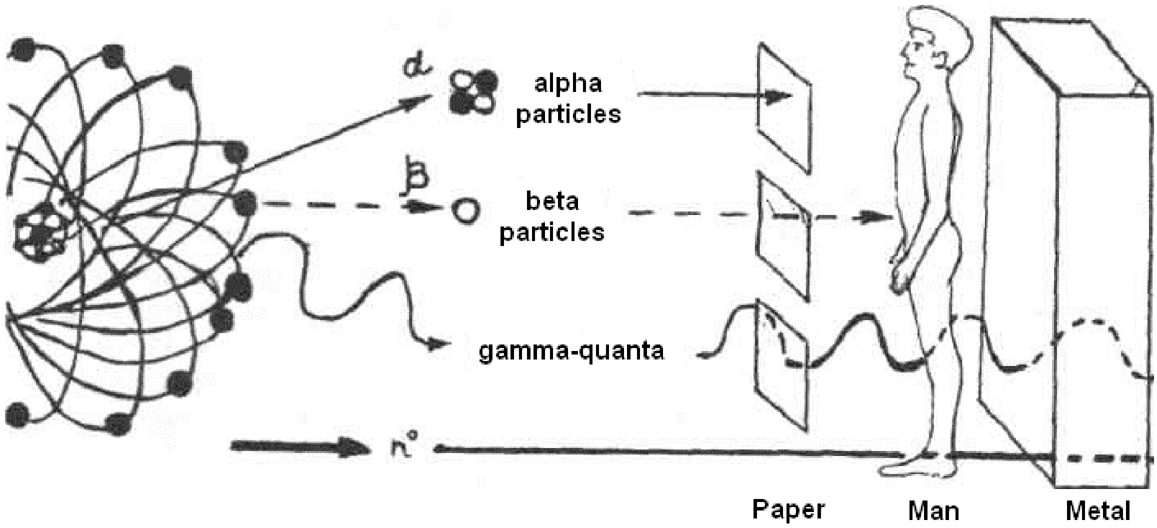


Figure 15. *Penetrating power of the main types of ionizing radiation*

IR is carried out using **weighting coefficients** for individual types of radiation or **quality coefficients**.

One compares the dose of a specific radiation, causing a certain biological effect, with the dose of standard radiation, giving the same effect. The standard radiation is equal to X-ray with the energy of 180–250 kiloelectronvolts (keV), the relative biological efficiency of which is taken as 1 (***tab. 10***).

The higher the specific ionization, the greater would be the weighting coefficient for the given type of radiation. Thus, the weighting coefficient shows how many times the biological effect of a given type of radiation is greater than that of beta, X-ray or gamma radiation at the same dose absorbed.

To assess harmful effects of irradiation with various types of IR, the concept of equivalent dose is introduced. **Equivalent dose** – the dose of any kind of radiation when irradiating a biological object, equated to the biological effect of x-ray or gamma radiation. This is the **absorbed dose** in the organ or tissue multiplied by the corresponding weighting factor for a given type of radiation. The system unit of measure is $J \times kg^{-1}$ = **Sievert (Sv)**. The extrasystem unit of the equivalent dose is **rem** (the biological equivalent of an x-ray or rad). One Sv = 100 rem. With the same absorbed dose, the biological effect of alpha radiation will be 20 times greater than that of beta, X-ray or gamma radiation.

An **equivalent dose** is used to determine the radiation safety of a particular person. But the equivalent dose does not allow evaluating the long-term effects of irradiation. An effective dose has been introduced to account for such effects.

Table 10

Weighing coefficients for individual types of radiation when calculating the equivalent dose

Kind of radiation	Weighing coefficient
Photons of any energy	1
Electrons and muons of any energy	1
Neutrons with energies of less than 10 keV From 10 to 100 keV From 100 keV to 2 MeV (mega-electronvolts) From 2 to 20 MeV Above 20 MeV	5 10 20 10 5
Protons with an energy of more than 2 MeV, in addition to recoil protons	5
Alpha particles, fission fragments, heavy nuclei	20

An **effective dose** is used as a measure of the risk of long-term effects of irradiation of the whole body and of individual organs, taking into account their radiosensitivity. The unit of measurement is $J \times kg^{-1}$ = Sv. It represents the sum of products of the equivalent dose for the corresponding weighting factor for a given organ or tissue. The most differentiated tissues are the most sensitive to ionizing radiation, those the cells of which multiply intensively.

Radiosensitivity of different cells varies in a huge dose range. Thus, in mouse liver cells, no morphological changes were observed after irradiation at the dose of 800 Gy, while mouse spermatozoa die from the dose of 0.05 Gy.

Radiosensitivity of tissue is directly proportional to proliferative activity and inversely proportional to the degree of differentiation of its constituent cells. Three groups of critical organs of human body have been identified with respect to radiosensitivity, i.e. organs, tissues, body parts or the whole body, whose irradiation under these conditions is most significant in relation to possible damage to health:

- **Group 1** – the whole body, sex glands, red bone marrow, they are most radiosensitive and are mostly affected.
- **Group 2** – muscles, thyroid gland, fatty tissue, liver, kidneys, spleen, gastrointestinal tract, lungs, lens and other organs not belonging to the first and third groups, they are less radiosensitive.
- **Group 3** – skin, bone tissue and distal limbs (brushes, forearms, ankles, feet), are relatively resistant to irradiation.

The weighting coefficients for tissues and organs in calculating the effective dose are equivalent factors in the organs and tissues used in radiation protection to account for the different sensitivity of different organs and tissues in the occurrence of stochastic radiation effects. When calculating the effective radiation dose, the following weighting factors are used: gonads – 0.2; red bone marrow, large intestine, lungs, stomach – 0.12; bladder, milk and thyroid gland, liver, esophagus – 0.05; skin, bones – 0.01.

To assess radiation situation, the **exposure dose** measured in X-rays (P) is determined. One X-ray corresponds to the formation in 1 cm^3 of air under influence of gamma-rays at 0°C and 760 mm Hg of 2.08×10^9 ion pairs.

The main sources of human exposure

All sources of IR are conditionally divided into natural and man-made. Natural sources include cosmic radiation, radionuclides of terrestrial and cosmic origin. A combination of natural sources determines the natural radiation background.

Technogenic IR sources are the result of scientific, engineering, technical and other types of people's activities, that is, they are artificially created for economic use or they are by-products of such activity. The totality of the radiation impact on people of natural and anthropogenic sources determines the total radiation dose, the magnitude of which can vary over a wide range.

Natural sources of ionizing radiation

Natural sources account for the bulk of the population's exposure to the globe.

Natural radioactivity. The biosphere is caused by terrestrial and cosmogenic radionuclides. The first appeared in the formation of the Earth and are represented by radioactive elements of uranium, radium and thorium family, as well as potassium-40, rubidium-87. Cosmic radiation is divided into primary, due to high-energy particles from interstellar space, and the secondary, arising from the interaction of primary radiation with atoms of the atmosphere.

Natural radionuclides are sources of both external and internal exposure of people. Cosmic radiation causes an average annual effective dose of external irradiation equal to 0.28 mSv, which increases when living in high mountains, flights on airplanes and spacecraft. So, for a 3-hour flight on a supersonic liner, the equivalent dose of irradiation is 0.05 mSv (5 mrem).

The terrestrial sources create an average effective dose of external irradiation in the open area of 4.1 mSv per year (41 mrem). This dose varies significantly depending on the nature of the rocks and the building materials used. Many places are known on the globe (in Brazil, India, Iran, France, Nigeria and other countries), where the levels of external exposure of the population reach 8–40 mSv per year.

The leading role in the formation of the dose of internal irradiation belongs to the radon gas and the products of its decay. The average annual effective dose received by the population due to radon is 1.0–1.24 mSv. Internal irradiation at the level of 0.18 mSv per year is also due to potassium-40, which is a part of the human body.

Thus, the average total dose of external and internal exposure of a person from all natural sources of IR is about 2 mSv per year. But this dose of public exposure can significantly increase due to use of building materials (granite, marble, tuff), mineral fertilizers, fuel combustion, extracted from the earth's interior – coal, oil, gas.

Technogenic sources of ionizing radiation

It is difficult to name an industry of practical activities of people (industry, agriculture, science, medicine, art), wherever sources of IR are not used. In this regard, a large number of people are exposed to the radiation factor. In the world there are about 1.6 million professionals (in Russia more than 170 thousand people) associated with the use of IR. The largest proportion of the professionals is medical specialists: radiology doctors, radiology technicians, doctors and nurses of radiological departments. Sources of radioactive radiation are used for:

- Improving the quality of chemical products. For example, irradiation of automobile tires increases their mileage by 20–30%
- Obtaining materials with predefined properties
- Studying and improving technological processes by introducing radioactive isotopes into chemical compounds. In particular, it is used for isotope separation, radiometric titration, for determination of microquantities of substances by neutron activation analysis

- Gamma-defectoscopy (defect detection) widely used in metallurgy, shipbuilding, gas and oil pipeline construction, for non-destructive quality control of products
- In nuclear reactors for the production of electrical energy
- Radiation sterilization and pasteurization of food products; irradiation of grain and potatoes in order to increase the shelf life of their products; destruction of trichinella in pork
- Diagnosis and treatment of various diseases

In 1954, USSR created the world's first nuclear power plant (NPP) in Obninsk, Kaluga region. Currently, more than 500 nuclear power reactors are in operation in 30 countries of the world. When used normally, exposure of the population due to releases to the environment averages 0.001 mSv per year, i.e., less than 0.1% of the dose of natural exposure. However, for people living near nuclear power plants, it can be much higher. The history of nuclear energy includes more than 300 accidents at nuclear power plants, which were accompanied by substantial exposure of the population and radioactive contamination of large areas. Radiation accidents and incidents took place in Great Britain (Windskale, 1957), USA (Idaho, 1961; Three Mile Island, 1979), Germany (Hame, 1986), Ukraine (Chernobyl, 1986), Russia (Tomsk 1993).

Along with stationary, mobile reactors are used – on nuclear submarines, nuclear icebreakers, etc.

The significant man-made source of IR is nuclear weapons. In 1945, Americans dropped atomic bombs on Japanese cities of Hiroshima and Nagasaki, and extremely negative consequences of this atomic bombardment are still present.

Until 1963, these weapons were tested in the atmosphere, which led to a global increase in the radiation background of the planet. The products of nuclear explosions contain more than 200 radioactive isotopes with mass numbers from 72 to 161, of which tritium (half-life of 12.3 years) and carbon (^{14}C) with a half-life of 5737 years are hygienically significant. The consequence of nuclear weapons testing in Semipalatinsk test site was radioactive contamination of the Altai Territory, Kemerovo, Novosibirsk and other regions of Siberia.

Radiation for medical purposes

Currently, the main contribution to the dose received by a person from technogenic sources of radiation is medical exposure. The term "medical exposure" refers only to the exposure of a patient for diagnostic or therapeutic purposes and does not apply to the personnel serving medical IR-related procedures, although the latter may have radioactive effect on it.

In medicine, IR and radioactive substances are mostly used:

- For diagnostics (fluoroscopy, radiography, fluorography, static scintigraphy for determining the spread of a radioactive indicator in organs and tissues, based on the recording of light flashes from the scintillator and emitting IR, dynamic scintigraphy, computed tomography, study of metabolic processes and blood flow velocity with izotopes;
- For treatment of mainly malignant neoplasms – tele-gamma therapy, close-focus X-ray therapy, radio-application therapy, intracavitary and interstitial radiation therapy;
- For scientific research – the method of radioactive labels or labeled atoms, based on the addition of a small amount of its radioactive isotope to the stable element.

Possessing similar biochemical properties, isotopes are included in metabolic processes, by their distribution in organs and tissues, one can judge the participation of stable elements in the functioning of the organism. The method of autoradiography is used to study the distribution of radioactive substances in the investigated object by the imposition of a photoemulsion sensitive to radioactive emissions, while the radioactive substances contained in the object seem to photograph themselves.

Artificial radionuclides (isotopes) are obtained by irradiating of stable elements with thermal neutrons, which, falling into the nuclei of atoms, form isotopes of the irradiated chemical element. In the diagnostics of cardiovascular diseases, phosphorus-32 and other isotopes are used, thyroid status is assessed with iodine-131, kidneys with gold-192. Radiation therapy uses radiopharmaceuticals – cobalt-60, cesium-137, iridium-192, etc.

Medical exposure is always carried out intentionally, although it is accompanied by a risk to the health of the patient irradiated. However, this risk must be justified by the benefit, which can not be obtained otherwise.

The greatest contribution to the irradiation of patients is due to X-ray diagnostics. In developed countries around the world, from 259 to 1419 radiological procedures are done per year per 1000 population, excluding x-ray studies of teeth and fluorography. In a number of industrially top countries, the frequency of X-ray of the lungs is reduced, because due to reduction in the incidence of tuberculosis, efficiency of mass surveys becomes questionable. Top doses of IR are received from radioisotope studies, coronary angiography, abdomen and pelvis computer tomography. With X-ray of the stomach, the dose of a single local irradiation is 3.5 mSv; with fluorography – about 0.7 mSv. For comparison, 0.001 mSv is received during the year with a daily 3-hour watching TV; 1.5–2 mSv is the annual intake of radionuclides into the body due to the natural background IR. Approximate doses, received from common radiology procedures, as compared to natural background radiation exposure are presented in the table 11.

Table 11

Comparison of background radiation and effective radiation dose in adults for several radiology procedures

Procedure	**Approximate effective radiation dose**	**Comparable to natural background radiation for:**
Computed Tomography – Abdomen and Pelvis	10 mSv	3 years
Computed Tomography – Abdomen and Pelvis, repeated	20 mSv	7 years
Computed Tomography – Colonography	6 mSv	2 years
Intravenous Pyelogram	3 mSv	1 year
Barium Enema (X-ray)	8 mSv	3 years
Upper Gastro-intestinal Study with Barium	6 mSv	2 years
Spine X-ray	1.5 mSv	6 months
Extremity X-ray	0.001 mSv	3 hours
Computed Tomography – Head	2 mSv	8 months
Computed Tomography – Spine	6 mSv	2 years
Computed Tomography – Chest	7 mSv	2 years
Computed Tomography – Lung Cancer Screening	1.5 mSv	6 months
Chest X-ray	0.1 mSv	10 days
Dental X-ray	0.005 mSv	1 day
Coronary Computed Tomography Angiography	12 mSv	4 years
Cardiac CT for Calcium Scoring	3 mSv	1 year
Bone Densitometry	0.001 mSv	3 hours
Mammography	0.4 mSv	7 weeks
Positron Emission Tomography – Computer Tomography (PET/CT)	25 mSv	8 years

In recent decades, radioisotope diagnostics using radiopharmaceuticals, which are negligibly small in weight terms of radionuclides and labeled compounds, are introduced into the body for the purpose of determining the functional capabilities of organs or for performing application, intracavitary and interstitial diagnostics and therapy. In medical practice, about 60 radionuclides and more than 100 labeled compounds having a relatively short effective half-life (from 6 hours to 30 days) are used, they are quickly removed from the body. The most common diagnostic procedure is a radioisotope scan of the organ to identify a tumor by the level of radionuclide accumulation in it.

The use of IR sources for medical purposes makes much more significant contribution to public exposure than the technogenically increased natural radiation background. However, the possible damage to it for the world population remains significantly less than the benefit of early diagnostics, timely and effective treatment of such serious diseases as cancer, tuberculosis and others, and consequently, increase in the life expectancy of people. Dose of irradiation with medical X-ray-radiological studies is 80 to 140% of the natural radiation background.

According to the requirements of radiation safety standards (NRB-99/2009), the limitation of medical exposure presupposes:

- Justification of radiological medical procedures and optimization of patient protection measures;
- When conducting preventive medical and scientific radiographic studies of practically healthy persons, the annual effective dose of their irradiation should not exceed 1 mSv;
- Persons assisting patients in performing X-ray radiological procedures should not be exposed to radiation at a dose exceeding 5 mSv per year;
- Dose rate of gamma radiation at a distance of 1 m from a patient who is administered a radiopharmaceutical with a therapeutic purpose, should not exceed 3 μSv/h at the outlet from the radiological department;

When using radiation sources for medical purposes, monitoring of patient doses is mandatory.

Thus, a person is affected by a complex of IR sources. Significance of these sources is not the same for different categories of persons irradiated: the greatest contribution to the collective dose of population exposure is made by the natural radiation background and medical exposure (***tab. 12***). In some cases irradiation from radioactive contamination of the biosphere

Table 12

Levels of exposure of the population from various sources (Sv/person)

Source of radiation	Average individual effective dose of irradiation	
	Russia	Average world value
Natural sources	2.4	2.4
Medical radiation, including: X-ray diagnostics Radionu- clide diagnostics	1.0 0.96 0.04	0.4 0.32 0.08
Global loss	0.022	0.007
Other man-made radiation	0.005	0.0005
Total	3.4	2.9

as a result of the operation of nuclear power facilities, as well as from nuclear weapons tests, is possible.

Biological effects of ionizing radiation

Features of biological action of IR:

1. Inability to be felt by a human body due to lack of appropriate receptors. Radiation has no smell, color, pressure, is not accompanied by the formation of noise, light, temperature. When irradiated, a person does not receive a respective sensory distress signal and thence can still keep being exposed, swallow, inhale a radioactive substance without any primary sensations. This way it is possible to receive large doses of radiation. To detect IR one uses radiometric instruments.
2. The presence of a latent period of manifestation of the biological effect. Visible skin lesions, malaise, characteristic of radiation sickness, appear some time after irradiation.
3. The presence of summation of absorbed doses effect, which occurs in a hidden way. If the human body is systematically exposed to the IR, the doses are summed up, which inevitably leads to radiation effects.

Factors influencing effects of ionizing radiation on the body

A biological effect of any electromagnetic radiation depends on the following factors:

- Energy of a quantum;
- Depth of penetration into the tissues of the body;
- Intensity of irradiation – the amount of energy per unit of area per unit of time;

- Irradiation regime that determines the radiation dose;
- Areas of irradiation;
- State of the body.

There are direct and indirect effects of IR on biological tissue. As a result of direct action, ionization and excitation of complex molecules occurs with their subsequent dissociation, breaks of chemical bonds. In excited state, the molecule of organic matter is a very short time – 1×10^{-14} s. During this time, the excitation energy is concentrated on one of the chemical bonds, which can lead to detachment from the molecule of some fragment. The result of ionization is an abrupt change in the electromagnetic field of the molecule, as a result of which the breakdown of chemical bonds is possible.

Indirect action is associated with radiation-induced chemical processes. The primary mechanism of the damaging effect of IR on the body is the **radiolysis of intracellular** water. When irradiating biological objects containing water in their composition, half of the dose absorbed by the cell affects water (indirect effect of IR), the second half – organoids and soluble substances of the cell (direct action), accordingly. Water, which in the human body is 65–70% of body weight, undergoes ionization, gets split into hydrogen and hydroxyl group (OH^-), which through the chain of secondary transformations form products with high chemical activity: hydroperoxide (HO_2), hydrogen peroxide (H_2O_2), as well as free radicals. These substances, which are not natural characteristic of a cell, are called radiotoxins, they interact with the organic substances of tissues, oxidizing and destroying them.

There are specific radiation-induced chemical transformations in tissues. In this case, of greatest pathogenetic significance is the effect of radiotoxins on the reactive protein structures of enzyme systems, in particular, the active sulfhydryl groups of proteins pass into inactive disulfide groups. Under the influence of radiation, nucleoproteins break down into protein and DNA.

Oxidation of unsaturated fatty acids and phenols produces lipidic radiotoxins (peroxides, epoxides, aldehydes, ketones) and quinone radiotoxins, which inhibit the synthesis of nucleic acids, which inhibit the activity of various enzymes that increase the permeability of biological membranes. In the organism irradiated, the normal course of biochemical processes and various types of metabolism is disrupted. Depending on the amount of the dose absorbed and individual characteristics of the body, these disorders can be reversible when the affected tissue restores its functions, or irreversible.

Negative physiological effects may appear immediately after exposure, but some cell lesions are detected only after mitosis, since they are associated with local damage to the chromosome apparatus due to direct radiation exposure. This is manifested by the rupture of chromosomes, the formation of their fragments, which can be preserved or restored. Correct reunion of chromosomal fragments (restitution) means a complete restoration of the structure and functions of the cell; Incorrect reunion (recombination) leads to the formation of chromosomal aberrations. Mutations, once arising, persist as a result of convergent DNA reduplication and are transmitted to all subsequent cell generations.

Thus, changes at the cellular level not only lead to disruption of the functions of individual organs and systems in the organism irradiated, but also cause hereditary changes that are transmitted to subsequent generations of people irradiated and contribute to induction of malignant neoplasms. Damage to the nuclear apparatus of cells, associated with a violation of nucleic acids exchange, is one of the most important mechanisms of general radiation damage.

Induced by the products of water radiolysis, chemical reactions spread to many hundreds and thousands of molecules not primarily affected by radiation. The specificity of the action of IR on a living organism is that the biological effect it produces is not due to the amount of energy transferred, but to the extent of its subsequent transformation. This largely explains the **radiobiological paradox** – the discrepancy between the insignificant amount of the energy absorbed and the extreme degree of severity of the biological response up to a lethal outcome.

Types of the radiation-induced effects

Biological consequences of IR exposure are manifested as two radiation-induced effects:

1. **Deterministic** (somatic) threshold effects are clinically significant effects that manifest themselves as an obvious radiation injury. They can be local (radiation burns, radiation dermatitis, radiation cataracts) and general (acute and chronic radiation disease, radiation infertility, manifested in temporary or permanent sterility, violations of hemopoiesis). Manifestation of early deterministic effects is characterized by a clear dependence on the radiation dose, which can cause radiation damage of varying severity – from hidden, minor damages without clinical

manifestations, to acute and acute radiation sickness. A formation of deterministic effects occurs with the accumulation of a significant dose of radiation, to prevent this, the exposure thresholds are set.

2. **Stochastic** (probabilistic, random, non-mandatory) effects are manifested as reduction in life expectancy, an increase in the number of patients with oncological diseases (leukemia) or congenital genetic damage in the offspring of the persons irradiated, they are of a no-threshold nature. At the same time, the severity of stochastic effects does not depend on the dose of irradiation, and the clinical course of such diseases is not specific, they do not differ from spontaneously arising for any indicators. Thus, any arbitrarily small doses of radiation can not guarantee against the appearance of stochastic effects. The magnitude of irradiation dose affects the probability of stochastic effects occurrence, but not their severity – the higher the dose of irradiation, the greater the incidence of malignant neoplasms or hereditary defects in the population, including each individual. Stochastic effects are also called remote effects of irradiation, which can occur at very long intervals, years and decades after irradiation.

Clinical manifestations of radiation lesions are diverse and variable in severity. This is due to the complex interrelationships of various factors. These are the individual characteristics of the irradiated organism: sex, age, state of neuroendocrine regulation, general physical health, presence or absence of chronic diseases, physiological state of the organism – pregnancy, lactation, chronic fatigue, malnutrition.

The dose and type of radiation are of decisive importance. When exposed to a dose of 250–750 mSv, short-term, minor changes in blood composition occur; 500–1000 mSv – the lower level of irradiation, capable of inducing radiation disease; 4500 mSv – severe degree of radiation disease, at which 50% of the people irradiated die; 2500–6000 mSv – the lethal irradiation dose.

Hygienic regulation of ionizing radiation effects

Radiation safety of the population is the state of protection of the present and future generations of people from harmful to their health impact of IR. Citizens of Russia have the right to radiation safety, which is provided through the implementation of a set of measures to prevent radiation exposure of human body to the extent above the established standards, the fulfillment of the requirements for ensuring radiation safety by citizens and organizations.

The basis of the radiation safety system is modern international scientific recommendations, the legislation of countries that have achieved a high level of radiation protection of population, and domestic experience, taking into account its achievements and shortcomings. At present, the NRB-99/2009 radiation safety standards are in force in Russia.

To ensure radiation safety, the following three basic principles are used:

- Exceeding the permissible limits of individual exposure doses to citizens from all sources of IR (the principle of regulation)
- Prohibition of all activities using IR, in which the benefits for individuals and societies do not exceed the risk of possible harm caused by additional exposure to the natural radiation background (the principle of justification)
- Attaining a lower affordable level of IR exposure, taking into account economic and social factors, individual doses of radiation and the number of individuals exposed to radiation when using any source of IR (optimization principle)

A differentiated approach is used in establishing acceptable levels of irradiation.

The NRB regulates the main dose limits for irradiation of the following groups of irradiated persons:

- **Group A** – persons from the staff, working with technogenic sources of ionized radiation;
- **Group B** – persons from the staff who, according to the working conditions, are in the area of exposure to technogenic sources of radiation;
- **The entire population**, including the personnel beyond the scope of their occupational activities.

The table 13 shows the main dose limits for the three categories of irradiated persons.

Observance of the annual dose limit prevents occurrence of deterministic effects, and controls the probability of stochastic effects at an acceptable level.

The main dose limits do not include doses from natural and medical exposures, as well as doses from radiation accidents. Special restrictions are imposed on these types of radiation.

With simultaneous exposure of human from the sources of external and internal exposure, the annual effective dose should not exceed the basic dose limits.

Table 13

The basic dose limits, mSv

The normalized quantities	Group A	Group B	Population
Effective dose	20 mSv per year on average for any consecutive 5 years, but not more than 50 mSv per year	5 mSv per year on average for any consecutive 5 years, but not more than 12.5 mSv per year	1 mSv per year on average for any consecutive 5 years, but not more than 5 mSv per year
Equivalent dose for the year: for the lens skin, hands and feet	 150 500	 37.5 125	 15 50

For women of childbearing age (up to 45 years) working with IR sources, additional restrictions are introduced – the equivalent dose on the surface of the lower abdomen should not exceed 1 mSv per month, and intake of radionuclides in the body for one year should not be more than 1/20 limit of the annual limit for the staff. For the period of pregnancy and lactation, a woman is transferred to work not related to radiation sources.

For pupils and students over 16 years of age who are undergoing vocational training using IR sources, annual doses should not exceed the values established for the B-group personnel.

For the persons exposed to IR, there are 3 classes of standards:

1 – Basic dose limits;

2 – Permissible levels of multifactorial exposure (for one radionuclide, intake route or one type of external radiation), which are derived from the basic dose limits. These are the annual limits.

3 – Control levels. This is the maximum permissible emissions into the atmosphere, the maximum permissible discharges of liquid waste, etc.

Principles of protection from ionizing radiation

When working with IR sources, there are two main types of effects on a person:

- External irradiation of the whole body or its part with X-ray radiation, gamma rays, neutrons
- Internal exposure when radioactive substances enter the body

Radioactive substances can enter the body in the form of gases, vapors, aerosols and in liquid form through the respiratory tract, digestive system, and the skin. When ingested, the most dangerous are alpha emitters.

Specific organization of the protection system depends on the type of IR source and type of radiation. There are closed and open sources of IR. Construction of a closed source prevents ingression of radionuclides into environment during the whole time of its usage. In contrast, if an open source is used, the radionuclides contained in it may enter environment.

The system of radiation protection for patients and medical personnel includes the following activities:

1. Planning and constructive measures – selection of a site for X-ray and radiology department; features of internal planning of premises; rational placement of special equipment, protective devices and protective structures;
2. Sanitary-dosimetric control of the personnel and environment;
3. Monitoring the health of staff (periodical medical examinations);
4. Organizational arrangements – professional mastery development, strict implementation of all rules of work with radionuclides, devices; high performing and labor discipline;
5. Means of personal protection of the personnel;

Protection when working with the sealed sources

The main damaging factor when working with sealed sources is external irradiation. By the nature of action, closed sources can produce **continuous** and **intermittent** (periodic) effect. The first group includes installations with gamma, beta and neutron emitters. Gamma emitters are radioactive isotopes of cobalt-60, tellurium-107, cadmium-109, iodine-137, which are placed in the form of powders in hermetically sealed steel ampoules and used in the form of radioactive beads, needles for intracavitary radiotherapy.

Beta-emitters are artificial isotopes of strontium-90, yttrium-90, gold-198, thallium-204. Neutron sources consist of a mixture of isotopes of radium, polonium and plutonium with beryllium and boron encased in steel ampoules. The activity of these radiators is different. The protection system will depend on the activity of the radiator, the type of radiation, the technology of working with radiation sources.

Sources of intermittent action are X-ray machines, charged particle accelerators.

The main parameters of IR protection are based on the physical laws, indicating that the dose of external exposure (D) is proportional to the activity of the source (Q) and the time of its action (t) and is inversely proportional to the square of the distance to the source (R):

$$D = \frac{Q \times t}{R^2}$$

Therefore, when working with IR sources of a closed type, the main principles of protection are the quantity, time, distance and screening based.

Quantity protection consists of the use of sources with the minimum intensity of radiation. However, the quantity protection in medical practice has not become widespread, since a decrease in the activity of the source inevitably leads to weakening of the therapeutic effect and inevitable need for increase in the time of exposure to achieve the aim desired.

Time protection consists of reducing the time spent working with IR sources. Time protection involves reducing the duration of personnel exposure by limiting the length of the working day and the number of procedures performed during the shift; automatism of work operations, high qualification of medical personnel, and their training.

Distance protection is the most effective principle of protection, since there is inversely quadratic dependence between the radiation dose and the distance: when the distance is increased by a factor of 2, the dose decreases by a factor of 4, and when the distance is increased 3 times, 9 times, respectively. To increase the distance, remote tools are used (tools with elongated handles, carts with long handles for transporting containers with radioactive preparations), remote manipulators, grippers, tongs, etc.

Screen protection is an effective type of protection when working with closed sources. It is based on the ability of various materials to absorb IR. The absorbing capacity of materials increases as the atomic mass of the chemical elements increases, as well as the relative density of the material and the thickness of the screen. Excellent protective properties are inherent for lead, with which the screening properties of other materials are compared. So, with respect to X-rays, a 12 mm thick steel sheet, 14 cm of barite concrete, 80 cm of concrete, 80–110 cm of brickwork are equivalent in thickness to a lead shield having thickness of 1 mm.

Depending on the penetrating power of the radiation, various materials are used for screening. When external irradiation is with alpha particles, no screening is necessary, since they have a small run in the air and are well retained by other materials (a sheet of paper). To protect against beta radiation, lightweight materials with low atomic weight are used – organic glass, plastics, aluminum (an aluminum layer 0.5 cm thick completely retards the beta particles), but **lead cannot be used for this purpose**, since hard bremsstrahlung occurs.

To protect against X-rays and gamma radiation, screens of lead, steel, leaded glass are used, and in those cases where it is necessary to protect adjacent rooms from radiation, the screen function is done with the structural elements of the building – brick, concrete, barite concrete.

To absorb neutron radiation, multilayer screens are needed. The first layer on the path of neutrons should be their motion decelerator – materials containing a large number of hydrogen atoms – water, paraffin, wax, concrete, polyethylene, wood, boron. A trap for neutrons is borated polyethylene. The second layer must be the slow neutrons absorber – cadmium, boron. The third layer on the path is no longer for neutrons, but for gamma radiation induced by neutrons braking, so there must be a lead shield.

According to the purpose and design, protective screens can be made in the form of containers for storing and transporting of radionuclides; in the form of screens to protect the workplace of personnel (stationary and mobile). The screens can also be used in personal protective equipment in the form of a shield made of plexiglas, gloves and aprons made of lead rubber, a viewing window made of special glass in the X-ray room, etc.

Calculation of basic parameters of protection from external exposure

In order to know if using a protection against radiation is necessary, we calculate the dose of radiation that can be obtained by working with IR under certain conditions. Calculation of the dose of beta and gamma irradiation (D), obtained from a point source without special protection provided, is made by the formula:

$$D = \frac{8.4 \times m \times t}{R^2}$$

where D is the exposure dose;
m is the gamma activity of the irradiation source in mg/eq. Ra;
8.4 is the dose rate produced by 1 mg of radium or any isotope with activity of 1 mg/eq. Ra at the distance of 1 cm;
t is the irradiation time in hours;
R is the distance from the irradiation source in cm;

Criterion for calculating the parameters of protection from external exposure is the maximum permissible dose, which for workers with IR sources is 5 rem per year (50 mSv per year). In calculations it is more convenient to use a weekly allowable dose, which is 0.1 rem (5 rem is divided into 52 weeks of the calendar year).

Substituting in the above formula the value of the weekly dose and expressing the distance in meters, we obtain a simplified formula for calculating the basic protection parameters:

$$\frac{m \times t}{r^2} = 120$$

where m is the gamma activity of the irradiation source in mg/eq. Ra;
t – exposure time for the working week (6 working days), in hours;
r is the distance from the radiation source, m;
120 is a constant coefficient;

This formula is applicable for calculating the protection by the quantity, time and distance.

The quantity protection consists of determining the maximum permissible activity of a source from which it is possible to work without a screen for a given time at a given distance.

Example. The operator is working at a distance of 1 m from the source of gamma radiation for 36 hours a week. What would be the maximum activity of the radiation source it can work with safely?

By the formula we calculate:

$$m = \frac{120 \times r^2}{t} = \frac{120 \times 1}{36} = 3.3\, mg/eq.\, Ra$$

Time protection consists of determining the duration of safe operation with a source of ionizing radiation within a week.

Example. The laboratory assistant works with an irradiation source of 10 mg/eq. Ra at a distance of 1 m from it. It is necessary to determine the permissible operating time for a week.

By the formula we calculate:

$$t = \frac{120 \times r^2}{m} = \frac{120 \times 1}{10} = 12\, hours\, per\, week$$

Distance protection consists of determining such a distance from a worker to the source of radiation, at which a professional activity can be conducted safely with the given radiation energy, during the specified period of time.

Example. The medical nurse works in the radiological department of a hospital and makes radium preparations with an activity of 3.3 mg/eq. Ra for 6 hours a day on the regular basis. How far from the source should it work to keep safe?

$$r = \sqrt{\frac{m \times t}{120}} = \sqrt{\frac{3.3 \times 36}{120}} = 1\,m$$

Screen protection is based on the ability of materials to absorb ionizing radiation. The intensity of absorption for gamma radiation is directly proportional to the specific gravity of materials the shield is made of and their thickness, and inversely proportional to the radiation energy. The thickness of a protective screen, which will attenuate the gamma radiation power down to the maximum permissible level, in practice can be calculated in two ways:

- According to the tables, based on taking into account the radiation energy;
- By the half-attenuation layer (without taking into account the radiation energy).

Calculation of the screen thickness by the tables. Depending on the energy of gamma radiation, its penetrating power will be different for a protecting shield of the same thickness, therefore special tables are compiled for accurate calculation of the screen thickness, in which the multiplicity (number) of attenuation and the energy of gamma radiation are taken into account (***tab. 14***).

If actual data does not precisely coincide with the numbers indicated in the table, the multiplicity of attenuation and radiation energy are found by interpolation method and in such a way that the subsequent values would provide more reliable protection.

Example. The laboratory worker is packing the radioactive gold-198 preparation with the energy of 0.4 MeV, and will receive a radiation dose of 1 radian without protection for a week. What should be the thickness of the lead shield the worker needs to apply to provide safe working environment?

Table 14

The thickness of the lead protective screen (mm), depending on the attenuation number and the energy of gamma radiation

The number of attenuation, K	Energy of gamma radiation, MeV									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
1.5	0.5	1.0	1.5	2	2	3	4	6	7	8
2	1	2	3	4	5	7	8	10	11.5	13
5	2	4	6	9	11	15	19	22	25	28
8	2	5	8	11	15	19.5	23.5	28	32	35
10	3	5.5	9	13	16	21	26	30.5	35.5	38
20	3	6	11	15	20	26	32.5	38.5	44	49
30	3.5	7	11.5	17	23	30	36.5	43	49.5	55
40	4	8	13	18	24	31	38	45	52	58
50	4	8.5	14	19.5	26	32.5	39.5	46	53	60
60	4.5	9	14.5	20.5	27	34.5	42	49.5	56	63
80	4.5	10	15.5	21.5	28	37	45	53	60	67
100	5	10	16	23	30	38.5	47	55	63	70
The number of attenuation, K	Energy of gamma radiation, MeV									
	1.25	1.5	1.75	2	2.5	3	4	6	8	10
1.5	9.5	11	12	12	12	13	12	10	9	9
2	15	17	18.5	20	20	21	20	16	15	13.5
5	34	33	41	43	44	46	45	38	33	30
8	42	48	52.5	55	57	59	58	50	43	38
10	45	51	56	59	61	65	64	55	49	42
20	58	66	72	76	78	83	82	71	63	56
30	65	73	80	85	88	93	92	80	72	63
40	68.5	78	86	91	91	100	99	87	78	68
50	72	82	90	96	100	106	105	92	83	73
60	75	85	95	101	104	110	109	97	87	77
80	80	92	101	107	111	117	116	104	94	82
100	84.5	96.5	106	113	117	122	121	109	99	87

The magnitude of the attenuation coefficient (the frequency of attenuation) of radiation is determined by the formula:

$$K = \frac{P}{P_0} = \frac{1}{0.1} = 10\, times$$

Where K is the multiplicity of the attenuation;
P – the dose received;
P_0 – the maximum permissible dose of irradiation for a week;

In our example, by the formula given above, the attenuation coefficient (number) is 10. In the table 14, at the intersection of lines

Table 15

Calculation of half-attenuation layers

The number of attenuation	2	4	8	16	32	64	128	256	512	1024
Number of half-attenuation layers	1	2	3	4	5	6	7	8	9	10

corresponding to the number of attenuation 10 and the radiation energy of 0.4 MeV, we find that the thickness of the lead shield required should be 13 mm.

Calculation of the screen thickness by the layers of half-attenuation. A layer of half-attenuation is called the material thickness, which attenuates the power of gamma radiation by the factor of 2. The number of half-attenuation layers, depending on the multiplicity of attenuation required, is presented in the table 15.

Example. It is required to weaken the intensity of gamma radiation of cobalt-60 by 1000 times with a lead screen, for which one layer of half attenuation is 1.8 cm.

According to the table 10, we find that 10 half attenuation layers are required to attenuate the radiation intensity 1000 times. Consequently, the total thickness of the lead shield is: 1.8 × 10 = 18 cm.

The thickness of one layer of half weakening is 1.8 cm for lead, 10 cm – concrete; 14 cm for soil; 25 cm for wood.

Protection when working with the open sources

Radionuclides that can pollute the environment and enter the body with inhaled air, food and water, and also through the skin of hands, are called the open IR sources. These are vapors, gases, liquids, powders. They, as a rule, cause internal irradiation of the body. When working with open sources, there is a danger of external, penetrating radiation and ingress of radionuclides into the body. Possible is contamination of hands, clothing, and equipment. There is danger of contamination of surfaces with emanating substances, since beta and gamma emitters enter the air. Many building materials (brick, concrete, wood, asphalt) and coatings (linoleum, tile) adsorb radionuclides and are difficult to get decontaminated later.

To protect against external radiation from the open sources, all the principles used when working with the closed sources (protection of quantity, time, distance and screen) are used.

Protective measures when working with open IR sources preventing a possibility of radionuclide entering the environment and human body include:

1. Organizational measures – organizations of three classes of work, depending on the radiation hazard group of the radionuclide due to internal irradiation and nuclide activity at the workplace.

2. Planning activities – the first class works can be carried out in special insulated buildings that have a three-zonal layout with mandatory sanitary access and a lock; the second class works can be carried out in an isolated part of the building, and the third class works – in separate rooms that have a fume hood, i.e. in conventional chemical laboratories.

3. Sealing of equipment and areas, this is achieved by the proper sanitation of laboratories and workplaces, ventilation systems, water supply and sewerage.

4. Maximum mechanization and automation of working operations with radionuclides.

5. Using non-absorbent materials for finishing the floor, walls, ceiling, equipment (stainless steel, glass, polyethylene, polyvinyl chloride, etc.).

6. Use of personal protective equipment – gowns, caps, gloves, aprons of elastic film, shoe covers, sleeves, shields, respirators, glasses, air suits.

7. Strict compliance with the rules of personal hygiene or so-called **radiation asepsis** – prohibition of storage of food and drinks at the workplace, prohibition of smoking and use of cosmetics, adherence to the rules for dressing and removing gloves, timely dosimetric control and decontamination of personal protective equipment.

SITUATIONAL PROBLEMS

1. The laboratory assistant has a 36-hour working week. His workplace is at a distance of 1.5 m from the source of gamma radiation. With what permissible activity of the source can it work without protection?

2. The laboratory uses a radiation source with an activity of 100 mg/eq of radium, the operator's workplace is at distance of 0.5 m from it. Determine the allowable residence time at the specified distance.

3. The source of gamma radiation is cobalt-60 with average quantum energy of 1.25 MeV. Determine the thickness of the lead shield, necessary to reduce the radiation dose rate from 60 to 0.76 μR/sec.

4. The nurse of the radiological department works for 36 hours a week with radium preparations with the activity of 5 mg/eq. Determine the allowable distance at which the specified time can be spent at the workplace by the nurse.

5. Calculate the time during which it is possible to operate without a shield with a gamma radiation source of 15 mg/eq. radium at the distance of 0.5 m.

6. The operator works 3 hours a week with a cobalt-60 source having activity of 120 mg/eq. Determine the safe distance at which you can stay safe during this time.

Problem solving

1:

$$m = \frac{120 \times r^2}{t} = \frac{120 \times 1.5^2}{36} = 7.5\, mg/eq.\, Ra$$

2:

$$t = \frac{120 \times r^2}{m} = \frac{120 \times 0.5^2}{100} = 0.3\, hours\; (18\, min)\; per\; week$$

3:

$$K = \frac{P}{P_0} = \frac{60}{0.76} = 80\, times$$

According to the table 14, at the intersection of lines corresponding to the attenuation number 80 and the radiation energy of 1.25 MeV, we find that the lead screen thickness required should be 80 mm.

4:

$$r = \sqrt{\frac{m \times t}{120}} = \sqrt{\frac{5 \times 36}{120}} = 1.25\, m$$

5:

$$t = \frac{120 \times r^2}{m} = \frac{120 \times 0.5^2}{15} = 2\, hours\; per\; week$$

6:

$$r = \sqrt{\frac{m \times t}{120}} = \sqrt{\frac{120 \times 3}{120}} = 1.75\, m$$

QUESTIONS FOR SELF-CONTROL

1. In what year were X-rays discovered?
2. What is the difference between isotopes and isobars?
3. What types of ionizing radiation are corpuscular?
4. What types of ionizing radiation have the highest penetrating power?
5. What characterizes the weighting coefficient of radiation?
6. What is the difference between the absorbed dose and equivalent dose?
7. Which organs are most sensitive to effects of ionizing radiation?
8. Why is ionizing radiation insensible to the human body?
9. What radiotoxins are formed in the organism irradiated?
10. What clinical symptoms and diseases are inherent for the deterministic IR effects?
11. What are the stochastic IR effects?
12. Principles of radiation safety.
13. Principles of protection when working with the closed sources of ionizing radiation.
14. What is radiation asepsis?
15. Does medical X-ray equipment belong to the open or closed sources of ionizing radiation?
16. For which categories of the persons undergoing IR the main dose limits exist?

6. BASICS OF OCCUPATIONAL PHYSIOLOGY

Purpose of the lesson: is to familiarize students with the basic concepts of occupational physiology and the methods of investigating functional changes occurring in the body of workers due to occupational activity.

Practical skills: to master the assessment methods of:

1. Muscular performance (dynamometry);
2. Functional state of the central nervous system (tremorometry, investigation of the critical frequency of light flashes fusion);
3. Psychic-physiological functions: attention (proof-reading), memory (by remembering numbers).

Theoretical part

The current stage of civil development is characterized by a great variety of types of labor activity, significant increase in the proportion of various types of mental work, computerization of production, high level of psychic-emotional tension. At the same time, there are jobs still being performed in the conditions of uncompleted automation, which can cause significant stress of all physiological systems of the human body, primarily, central nervous, cardiovascular systems, musculoskeletal system, visual analyzer, etc.

Currently, in the context of the economic crisis, one of the negative manifestations of which is reduction in the number of jobs and redistribution of the amount of work performed for the remaining workers, there are often instances of non-compliance with hygienic standards of work, which immediately affects the health of workers. Therefore, the urgency of assessing and regulating the elements of the labor process both at state and private enterprises is growing.

Basic concepts of occupational physiology

Occupational physiology – the division of occupational health and physiology, studying the changes in the functional state of the human body, occurring under the influence of work and working conditions, with the goal of developing physiologically justified measures to prevent fatigue, improve efficiency and preserve human health.

Work is a person's activity aimed at creating of consumer goods; work is a social concept.

From the physiological point of view, depending on whether muscular or central nervous system activity predominates, the physical and mental labor is principally distinguished.

Physical work is an activity in which the main burden is on the locomotors system with the cardiovascular and respiratory systems supporting it.

Mental work is represented by all types of work associated with receiving, processing of information, whereby the primary stress is of the sensory apparatus, attention, memory, activation of thinking processes, emotional sphere.

Changes in the functional state of the body in the process of labor are determined by the work performed at that time. From the point of view of physics, work is all kinds of energy transformation (the product of the force acting on the body or path). From the standpoint of occupational physiology, work is the transformation of energy associated with human activities (his hands, legs, the human body as a whole).

There are two types of muscular work – **dynamic** and **static**. Dynamic work is the process of muscle contraction, leading to the movement of the cargo itself, the human body itself and its individual parts in space. Dynamic positive work is associated with the movement of the load in the direction opposite to the action of gravity (lifting the load), dynamic negative – with the movement of the load in the direction of gravity (lowering the load).

By the amount of the muscles involved, there are three types of muscular work: **general**, **regional** and **local**. In the implementation of **general muscular work** more than 2/3 of the skeletal muscles are involved, including the legs and trunk (agricultural work, the work of the loader). **Regional muscular work** is performed by the musculature of the shoulder girdle and upper limbs. It involves 1/3 – 2/3 of the entire musculature. **Local muscular work** is performed with the participation of less than 1/3 of the entire musculature.

Static work is the process of muscle contraction necessary to maintain the body and its parts in space, fixing tools and objects of labor, attaining the work posture. In this case, muscle tension occurs without increasing their length and moving in space; the body is not moved. A static work is more tiring than dynamic, since the tension of the same muscle groups lasts continuously without pauses and rest. Blood circulation in working muscles is more difficult, oxygen intake in them is reduced, but right after the static work, oxygen consumption sharply increases and blood flow increases.

Basic forms of work

1. The works requiring significant muscle activity are characterized by high tension of the physical forces of the body, performance of general physical work, loading mainly of the muscular, cardiac and respiratory systems, up-regulation of energy exchange in the body; they require a long (up to 50% of the working time) rest. The energy loss makes up 4000–6000 kcal per day (loaders, diggers, masons, etc).

2. Mechanized forms of labor are characterized by operating of regional and local muscular work, both dynamic and static. The share of participation in the work of large muscle groups decreases, the importance of speed and accuracy of movements increases; special knowledge and skills for the management of tools, mechanisms, machines is required. Energy costs in this work range from 3000–4000 kcal/day. Examples of mechanized labor are turning, locksmithing, straightening and other work.

3. Forms of labor associated with semi-automatic and automatic production. Work in semiautomatic production is associated with implementation of simple operations (to submit the part for processing, to start the machine, to extract the finished part), associated with muscular loads, mainly local, sometimes regional, with the visual analyzer tension during monitoring the work of the machine, with monotony. Vapid and low-informative work is accompanied by a loss of creativity and leads to a progressive decrease in the activity of various structures of the central nervous system. Examples of such forms of work can serve as professions of punchers, grinders, sewing machines.

The labor associated with automatic production is reduced to ensuring the uninterrupted operation of production equipment. Some types of such work require frequent and uncomplicated interference with the work of machine tools (weaving), others are characterized by long-term continuous monitoring followed by diagnostics and solving of a variety of problems, which requires knowledge of a complex device of equipment, software, and high qualification. A prolonged state of waiting and readiness for action (operational rest) can lead to inhibition of nerve centers.

4. Group-based forms of labor (conveyor) consist of the moving of the product (or its parts) during the course of its processing from one worker

to another. This requires synchronized work of the conveyor participants, which are connected by a certain tempo and rhythm of work. Such work can be relatively easy in terms of the physical energy expended (local muscular work), for example, the assembly of watches, microcircuits. In other conditions there are significant muscle loads (regional muscular work) – assembling on a conveyor of cars. Workers of the conveyor constantly perform the same simple monotonous operations; labor is characterized by monotony, accompanied by tension of various muscle groups, the visual analyzer.

5. Forms of labor associated with remote control over production processes and mechanisms. With these forms of labor, a person performs the functions of tracking, control, and regulation. Its functional state is characterized by the stress of analyzers, attention, emotional stress, physical inactivity. An example of such forms of work is the work of operators, dispatchers.

6. Forms of intellectual (mental) work. The executive work consists in performing certain actions and making stereotyped decisions with sufficient amount of information and time (laboratory technicians, nurses).

Management work is the work of directors, group leaders, instructors as well as teachers. Its features are the excessive volume of incoming information, a shortage of time for its processing, increased responsibility for the decisions made, the need to communicate with a large number of people, emergence of conflict situations.

Operator's work includes the professions associated with servicing cars, characterized by high emotional tension, great responsibility.

Creative work is the work of scientists, writers, composers, artists, designers. Such work consists of solving complex problems in the absence of known algorithms, creating of new algorithms. Such work requires a strain of memory, thinking activity, constant focused attention to the object of activity.

The work of students requires a strain of memory, attention, perception, and is characterized by stressful situations (exams, tests).

Functional changes in human body during physical and mental work

The core of specific labor process is elaboration of a conditioned reflex, which is formed by two stages: irradiation of excitation to the central nervous system (the stage of training) and concentration of excitation in specific sections of the central nervous system with formation of a dominant state of increased excitability in a specific functional system. The functional system is a closed cyclic formation with feedback present about results of the action. The most important elements of the functional system are: afferent synthesis – decision making – construction of an action program – acceptor of the action result – the result of the action – the inverse afferentation.

In the process of activity, a dynamic stereotype is developed in the person – a stable, harmonious system of reflexes, which is formed as a result of training – multiple repetition of conditioned stimuli in a certain sequence and after a certain period of time. Its mechanism consists of the formation in the brain of repeated nervous processes. Changing the conditions leads to breaking the stereotype and replacing it with a new one. The dynamic stereotype includes vegetative components in addition to the motor ones, which create a life support system for implementation of work activity. As the dynamic stereotype is strengthened, the transition from one element of the operation to the next occurs without switching attention and thinking to the performance of each element.

Energy loss and oxygen consumption at various types of work

The main energy costs depend on how muscular is the work, as well as on how the work is information intense, degree of emotional stress, microclimatic conditions (temperature, humidity, etc.). With mental labor, energy costs are not great, only 5–15% higher than the basic metabolism amounts. Consumption of oxygen by the brain per 100 g of substance is 15–20 times greater than that of muscles, but this affects the total energy expenditure insignificantly, since the brain accounts for only 2.5% of the body weight. Energy costs when working in sitting position increase by 5–10% of the basic metabolism, while standing – by 10–25%, with forced uncomfortable posture – by 40–50%. The body temperature during heavy work increases by 1–1,5 °C.

The need for oxygen in an organism is greater the more intensive is the work. In the first 2–3 minutes of muscle work, there is increase in oxygen consumption, then a steady high intake is established, and after work, the increased consumption of oxygen is kept for some time to eliminate its oxygen deficiency. For mild and moderate work, prolonged steady oxygen consumption is observed, recovery to a state of rest takes place in few minutes. With very hard work, achieving of maximum oxygen consumption does not meet the needs of the body, oxygen debt is formed, and complete oxidation of decomposition products occurs during the recovery period, which becomes considerably extended.

With a static work, muscles work almost in anaerobic conditions. In the period following the work, oxygen consumption sharply increases, and then gradually falls, the recovery period can also be prolonged.

Cardiovascular effects

There is a linear relationship between intensity of a muscular work performed, oxygen consumption and cardiovascular system activity. The cardiac output increases 5 to 10 times – from 3–5 l/min at rest to 20–40 l/min during muscular work. This is due to increase of stroke volume of the left ventricle in more than 2 times (at rest it is 60–80 ml) and also of the heart rate. At easy physical work the heart rate does not exceed 100–120 beats per minute. In severe work, heart rate can reach 140–160 or more per minute. Moreover, in untrained people, the increase in the cardiac output during work is provided mainly by increase of the heart rate, whereas in the trained ones – by increase in the stroke volume, accordingly. With sedentary local work, the heart rate is reduced by 6–12 beats per minute.

Simultaneously with activity of the heart increased, systolic pressure increases 1.5 to 2 times up to 180–200 mm Hg. Diastolic pressure is changed little during work, while increase in the pulse pressure can be seen.

With mental work, changes in cardiovascular activity are less pronounced and unstable. However, with emotional stress, heart rate and systolic blood pressure can increase to the maximum values, near those inherent for physical work.

Respiratory system effects

The respiratory function is very labile and changes significantly in connection with work: there is increase in the frequency of respiration from 10–20 to 30–40 per minute. The depth of breathing increases by 30–40%. The volume of pulmonary ventilation increases: if at rest it is 5–8 l/min, then with intensive muscular work it can reach 50–100 l/min. At the same time, the blood flow rate increases, and the total capacity of the capillaries increases. All changes lead to increase in the rate of gas exchange.

Changes in the blood system

During physical work, there are significant morphological, physical and chemical changes in the blood. Morphological changes manifest themselves as increase in the number of erythrocytes and leukocytes by leaving the depot and strengthening of erythropoiesis (as indicated by reticulocytosis) and leukopoiesis.

Physical changes in blood in connection with work are characterized by increase in the osmotic resistance of erythrocytes; however its decrease in contrast may be seen during a heavy work, acidosis and high air temperature. Osmotic pressure and blood viscosity increase, the liquid phase of blood decreases.

Chemical effects are changes in the content of glucose, lactic acid, alkaline reserves, blood gases. Increase in blood glucose occurs at the beginning of work, with emotional stress. Reducing of glucose can occur in the trained individuals when doing the usual work; in the untrained persons, especially when performing heavy and prolonged work, a sharp, life-threatening decrease in glucose in the blood can occur.

The lactic acid content increases depending on the severity of the work performed. In the trained individuals lactic acid is formed in lesser amounts, and oxidation occurs faster than in the untrained ones. The level of alkaline blood reserves decreases with accumulation of lactic acid.

With mental work, blood changes are insignificant and changeable. There may be some decrease in glucose levels, increase in the content of inorganic phosphorus, cholesterol, creatine; decrease in alkaline blood reserves.

Changes in the endocrine functions

Increase in the intensity of physical work is accompanied by increase of the blood concentration of adrenaline, norepinephrine, cortisone, corticosterone. With prolonged muscular activity, the activity of the sympathetic-adrenal and hypophyseal-adrenal system gradually decreases; corticosteroid content in the blood gradually decreases, which leads to decrease in the functional capabilities of myocardium and skeletal muscles. Decrease of the insulin levels occurs as a result of decrease in its secretion and enhancement of disintegration. In such a situation, the fat depot is used as a source of energy in muscle work.

Efficiency and changes in the central nervous system activity

Performance – the value of a person's functional capabilities, characterized by the quantity and quality of work performed for a certain time. It depends on a number of external and internal factors. Among external factors, environmental conditions, intensity of labor activity, degree of rational organization of the labor process are of paramount importance. Out of internal factors – physical, physiological and psychological state; age, fitness degree are distinguished; also motivation for work, personal characteristics are of great importance.

Workability throughout a day, week, month, year varies widely and passes through several successive phases (***fig. 16***).

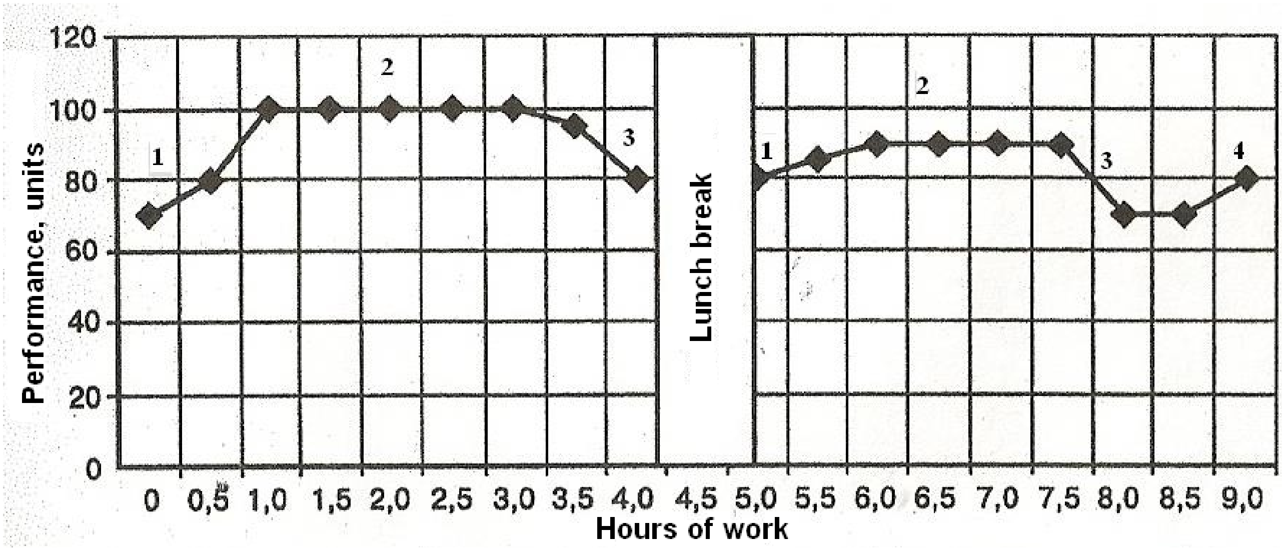


Figure 16. *Operational phases: 1 – the working-in phase; 2 – the phase of high steady performance; 3 – the phase of decline in efficiency; 4 – the final attempt;*

1. The working-in phase is a period, wherein mobilization of functional systems occurs, individual efficiency is gradually increasing. The working-in phase lasts few minutes for experienced and trained people and up to 1–1.5 hours otherwise; for creative work it may take up to 2.5 hours.

2. The high stable performance phase is characterized by stability of physiological functions. The efficiency is maximized. Duration of this phase is 2 – 2.5 hours or more.

3. The phase of decrease in the working capacity indicates development of fatigue in the regulatory structures of the central nervous system with increase in the time of reflexes. At the same time, concentration and refocusing ability weakens. Labor productivity is

reduced; is usually manifested by an increase in the number of errors, unnecessary movements, slowing of professional tasks completion.

Similarly, working capacity changes in the first and second half of the day (after lunch). But in the second half of the day the working-in phase is less prolonged, the stable working phase is less efficient and shorter in time, and decrease in efficiency point comes earlier and more rapidly. Sometimes at the end of the shift (20–30 minutes before the end of the shift), a short-term increase in working capacity is noted in anticipation of the rest. This is called “the final attempt”.

The top level of working efficiency is observed at 8 to 12 hours in the morning and at 14 to 17 hours afternoon. In the daytime, the lowest working capacity is observed at 12 to 14 hours. In the evening, work capacity also decreases.

The similar performance phases exist with respect to the working week, training quarter, semester, year. During the week, the highest working capacity falls on the 2nd, 3rd and 4th days of the working week. On Monday, work capacity is relatively lower due to the working-in, by the end of the week – due to fatigue developed.

A deviation from the typical performance curve indicates there is a mismatch between the worker's capacity to work, actual conditions and intensity of the work being performed, presence of unfavorable external and internal factors.

Fatigue is a functional condition, accompanied by decrease in working capacity, caused by intense or prolonged activity, expressed in the deterioration of quantitative and qualitative performance indicators, usually ending after work. Fatigue develops not only in working muscles, but primarily in the central nervous system, and is manifested by development of inhibition, which is restrictive, protects nerve cells from overexertion and death. By its biological essence, fatigue is a normal physiological cortical defense reaction, manifested as the mechanisms of limiting of working capacity.

The picture of a physical and mental fatigue is similar. Mental and physical fatigue affect each other. With severe physical fatigue, a mental work is unproductive and vice versa. This is due to transfer of inhibition from the most tired centers to the neighboring ones. With a mental fatigue, functional changes of the central nervous system, higher nervous activity, analyzers, and mental activity were noted. Disorder of attention, deterioration of memory, thinking, accuracy and coordination of movements is usually seen. Fatigue goes away after a rest (breaks in work, night rest, week-ends, holidays). If the rest is not sufficient to completely restore working capacity before beginning of the next labor period, resumption of work occurs with the fatigue still present, and then overwork develops.

Exhaustion is a pathological condition that can lead to increase in morbidity. Depending on the type of work load pathological syndromes are different in their manifestation. Physical overload leads to development of a number of occupational diseases, specifically affecting the muscular-skeletal and peripheral neural systems (myositis, diseases of the spine and joints, etc.). Mental overloads can manifest themselves as neurotic disorders, autonomic dysfunction, hypertension, ischemic heart disease, etc.

Examination of physiological functions in assessment of performance and fatigue

Evaluation of physiological changes occurring in human body as a result of labor activity should be made according to the absolute values of the relevant indicators, or by the relative values, expressed as changes in their magnitude at the end of the working day, expressed in percentage as compared to their initial level at the beginning of the day

Muscular efficiency examination

1. Ergography. The method is based on measuring the work done with a finger, or entire arm produced at a certain rate with the maximum force. The person sits down near the table with ergograph device (***fig. 17***), covers the handle of the device with his fingers, inserts the index finger into the loop at the end of the cable, to which a weight of 2 kg is attached, and on commands of the metronome (1 time per second) during 2 minutes produces maximum flexion and extension of the finger. The amount of bending (the height at which the load is lifted) is recorded on paper moving by means of paper pulling mechanism. According to the ergogram obtained, a number of indicators characterizing muscular activity are calculated and evaluated.

2. Dynamometry allows you to assess the strength (maximum muscle force) and endurance to static loads – it is determined by the time during which the individual is able to maintain certain force, making up about 50–75% of the maximum force. The study is carried out using dynamometers. With heavy physical work, the muscle strength is usually reduced, with small loads, the strength level may not change or even increase. Stamina is a more sensitive indicator of the functional state of the muscular system, it

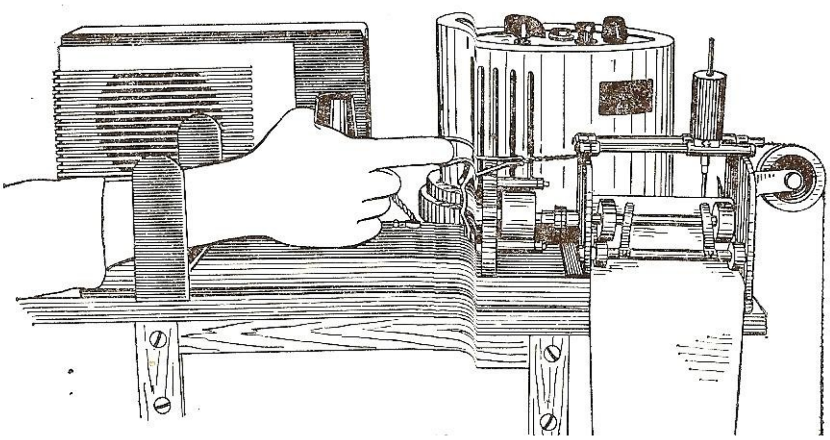


Figure 17. *The finger ergograph device*

is directly dependent on the severity of the work performed and decreases earlier than the change in muscle strength occurs.

Cardiovascular system examination

The most accessible methods for cardiovascular system examination are measurement of the heart rate (HR), blood pressure (BP) and electrocardiography (ECG).

When examining the heart rate, determine the absolute values, response to the dosed loads (squats, veloergometry), recovery time, effects of functional tests (orthostatic).

Examination of the respiratory system

The respiratory function is studied in terms of the breathing rate, breathing depth, volume of pulmonary ventilation (minute volume of breathing), oxygen saturation (by the oxymetry method). The principle of the oxymeter is based on the capture of the blood color by photoelectric sensor device, which depends on degree of oxygen saturation. Measurements are made on the auricle first at rest, then after a deep breath and as well after delay in breathing.

Examination of functional state of the central nervous system

1. **Chronoreflexometry** is the method based on the study of conditional reflex activity, specifically by measuring the time of the latent period of response to light and sound stimuli and by the number of erroneous reactions. Decrease of the latent period is associated with predominance of excitation processes in the cerebral cortex, its elongation

– with inhibition, accordingly. Errors are an indicator of reduced mobility of nervous processes.

To determine the latent period of a simple acoustic and visual-motor reaction, sound or light stimuli are applied 10–15 times at intervals of 3–4 seconds. In this case, each time the latency period is recorded (the reaction time from the moment the signal is fed to the time of the response), then its average duration is calculated.

In the study of complex sensor-motor reaction, positive stimuli (signals to which the subject should respond) being the positive exposure, would alternate with the negative stimuli (all other signals). Next, the average specific latency period and the number of erroneous responses is calculated. Chronoreflexometer device is used for this study (***fig. 18***).

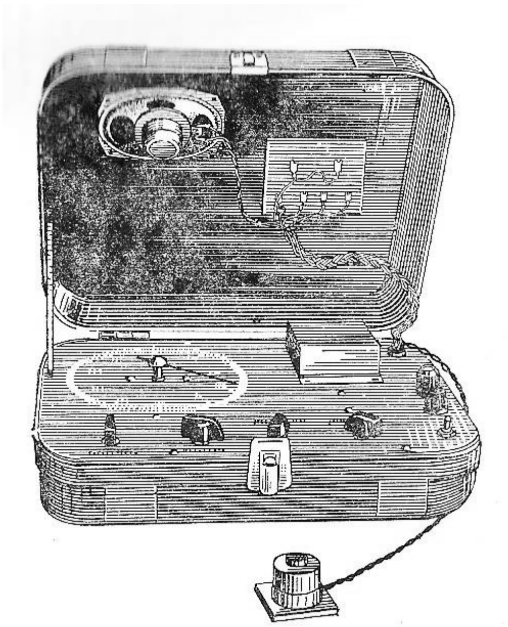


Figure 18. *Chronoreflexometer*

2. Investigation of the functional state of analyzers: measuring of the **critical frequency of light flashes fusion**. The subject is given light signals starting at a frequency of 25 Hz. Such signals people perceive as distinctive pulses of light. Gradually, the frequency of the light signals is increased up to the point, when the sensation of flickering is replaced by the perception of signals as an uniform, unblinking light. The frequency at which this occurs is called the critical frequency of light flashes fusion. This method helps to know mobility of the nervous processes in the visual analyzer and can serve as an integral indicator of functional state of central nervous system.

Similarly, with the use of low-frequency sound generators, the critical frequency of sound fusion is determined.

3. **Tremorometry**. Involuntary tremor of limbs is a normal physiological phenomenon. However, depending on working conditions and degree of fatigue, the frequency and amplitude of tremor can increase. The tremor amplitude is independent of frequency and can be hardly felt or very large, reaching a few centimeters.

Changes in tremor can occur due to dysfunction of the central nervous system and the muscular system, so tremorometry can be used to objectively study the functional state of these systems in working activity.

The tremor of the hands is determined with the help of an electrotremorometer (***fig. 19***): the touches occurring when the metal pointer (1) is drawn through the shaped slots of the plate (2) are counted. Each touch leads to the closure of the electrical circuit and is recorded by the counter (3).

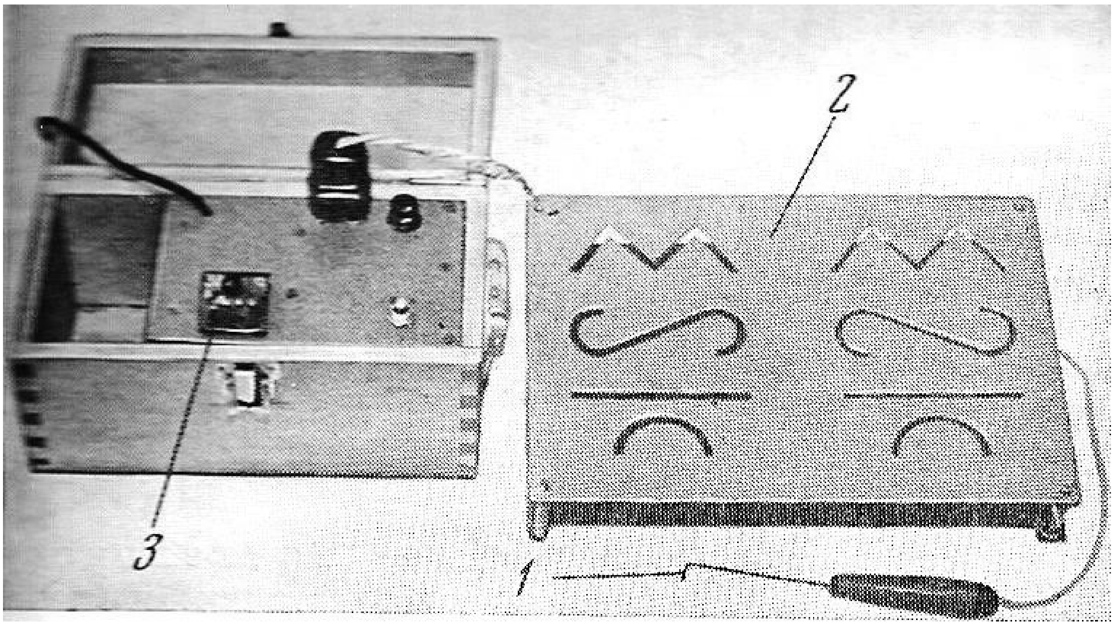


Figure 19. *Electrotremorometer (explanations in the text)*

Psycho-physiological studies

1. **Study of attention** by the method of **finding numbers**. The principle of the method lies in the fact that the person under investigation must find (to name and indicate) the order of the numbers in the table, located arbitrarily, as soon as possible. The time spent on the task is the basis for judgment about the amount of attention and speed of mental processes.

2. **Study of attention** by the method of **finding numbers with switching**. The person being tested is shown a black and red table with numbers from 1 to 24. He should find black and red numbers, alternately calling first one black, then one red, while black should be called in ascending order, and red ones in descending order. When assessing the results, the time taken to complete the task (up to 2 minutes – good quality of attention), the number and nature of errors are taken into account.

3. **Study of attention** with the help of **proof-reading**. The method allows you to study the stability, focus, and fatigue, speed and productivity of work, the overall mental performance. The test is conducted as follows: the participants of the experiment receive proof-reading tables made up of letters, numbers, Landolt rings or geometric figures (***fig. 20***), and within 2 minutes are introduced into their construction. After that, they turn the tables upside down and listen to the explorer's explanations.

The researcher gives the task to delete certain letters or their combinations in a certain way as quickly and carefully as possible, gives the "Start" command and detects the time (1–2 minutes). At the command "Stop" the subjects mark the place in the table with a square bracket, at which they managed to complete the task.

General principles of occupational activity regulation

Assessment of work in terms of severity and intensity

Functional tension of the body as a whole during work can be characterized from two sides – energetic and informational. The energy load mostly characterizes a physical work, while the information load is considered when an intellectual work is concerned. Quantitatively, the physical load is assessed in terms of severity, whereas the mental – by the labor intensity, accordingly.

Labor severity is a characteristic of the working process, reflecting the primary burden of the muscular-skeletal and functional systems of the body (cardiovascular, respiratory, etc.) that supports its activity.

Labor intensity is a characteristic of the working process, reflecting the burden mainly on the central nervous system, sensory organs, emotional sphere of the worker.

Based on the gradient of possible impact of labor process on the health of workers, all working conditions are divided into 4 classes: the optimal, acceptable, harmful and dangerous.

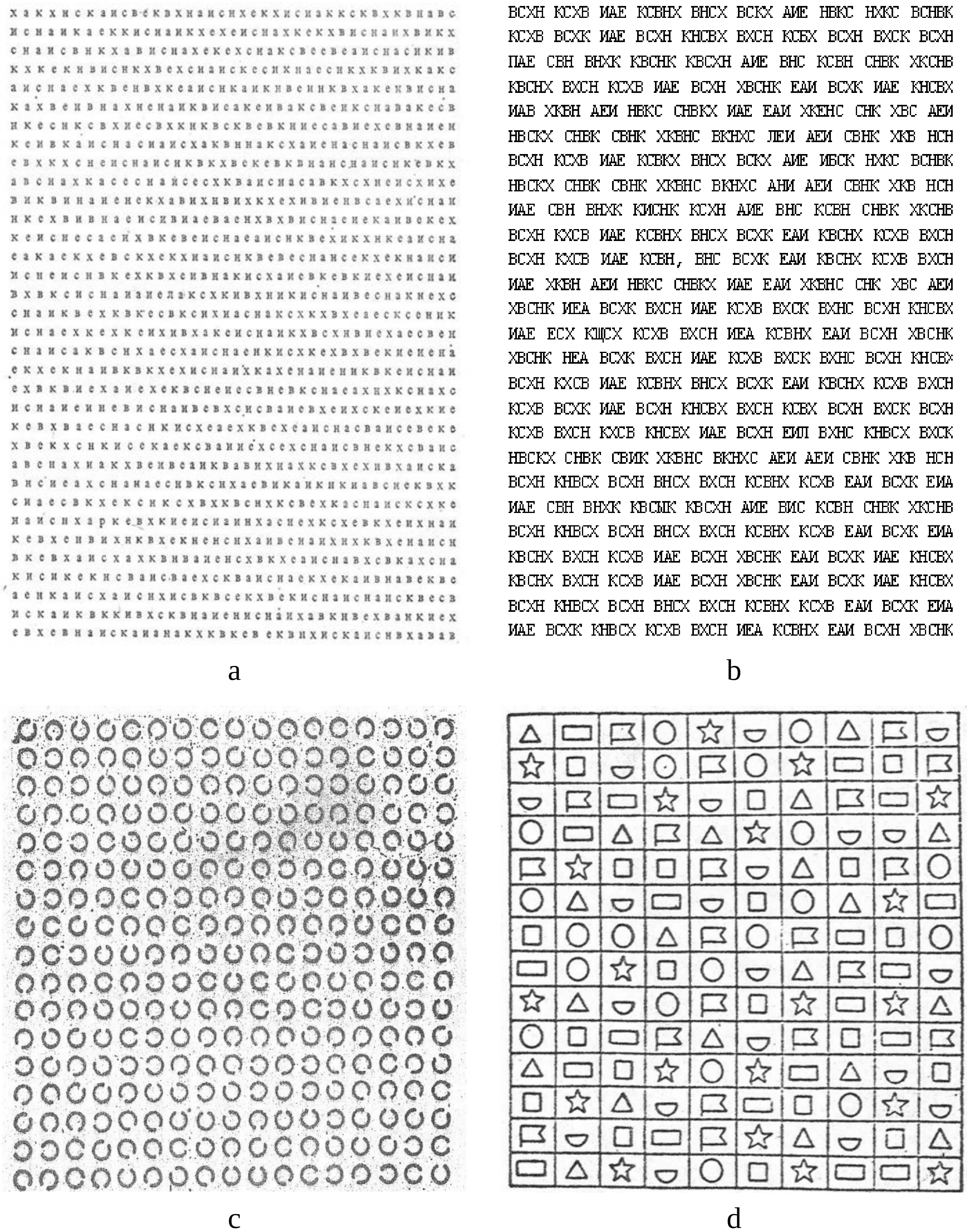


Figure 20. *a – The V.Ya. Anfimov correction table, b – The A.G. Ivanov-Smolensky correction table, c – Landolt rings, d – geometric shapes*

Optimal working conditions (1 class) are the conditions under which the health of the employee is preserved and prerequisites are created to maintain a high level of efficiency.

Acceptable working conditions (2 class) are characterized by such levels of labor process factors in which possible changes in the functional state of the body are restored during a regulated rest or by the beginning of the next shift and do not have adverse effects on the health of workers and their offspring in the near and distant period.

Harmful working conditions (3 class) are the conditions under which the factors of the labor process have an unfavorable effect on the worker's organism and/or his offspring: cause functional changes in the organ systems (3.1); mild forms of occupational diseases (3.2); of medium severity (3.3); severe forms of occupational diseases (3.4), accordingly.

Dangerous (extreme) working conditions (grade 4) may be the cause of acute illness or sudden sharp deterioration in health, endanger life; high risk of developing acute occupational lesions, including severe forms.

Ergonomic and **physiological** indicators are used to assess severity and intensity.

The main ergonomic indicators of the working process severity

1) **Physical dynamic load**. It is calculated by multiplying the weight of the load, moved manually in each operation, by the path of its movement in meters (kg×m). The total number of operations for the transfer of cargo per shift is calculated and by summation the amount of external mechanical work per shift is determined as a whole.

2) **The weight of the cargo lifted and moved** is determined manually by weighing or according to the documents on the product. The maximum value is taken into account.

3) **Stereotype working movements** – determine the number of elementary movements (local or regional) by counting them for 10–15 minutes and recalculating the duration of this work.

4) **Static load** is calculated by multiplying the value of the force retained (load weight) and the retention time.

5) **Working posture** – free, uncomfortable, fixed, forced – is determined visually. **Free postures** include comfortable sitting postures that allow the body to work or its parts to change its position (lean back, change the position of the legs, hands). **Fixed working posture** – the impossibility of changing the mutual position of different parts of the body

relative to each other (for example, the laboratory assistant works with a microscope). The uncomfortable working postures are poses with a large inclination or turn of the trunk, with arms raised above the shoulder level, with uncomfortable placement of the lower extremities. **Forced postures** include working postures lying, on the knees, squatting, etc. The time of staying in one or another pose is calculated as a percentage of the 8-hour shift. If by the nature of the work the work postures are different, then the evaluation should be carried out according to the most typical position for the work.

6) **Body slopes**. They determine the number of slopes per shift (by direct counting per unit of time and recalculation for the entire work time) and the depth of the body slopes (in degrees). Slopes of more than 30° take place if a person takes any objects, raises a load or performs actions by hands at a height of not more than 50 cm from the floor. The slopes are evaluated according to the maximum values.

7) **Movement in space** is calculated by multiplying the number of steps per shift (determined by the pedometer) by the step length (the male step in the production environment is on average 0,6 m, and the female – 0,5 m). The obtained value is expressed in km.

The overall assessment of physical labor severity is carried out on the basis of all the above indicators. First, a class is established for each measured indicator (***sup. 2, p. 172***).

The final assessment of the labor severity is established according to the most sensitive indicator, referred to the largest class. In the presence of two or more indicators of classes 3.1 and 3.2, the overall score is set one degree higher. According to this criterion, the highest degree of severity is class 3.3.

Factors characterizing the labor intensity include: intellectual, sensory, emotional loads, degree of monotony of the loads, the mode of operation.

Ergonomic indicators of intellectual work intensity

1) The **content of the work** indicates the degree of difficulty in completing the task: solving simple problems (lab technicians); completion of tasks on the instruction (nurses); complex problems with a choice of known algorithms (drivers, air traffic controllers); creative (heuristic) activity with solution of complex tasks in the absence of an algorithm (scientists, designers, doctors).

2) **Perception of signals** (information) and their evaluation, comparison with the standard, followed by correction. For example, a turner making a part and compares it with the sample; a dispatcher evaluates the incoming information and corrects the movement of the aircraft; the doctor compares the symptoms of the patient with the known, evaluates the results of the tests, comparing them with the norm.

3) **Distribution of functions** by degree of complexity of the task. It can be simple functions – processing and execution of a specific task (lab technicians); processing and implementation with subsequent verification of the task (medical sisters, telephonists). Processing, checking and monitoring the performance of the task indicates a greater degree of complexity of the functions performed (masters of industrial enterprises, telegraphists, designers, drivers of vehicles). The most difficult function is preliminary preparatory work with the subsequent distribution of tasks to other people, which is typical for such professions as managers of industrial enterprises, air traffic controllers, scientists, doctors, etc.

4) **Nature of the work performed**:

- Work is carried out according to an individual plan (laboratory technicians);
- Work proceeds according to a strictly established schedule with possible correction of it as necessary (nurses, telephonists, telegraphists, etc);
- Work is carried out in conditions of time deficit (masters of industrial enterprises, scientists, designers);
- Work in conditions of shortage of time and information. At the same time, high responsibility for the final result of work is noted (ambulance doctors, surgeons, obstetricians, traumatologists, resuscitators, industrial managers, drivers of vehicles, air traffic controllers).

Ergonomic indicators of sensory loads intensity

1) **Duration of the focused observation** (in % of the shift time). The greater the percentage of time during a shift allocated to a concentrated observation, the higher the tension. Concentrated supervision of more than 75% of the shift takes place in the telephone operators, air traffic controllers, drivers; 51–75% – with doctors; from 26 to 50% of nurses, masters of industrial enterprises; up to 25% of the total time of the shift – from enterprise managers, scientists, designers.

2) **Density of signals** (light, sound) and messages on average for 1 hour of operation – the number of perceived and transmitted signals. Air traffic controllers – more than 300, the driver during the control of vehi-

cles on average about 200 signals for an hour. The work of telegraphists belongs to this class. In the range of 75 to 175 signals is sent for an hour to the telephonists. The smallest number of signals and messages is characteristic for such professions, as laboratory technicians, managers, masters, scientists, designers.

3) **The number of objects of simultaneous observation**. The greatest number of objects of simultaneous observation is established for air traffic controllers – 13, a little bit lower is this number for drivers of vehicles – 8–9. Up to 5 objects of simultaneous observation are noted among masters, supervisors, nurses, doctors, designers and others.

4) The size of the object of discrimination.

5) Working with optical instruments.

6) Monitoring the screen of the video terminal (hours per shift).

7) Load on the auditory analyzer.

8) The load on the voice device (the total number of hours spoken per week).

Ergonomic indicators of emotional loads intensity

1. Degree of responsibility for the result of own activity.
2. Degree of risk to your life.
3. Responsibility for the safety of others.
4. The number of conflict situations per shift.

Ergonomic indicators of monotony of loads

1. The number of elements (techniques) required to implement a simple job or repeatedly recurring operations.
2. Duration (s) of simple work assignments or recurring operations.
3. Time of active actions (in % of the shift duration).
4. Time of passive observation of the process, in % of the shift time.

Ergonomic performance indicators

1. Actual working hours.
2. Shift type of work.
3. Presence of regulated breaks and their duration (without lunch break).

A general assessment of the work process intensity is carried out taking into account all the listed indicators, regardless of the profession. For each of the indicators separately, its own class of working conditions is defined (***sup. 3, p. 175***). For example, item 2.5. – working with a microscope 51–

75% of working time refers to the class of working conditions 3.1. – harmful hard work.

In case if some indicator is not represented (profession-specific), then for this indicator, 1st class (optimal) labor intensity is assigned.

In the final assessment of labor intensity:

Optimal (1 class) is established in cases where 17 or more indicators have class 1, and the rest – class 2, accordingly. At the same time there are no indicators related to class 3 (harmful);

Acceptable (2 class) is established in the following cases:

- when 6 or more indicators are assigned to class 2, and the rest to class 1;
- when up to 5 indicators are assigned to 3.1 and/or 3.2 classes of harmfulness, and the remaining indicators have an estimate of the 1st and/or 2nd classes;

Harmful (class 3) is established in cases where 6 or more indicators are assigned to class 3.

If this condition is met, **the 1st degree intensive labor** (3.1) is:

- when 6 indicators are of class 3.1, and the remaining indicators refer to 1 and/or 2 classes;
- when 3–5 indicators are classified as class 3.1, and 1–3 indicators are assigned to class 3.2.

The 2-degree intensive labor (3.2):

- when 6 indicators are assigned to class 3.2;
- when more than 6 indicators are assigned to class 3.1;
- when 1 to 5 indicators are assigned to class 3.1, and 4 to 5 indicators – to class 3.2;
- when 6 indicators are assigned to class 3.1 and there are 1 to 5 indicators of class 3.2.

In those cases where more than 6 indicators have an estimate of 3.2, the intensity of the labor process is estimated as one degree higher – class 3.3.

Example of labor severity assessment

Description of the work. The bread handler in a standing pose (75% of the shift time) manually puts the finished bread from the laying table into trays. At the same time, he takes 2 loaves (one loaf in each hand), weighing 0.4 kg each (one-time lifting of the load is 0.8 kg) and transfers to the distance of 0.8 m. In total, 550 stacks are laid by the stacker, 20 loaves. Therefore, for the shift, she puts 11000 loaves. When moving from the table to the tray, the worker holds the loaves for three seconds. The trays in which the bread is laid are in containers and when stacked in the lower rows the worker is forced to make deep (more than 30°) inclines, the number of which reaches 200 per shift.

We will carry out calculations using the supplement 1 (***p. 171***):

Item 1.1. – physical dynamic load: 0,8 kg × 0,8 m × 5500 (because at one time the employee raises 2 loaves) = 3520 kgm – class 3.1;

Item 2.2. – weight of one-time lifting of cargo: 0,8 kg – class 1;

Item 2.3. – the total weight of the cargo during each shift hour is 0.8 kg × 5500 = 4400 kg and divided by 8 hours of work per shift = 550 kg – class 3.1;

Item 3.2. – stereotyped movements (regional load on the muscles of the hands and shoulder girdle): the number of movements during the laying of bread per shift reaches 21000 – class 3.1;

Item 4.1.-4.2. – static load with one hand: 0.4 kg × 3 s = 1.2 kgs, because the loaf is held for 3 s. The static load per shift with one hand is 1.2 kgs × 5500 = 6600 kgs, with two hands – 13200 kgs (class 1);

Item 5. – working posture: standing up to 80% of the shift time – class 3.1;

Item 6. – slopes of the body for the shift – class 3.1;

So, out of 7 indicators that characterize the severity of labor, 5 belong to class 3.1. Since in the presence of 2 or more indices of class 3.1, the total score is increased by one degree, the final assessment of the labor process severity of the bread handler is class 3.2 – the class of working conditions is harmful – grade 2 hard work.

Example of calculating the working process intensity

In the outpatient clinic surgeon treats patients for 6 hours a day. For one patient the doctor spends 1.5 to 9.5 minutes. At the same time, he talks with the patient for 10 seconds (at the medical examination) to 4 minutes (with the primary patient), including himself talking 51–76% of the communication time. He conducts an examination of one patient for average 40 seconds. He gets acquainted with the medical documentation for about 2 minutes, writes about 3 minutes. Most of the time the doctor combines various activities.

In this case, more than 6 indicators belong to class 3.2. Therefore, the overall assessment of the polyclinic surgeon's labor intensity corresponds to class 3.3. ***(tab. 16***)

Table 16

Calculation of surgeon's working process intensity

Indicators		Working condition class				
		1	2	3.1	3.2	3.3
1. Intellectual Loads						
1.1	The content of the work. Heuristic (creative) activity, which requires algorithm elaboration, individual leadership in difficult situations				+	
1.2	Perception of signals and their evaluation. Perception of signals followed by a complex evaluation of related parameters. Comprehensive assessment of all production activities				+	
1.3	Distribution of the function by the degree of complexity of the job. Control and preliminary work on the distribution of tasks to other persons				+	
1.4	The nature of the work. Work in conditions of shortage of time and information with increased responsibility for the final result				+	
2. Sensory Loads						
2.1	Duration of focused observation: 1.5–75% of shift time			+		
2.2	Density of signals and messages on average for 1 hour of operation: up to 75	+				
2.3	Number of simultaneous objects: up to 5	+				
2.4	The size of the object of discrimination with the duration of concentrated attention: more than 5 mm – 100 % of shift time	+				
2.5	Work with optical instruments with the duration of the focused observation: up to 25% of the time of the shift	+				
2.6	Monitoring the screen of the video terminal: up to 2 hours per shift with alphanumeric type of information display	+				
2.7	Load on the auditory analyzer. Intelligibility of words and signals from 100 to 90%. No interference	+				
2.8	The load on the voice device (the total number of hours, slandered per week): up to 16	+				

Table 16 (continued)

3. Emotional Loads						
3.1	Degree of responsibility for the result of their own activities. The significance of the error. Responsible for the functional quality of the final products, work, tasks				+	
3.2	Degree of risk for own life: likely				+	
3.3	Responsibility for the safety of others: possible				+	
3.4	Number of conflict situations per shift: 5–7			+		
4. Monotonicity of loads						
4.1	The number of elements required to implement a simple job or repetitive operations: >10	+				
4.2	The duration of simple tasks or repetitive operations: 100–25 seconds		+			
4.3	Time of active actions: 20% or more by the time of the shift	+				
4.4	Monotony of the production environment: less than 75% of the time of passive observation of the technological process from the time of the shift	+				
5. Operating mode						
5.1	Actual working hours: 8 hours		+			
5.2	Change of work. Two-shift work (no night shift)		+			
5.3	Presence of regulated breaks				+	
Number of indicators in each class		10	3	2	8	
General assessment of labor intensity *						+

Fatigue prevention

Legislative measures are aimed at creating a rational mode of work and recreation, which is established taking into account the characteristics and conditions of a particular type of activity. The mode of work and rest means the total duration of the working day, weeks, the duration of the holidays and vacations.

Rational mode of work and rest – the alternation of periods of work and rest, in which high performance is maintained for a long time without signs of fatigue. Intra-shift mode of work and rest is envisaged – introduction of a lunch break in the middle of the working day and short-term regulated breaks, the duration of which is determined taking into account the severity and intensity of work. With mental hard work, work that requires a lot of nervous tension and attention, fast and accurate movements of the hands, more frequent, but short, 5–10 minute breaks are advisable. When performing heavy physical work, you should combine work for 15–20 minutes with rest of the same duration.

Organizational measures are, first of all, in the rational organization of the workplace.

1. Design of production equipment and the organization of the workplace must correspond to the anthropometric data and psycho-physiological capabilities of a person.

2. Using the optimal working posture, alternating standing and sitting position. Long work in the vertical position is a factor that increases the risk of developing varicose veins, thrombophlebitis, promotes the development of edema of the lower extremities, flat feet. With prolonged sitting, stagnation in the pelvic organs, difficulty in the work of the circulatory and respiratory organs, static tension of the muscles of the neck, shoulder girdle, and back can occur. Change of posture leads to redistribution of load on muscle groups, improvement of circulation conditions, reduces monotony.

3. The optimal working posture when sitting works is provided by the design of the chair: size, shape, area, seat and backrest inclination, height adjustment. The design of the working chair should provide good support, and the shape – to promote the most uniform distribution of effort and pressure, depending on the body weight.

4. Convenient placement of individual elements of production equipment. In the area of easy reach should be placed the most frequently used items, in the zone of acceptable reach – the rest. The height of the working surface is determined depending on the nature, severity and accuracy of the work.

5. Performing work at the optimal pace, rhythm.

6. An important means of preventing fatigue are exercise and training. Exercise is the improvement of skills as a result of repetitive activities. During the exercise, a complex interaction is established between the central nervous system, receptors, motor apparatus, respiratory, cardiovascular and other systems, which occurs as the formation of conditioned reflexes. As a result of the exercise, muscle strength increases, the speed and accuracy of working movements increases, since there is no need to switch attention from one element of work to another each time, and the recovery period is shortened. A dynamic stereotype is developed.

7. Production gymnastics. It is based on the phenomenon of active recreation, described by I.M. Sechenov: weary muscles and nerve centers are better restored not at complete rest, but with the work of other muscle groups, with a change in the type of activity.
8. Functional music helps to reduce labor tediousness, improve mood, increase efficiency, but it is not recommended to use it when working with considerable concentration of attention, with mental hard work.
9. Psycho-physiological unloading rooms with a pleasant interior, comfortable furniture, special music, etc.

PRACTICAL PART

1. Using this manual familiarize yourself with the methods of studying physiological functions used in assessing the working capacity and fatigue.
2. Investigate the frequency and amplitude of tremors with tremorometer.

Investigation of tremor frequency. The tremorometer is placed on the table at the level of the seated person's shoulder, is plugged-in, and the arrow of the counter is moved to zero. The examinee takes the tremor pin in his hand. The posture of the examinee should be comfortable, the arm with the stem should not be fixed relative to the trunk or the table.

The examinee performs a dynamic test, for this he inserts a pin into the linear (or curved) slit of the panel of the tremorometer and conducts it as quickly and accurately as possible from the beginning of the slot to the end and back, trying not to touch the walls. The timing of the pin along the slot and back is fixed by the stopwatch assistant, the number of touches is recorded automatically by the touch meter.

Next, the **frequency of tremor** (the number of touches per second) is calculated, for this the number of touches is divided by the duration of the experiment. A high level of coordination of movements is indicated by a frequency of less than 0.2 touches per second, an average level of 0.2 to 0.4 touches per second and low level of more than 0.4.

Investigation of the tremor amplitude (static test). For this, the examinee consistently holds the pin in round holes of different diameters (10, 7, 5, 3 mm) located on the panel of the tremorometer, trying not to touch the walls. First, the pin is inserted for 10 seconds into the largest hole if no touch occurs during this time, the pin is placed in the next hole, etc. The experiment ends as soon as the subject touches the hole with the pin. This takes into account the diameter of the hole and the holding time of the pin without touching it in this hole. The tremor amplitude is calculated by the formula:

$$A_{tr} = \frac{D - 1.5}{2 \times t}$$

where: $A_{tr.}$ – tremor amplitude, mm;

D – diameter of the hole in which the first touch occurred before the expiration of 10 seconds of holding the pin in it;

1,5 – diameter of the pin;

t – is the retention time of the pin without touching (s).

3. Investigate the critical frequency of light flashes fusion. The study is done monocular-wise on the left or right eye in conditions of artificial illumination of the training room. Before the beginning of the study, the subject gets acquainted with the essence of the phenomenon, is convinced of the presence of the transition of the light signal from intermittent to continuous when the frequency of flickering changes. The experimenter smoothly increases the frequency of light flashes and determines its value, in which the subject experiences a feeling of fusion of light flashes.

4. Conduct a proof-reading test. Students are given proof-reading tables of Ivanov-Smolensky, get acquainted with their construction. Then listen carefully and remember the task that the teacher gives. The beginning and the end of the task are performed at the command of the teacher. The task is given for 1 minute. Time is controlled by stopwatch.

Further we count:

1) The total number of characters viewed per minute (40 characters in one line), N;

2) The number of errors (mistakes are the omissions of characters to be struck, the striking of unprinted characters, the deletion of characters not in the manner prescribed), ER;

3) The number of correctly crossed signs, P;

4) Indicator of the work accuracy, WA = P / (P + ER);

5) Productivity of work: PR = N x T, where T is the time of the work, min;

6) Integral indicator of the CNS state: S = (N – ER) / T.

5. Investigate memory using the method of memorizing numbers. The teacher demonstrates to students a table (memory blank) for 30 seconds, which shows 12 two-digit numbers, after which the table clears. Students record the numbers for 1 minute, which they remember. Then the table is hung up again, and the students compare their results to the numbers in the

table. The total number of correctly recorded numbers is taken into account. Playing more than 8 numbers indicates good storage, 4–8 – about satisfactory memory, less than 4 – about insufficient memory.

6. Study the attention by the method of finding numbers. For the study, a student is invited. From the distance of 70 cm the teacher shows a table in which the numbers from 1 to 25 are arbitrarily located. The task of the student: as soon as possible to find, specify and name all the numbers in order. The time for the task is fixed by the stopwatch by another student. The time spent for this task up to 45 s is considered a good result, 45–55 s is satisfactory and over 55 s is unsatisfactory.

To assess performance and fatigue, testing should be carried out at the beginning of work, at various periods of its implementation, at the end of work, and thereafter to assess the rate of recovery of physiological functions. In repeated studies, tables should be replaced.

QUESTIONS FOR SELF-CONTROL

1. The concepts of "labor", "work". Mental and physical labor, dynamic and static work.
2. Characteristics of the basic forms of work.
3. Functional changes in the body during physical and mental labor.
4. Efficiency, phases of change in working capacity.
5. The concepts of "fatigue" and "overwork".
6. Methods of studying physiological functions used for assessing performance and degree of fatigue:
   - study of muscular efficiency;
   - study of the cardiovascular system functions;
   - study of the respiratory system functions;
   - examination of the functional state of the central nervous system (chronoreflexometry, critical frequency of flashing light fusion, tremorometry),
   - psycho-physiological studies.
7. The concepts of "labor severity" and " labor intensity". Classification of working conditions by severity and intensity.
8. Basic ergonomic indicators of the working process severity.
9. Factors and basic ergonomic indicators characterizing intellectual work intensity.
10. Assessment of working conditions by the severity and intensity.
11. Prevention of fatigue in physical and mental work.

TEST TASKS

Select one correct answer

1. THE RESPIRABLE FRACTION OF INDUSTRIAL DUST HAS PARTICLES SIZE OF (µM)
   1) Less than 5
   2) 5–10
   3) More than 10
2. THE RADICAL METHOD TO COMBAT INDUSTRIAL NOISE IS
   1) Use of personal protective equipment
   2) Use of facing porous materials for decoration of premises
   3) Technological process improvement and using of mechanisms for noise reduction at the source of its origin
   4) Planning activities
3. PERIODICITY OF PREVENTIVE MEDICAL EXAMINATIONS OF WORKERS DEALING WITH HARMFUL CHEMICALS (HC) DEPENDS ON
   1) Concentrations of HC in the air of the working area
   2) Volatility of HC
   3) Solubility of HC
   4) Hazard of HC
4. SILICATOSIS, MOST FREQUENTLY COMPLICATED WITH LUNG CANCER
   1) Kaolinosis
   2) Asbestosis
   3) Talcicosis
5. WHEN TESTING CONTENT OF DUST OR HC IN THE AIR, FOR ACCURATE CALCULATING OF THE VOLUME OF THE AIR ASPIRATED, WE MUST DETERMINE
   1) Barometric pressure
   2) Wind speed
   3) Absolute humidity
   4) Relative humidity

6. THE UPPER AUDIBLE THRESHOLD (THE PAIN THRESHOLD) OF THE SOUND PRESSURE ENERGY IS ON AVERAGE (DB)
   1) 80
   2) 100
   3) 120
   4) 140
   5) 160

7. EXPRESS-METHOD OF TESTING THE AIR OF INDUSTRIAL PREMISES FOR CONTENT OF HC IS CARRIED OUT WITH THE HELP OF
   1) Electric aspirator
   2) Luxmeter
   3) Anemometer
   4) Universal gas analyzer

8. THE LEAST IRRITANT EFFECT ON THE BODY IS PRODUCED BY THE NOISE
   1) Narrowband
   2) Broadband
   3) Intermittent
   4) Impulse

9. WHEN DOING PROPHYLACTIC MEDICAL EXAMINATION OF PERSONS WORKING WITH BENZENE, LABORATORY ANALYSIS MUST INCLUDE
   1) Urine
   2) Bile
   3) Gastric juice
   4) Blood

10. MOST FREQUENTLY AFTER ENTERING THE ORGANISM, THE FOLLOWING CHEMICALS ARE DEPOSITED
   1) Organic
   2) Inorganic
   3) Organic-elemental

11. WITH A LONG-TERM INDUSTRIAL NOISE EXPOSURE THE AURAL HEALTH DISORDERS (EAR-RELATED) OCCUR EARLIER THAN THE EXTRA-AURAL ONES
   1) Is true
   2) Is incorrect

12. IF INDUSTRIAL NOISE LEVEL IS CHANGED BY NO MORE THAN 5DB WITHIN THE 8-HOUR WORKING DAY, SUCH A NOISE IS CALLED AS FOLLOWS
    1) Permanent
    2) Unstable
    3) Pulse

13. BY DEFAULT MUCOSA CELLS OF THE UPPER AND MEDIUM RESPIRATORY TRACT RETAIN THE FOLLOWING (%) OF DUST
    1) 10–30
    2) 30–50
    3) 50–90

14. FIBROGENIC POTENTIAL OF INDUSTRIAL DUST DEPENDS ON THE CONTENT IN ITS COMPOSITION OF THE FOLLOWING SILICA FORM
    1) Free
    2) Bonded

15. WHAT KIND OF VITAMIN NOISY SHOP WORKERS SHOULD RECEIVE
    1) B1
    2) B2
    3) B6

16. TO WHICH GROUP OF THE EFFORTS COMBATING INDUSTRIAL DUST, PROPER VENTILATION REFERS?
    1) Technological
    2) Legislative
    3) Sanitary and technical

17. STRUCTURAL NOISE ARISES IN
    1) Flow of liquids
    2) Motion of gases
    3) Friction, sliding of solids
    4) Propagation of impact noise on the structure of the building

18. AUDIO ANALYZER OF HUMAN BODY IS MOST SENSITIVE TO SOUND WITH A FREQUENCY OF (HZ)
    1) 400–1000
    2) 1000–4000
    3) 4000–8000

19. WHICH INDICATOR DOES CHARACTERIZE A RISK OF QUICK AND EVEN DEATH-INFLICTING POISONING BY CHEMICALS
    1) Distribution coefficient
    2) Safety factor
    3) Coefficient of aeration

20. IS REFERRED TO EXTREMELY HAZARDOUS CHEMICALS
    1) Substances that cause bone marrow suppression, hemorrhages
    2) Substances that destroy the mucous membrane of the eyes, upper respiratory tract
    3) Blastomogeneous, mutagenic, embriotropic substances

21. THE FACTORS ENHANCING DANGER OF POISONING BY CHEMICALS THROUGH THE SKIN
    1) High toxicity, good water and fat solubility
    2) High toxicity and skin temperature
    3) Ph of the skin and degree of hydration

22. WHEN DEPOSITING OF LIPID-SOLUBLE CHEMICALS OCCURS THE MOST OF THEM IS STORED IN
    1) Bone tissue
    2) Bone marrow
    3) Blood

23. SELECTIVE EFFECTS OF POISON ON THE ORGANISM HAPPENS
    1) Only with its minimum amounts
    2) Only with high doses and long exposure time
    3) Both with its minimum amounts, and with exposure to high doses during long time

24. TECHNOLOGICAL MEASURES TO PREVENT HARMFUL IMPACTS OF CHEMICALS ON THE ORGANISM
    1) Usage of mechanical exhaust ventilation
    2) Rational organization of working and rest conditions for the workers
    3) Application of remote process control

25. THE MOST INTENSIVE ABSORPTION OF CHEMICALS IS IN
    1) Oral cavity
    2) Small intestine
    3) Large intestine
    4) Stomach

26. A METABOLIC TRANSFORMATION OF CHEMICALS IN THE BODY ALWAYS ENDS WITH A LESSER TOXICITY
1) Is true
2) Is incorrect

27. SPECIFIC SUPPRESSION OF HAEMOPOESIS IS A FEATURE OF POISONING WITH
1) Benzene
2) Carbon monoxide
3) Gasoline

28. FATIGUE COMES EARLIER IN CASE OF
1) Static work
2) Dynamic positive work
3) Dynamic negative work

29. PERIOD OF STEADY WORKING EFFICIENCY IS
1) Longer in the afternoon
2) Shorter in the afternoon
3) Has the same duration in the first and second half of the day

30. OVERWORK IS
1) A functional state, accompanied by a feeling of fatigue, decrease in working capacity, caused by intense or prolonged activity and it terminates before the beginning of the next working time
2) A normal physiological defense reaction, manifested to limit operability of the person
3) A condition accompanied by a feeling of fatigue, decrease in working capacity, which does not pass before the beginning of the next working time, leading to somatic and occupational diseases

31. STUDY OF FUNCTIONAL STATE OF THE CENTRAL NERVOUS SYSTEM IS CONDUCTED BY THE METHOD
1) Dynamometry
2) Chronoreflexometry
3) Ergometry

32. MOST SENSITIVE INDICATOR OF THE FUNCTIONAL CONDITION OF THE MUSCULAR SYSTEM IS
1) Strength (maximum muscular effort)
2) Endurance

33. DEFINITION OF THE CRITICAL FREQUENCY OF FLASHING LIGHT FUSION IS USED FOR THE FUNCTIONAL ASSESSMENT OF
   1) Muscular system
   2) Central nervous system
   3) Cardiovascular system

34. PROOF-READING IS APPLIED FOR ASSESSMENT OF
   1) Attention
   2) Memory
   3) State of the visual analyzer

35. ERGONOMIC INDICATOR OF THE LABOR INTENSITY
   1) Number of objects under simultaneous observation
   2) Degree of responsibility
   3) Physical dynamic load

36. LABOR SEVERITY IS ASSESSED BY
   1) Actual working day duration
   2) Static load
   3) Dynamic load

37. WITH INTENSE MENTAL WORK THE BEST BREAKS WOULD BE
   1) Frequent, duration of 5–10 minutes
   2) Rare, up to 1 hour
   3) For 15–20 min, alternating with work of the same duration

38. THE UNIT FOR RADIOACTIVITY BY THE INTERNATIONAL SYSTEM OF UNITS
   1) Sievert
   2) Gray
   3) Becquerel

39. REFERS TO PHOTONIC RADIATION
   1) Alpha radiation
   2) Neutron
   3) X-ray

40. THE MOST PENETRATING POWER IS INHERENT FOR
   1) Alpha radiation
   2) Beta radiation
   3) Gamma radiation

41. WEIGHING COEFFICIENT FOR CERTAIN RADIATION TYPES IS USED FOR CALCULATION OF
   1) Absorbed radiation dose
   2) Equivalent radiation dose
   3) Exposure dose

42. THE MOST RADIOSENSITIVE ORGANS OF HUMAN BODY
   1) Skin, bones, brushes, forearms, ankles, feet
   2) Muscles, thyroid, fatty tissue, liver, kidneys
   3) Gonads, red bone marrow

43. AVERAGE DOSE OF NATURAL IRRADIATION (MSV PER YEAR)
   1) 2
   2) 20
   3) 200

44. THE MAXIMUM PERMISSIBLE EFFECTIVE DOSE OF RADIATION EXPOSURE FOR THE A-GROUP PERSONNEL SHOULD NOT EXCEED (MSV PER YEAR)
   1) 50
   2) 100
   3) 300

45. X-RAY APPARATUS REFERS TO
   1) Open sources of ionizing radiation
   2) Closed sources of continuous action
   3) Closed sources of intermittent action

46. FOR THE PROTECTION FROM BETA-RADIATION IS USED
   1) Lead
   2) Paraffin
   3) Aluminum

47. INTERNAL RADIATION EXPOSURE OF THE ORGANISM IS POSSIBLE WHEN USING
   1) Open sources of ionizing radiation
   2) Closed sources of continuous action
   3) Closed sources of intermittent action

48. FOR PREVENTION OF INTERNAL IRRADIATION OF THE ORGANISM WHEN OPERATING WITH OPEN SOURCES OF IONIZING RADIATION, THE MOST EFFECTIVE ARE
   1) Time protection
   2) Screen protection
   3) Keeping with “radiation asepsis”

49. WITH RESPECT TO INCORPORATION OF RADIOACTIVE SUBSTANCES THE MOST DANGEROUS ARE
   1) Alpha emitters
   2) Beta emitters
   3) Gamma emitters

50. DETERMINISTIC RADIO-INDUCED EFFECTS ARE EXPRESSED AS
   1) Lifetime reduction of the persons irradiated
   2) Development of malignant neoplasms
   3) Development of radiation disease

ANSWERS FOR TEST TASKS

1. 1)	14. 1)	27. 1)	40. 3)
2. 3)	15. 1)	28. 1)	41. 2)
3. 4)	16. 3)	29. 2)	42. 3)
4. 2)	17. 4)	30. 3)	43. 1)
5. 1)	18. 2)	31. 2)	44. 1)
6. 4)	19. 1)	32. 2)	45. 3)
7. 4)	20. 3)	33. 2)	46. 3)
8. 2)	21. 1)	34. 1)	47. 1)
9. 4)	22. 2)	35. 3)	48. 3)
10. 2)	23. 3)	36. 1)	49. 1)
11. 2)	24. 3)	37. 1)	50. 3)
12. 1)	25. 2)	38. 3)	
13. 3)	26. 2)	39. 3)	

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10. Federal Law "On the Use of Atomic Energy" №. 170-FZ dated 11.21.1995.
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12. Radiation safety standards NRB-99/2009. Sanitary regulations and

standards SanPiN 2.6.1.2523–09.
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14. Guidance on the hygienic assessment of working environment factors and final process. Criteria and classification of working conditions. P 2.2.2006.05.
15. GOST P 12.4.191–2011 (EN 149:2001+A1:2009). Occupational safety standards system. Respiratory protective devices. Filtering half masks to protect against particles. General specifications
16. Radiation Dose in X-Ray and CT Exams: Effective radiation dose in adults [Electronic Resource] Access mode: https://www.radiologyinfo.org/en/info.cfm?pg=safety-xray.

Supplement 1

General medical contraindications for admission to work related to harmful substances and adverse water factors

1. Congenital anomalies of organs with severe functional insufficiency.
2. Organic diseases of the central nervous system with persistent severe grade dysfunctions.
3. Epilepsy with frequent seizures and personality changes.
4. Diseases of the endocrine system with severe impairment of function.
5. Malignant neoplasms.
6. Pronounced forms of diseases of blood and blood-forming organs.
7. Arterial hypertension stage II and III.
8. Heart disease with circulatory failure.
9. Chronic lung disease complicated with severe pulmonary heart disease, tendency to bleeding.
10. Bronchial asthma of severe course with pronounced functional impairment of respiratory and circulatory systems out of turns.
11. Active forms of tuberculosis of any localization.
12. Peptic or duodenal ulcer with chronic recurrent course and tendency to bleeding.
13. Liver cirrhosis and active chronic hepatitis.
14. Chronic kidney disease with symptoms of renal failure.
15. Diseases of the connective tissue.
16. Diseases of the neuromuscular system and musculoskeletal system with persistent impairment of functions that interfere with professional performance.
17. Pregnancy and lactation.
18. History of habitual miscarriage and fetal abnormalities in women planning childbearing.
19. Menstrual function abnormalities, accompanied by uterine bleeding (except works related to a sight tension).
20. Decompensated glaucoma.

Supplement 2

Classes of working conditions according to the severity of the labor process

Indicators of the severity of the labor process	Classes of working conditions			
	Optimal	Acceptable	Harmful work	
			1 degree	2 degrees
	1	2	3.1	3.2
1. Physical dynamic load (units of external mechanical work per shift, kg × m)				
1.1. Regional load (with predominant participation of the muscles of the hands and shoulders) when moving a load by up to 1 m: for men for women	up to 2500 up to 1500	up to 5000 up to 3000	up to 7000 up to 4000	more 7000 more 4000
1.2. With a total load with participation of muscles of hands, trunk, legs):				
1.2.1. When moving the load to a distance of 1 to 5 m: for men for women	up to 12500 up to 7500	up to 25000 up to 15000	up to 35000 up to 25000	more 35000 more 25000
1.2.2. When moving the load to a distance of more than 5 m: for men, for women	up to 24000 up to 14000	up to 46000 up to 28000	up to 70000 up to 40000	more 70000 more 40000
2. The mass of lifted and moved goods manually (kg)				
2.1. Lift and move (one-time) severity with alternation for another job (up to 2 times per hour): for men for women	up to 15 up to 5	up to 30 to 10	up to 35 up to 12	more 35 more 12

				Supplement 2 (continued)
2.2. Lifting and moving (one-time) weights constantly during a work shift: for men for women	up to 5 up to 3	up to 15 up to 10	up to 20 up to 10	>20 >10
2.3. Total mass of cargo, relocated per hour:				
2.3.1. From the working surface: for men for women	up to 250 up to 100	up to 870 up to 350	up to 1500 up to 700	>1500 >700
2.3.2. From the floor: for men for women	up to 100 up to 50	up to 435 up to 175	up to 600 up to 350	>600 >350
3. Stereotyped labor movements (quantity per shift)				
3.1. With local load (with participation of the muscles of the hands and fingers)	up to 20000	up to 40000	up to 60000	>60000
3.2. With regional load (when working with the predominant participation of the muscles of the arms and shoulder girdle)	up to 10000	up to 20000	up to 30000	>30000
4. Static load – static load value per shift while holding the load, application of effort (kg-sec × sec)				
4.1. By one hand: for men for women	up to 18000 up to 11000	up to 36000 up to 22000	up to 70000 up to 42000	>70000 >42000
4.2. By two hands: for men for women	up to 36000 up to 22000	up to 70000 up to 42000	up to 140000 up to 84000	>140000 >24000

Supplement 2 (continued)

4.3. With participation of the muscles of the body and legs: for men for women	 up to 43000 up to 26000	 up to 100000 up to 60000	 up to 200000 up to 120000	 >200000 >120000
5. Working posture				
5.1. Working posture	Free, comfortable posture, possibility to change the worker's body position (sitting, standing). Standing in a pose for up to 40% of the shift time	Periodically up to 25% of the shift time, not walking comfortably (working with the torso, uncomfortable limbs' pose, etc.) and/or fixed position (impossibility of changing of different body parts relative to each other). Staying upright for up to 60% of the shift time	Periodic, up to 50% of the shift, being in an uncomfortable and/or fixed posture; staying in a forced pose (kneeling, squatting, etc.) up to 25% of the shift time. Standing for up to 80% of the shift time	Periodic, up to 50% of the shift time, being in a not comfortable and/or fixed posture; stay in a forced pose (kneeling, squatting, etc.) up to 25% of the shift time. Standing for up to 80% of the shift time
6. Trunk bends				
6.1. Body bends (forced more than 30 degree), number per shift	up to 50	51–100	101–300	over 300
7. Movement in space due to the technological process, km				
7.1. Horizontally	up to 4	up to 8	up to 12	more than 12
7.2. Vertically	up to 1	up to 2.5	up to 5	more than 5

Supplement 3

Classes of working conditions in terms of intensity of the labor process

Indicators of intensity of the labor process	Class of working conditions			
	Optimal	Acceptable	Harmful	
	Mild labor intensity	Moderate labor intensity	Hard work	
			1 degree	2 degree
	1	2	3.1	3.2
1. Intellectual loads:				
1.1. The work content	No need to make a decision	Solving simple tasks according to instructions	Solution of complex problems with a use of known algorithms (series of instructions)	Heuristic (creative) activity requiring an algorithm elaboration, doing sole decisions in difficult situations
1.2. The perception of signals (information) and their evaluation	Signal perception, but no correction required	Perception of signals with subsequent correction of actions and operations	Perception of signals with subsequent comparison of the actual values of the parameters with their nominal values. Final evaluation of the actual values for the parameters	Perception of signals with subsequent integrated assessment of related parameters. Comprehensive assessment of all production activities
1.3. Distribution of functions by degree of complexity tasks	Processing and execution of the task	Processing, completing the task and its check	Processing, verification and control of the task	Control and preliminary work on the distribution of tasks to others persons

Supplement 3 (continued)

1.4. Nature of the work performed	Work according to an individual plan	Work according to the established schedule with its possible correction in the course of activity	Work under time pressure	Work in conditions of lack of time and information with increased responsibility for the final result
2. Sensory loads				
2.1. Duration of focused observations (% shift time)	up to 25	26–50	51–75	>75
2.2. Density of signals (visual, audio) and messages on average for 1 hour of work	up to 75	76–175	176–300	>300
2.3. Number of simultaneously observed production objects	up to 5	6–10	11–25	>25
2.4. Size of the object of discrimination (when the distance from the eyes of the worker to the object of discrimination is no more than 0.5 m) in mm with the duration of concentrated observation (% of the shift duration)	>5 mm –100%	5–1 mm – >50%; 1–0.3 mm – ≤50%; <0.3 mm – up to 25%	1– 0.3 mm – >50%; <0.3 mm – 26–50%	<0.3 mm – >50%

				Supplement 3 (continued)
2.5. Work with optical devices (microscopes, loupes, etc.) with long concentrated observation (% shift time)	up to 25	26–50	51–75	>75
2.6. Watching video terminal screens (hours per shift):				
alphanumeric information on the screen:	up to 2	up to 3	up to 4	>4
graphic information on the screen:	up to 3	up to 5	up to 6	>6
2.7. The load on the hearing analyzer	Intelligibility of words and signals from 100 to 90%. No interference	Intelligibility of words and signals from 90 to 70%. There are interferences against which speech can be heard at a distance up to 3.5 m	Intelligibility of words and signals from 70 to 50%. There are interferences against which speech is still heard at a distance up to 2 m	Intelligibility of words and signals is less than 50%. There are interferences against which speech is audible at a distance up to 1.5 m
2.8. Load on the vocal apparatus (total hours, slandered per week)	up to 16	up to 20	up to 25	>25

				Supplement 3 (continued)
3. Emotional stress				
3.1. The degree of responsibility for the result of own activities. Significance of error	Responsible for the implementation of individual elements of tasks. It entails additional effort in the work of the employee	Responsible for the functional quality of auxiliary works (tasks). It entails additional efforts on the part of the higher management (brigadier, foreman, etc.)	Responsible for the functional quality of the main work (tasks). Entails corrections due to the extra effort of the whole team (group, brigades, etc.)	Responsible for the functional quality of the final product, work, task. Damage to the equipment, stopping of the process, and danger to life
3.2. Degree of risk for own life	Is excluded			Likely
3.3. Degree of responsibility for security of other persons	Is excluded			Is possible
3.4. Number of conflict situations caused by professional activities per shift	Absent	1–3	4–8	>8
4. The monotony of loads				
4.1. The number of elements (techniques) required for the implementation of a simple task or in repetitive operations	>10	9–6	5–3	<3
4.2. Duration (in seconds) of performing simple jobs or repetitive operations	>100	100–25	24–10	<10

Supplement 3 (continued)

4.3. Time of active actions (% shift time). The rest of the time – watching over the progress of production process	20 or more	19–10	9–5	<5
4.4. The monotony of the production environment (time of passive observation over the progress of the production process, % of the shift time)	<75	76–80	81–90	>90
5. Mode of operation				
5.1. Actual working hours	6–7 h	8–9 h	10–12 h	>12
5.2. Shift work	One-shift work (no night shifts)	Two-shift work (without night shifts)	Three-shift work (night work)	Irregular shift work, including night work
5.3. Regulated breaks and their duration	Breaks are regulated, of sufficient duration: 7% or more of the working time	Breaks are regulated, of insufficient duration: from 3 to 7% of the working time	Breaks are not regulated and of insufficient duration: up to 3% of the working time	No breaks

CONTENTS

Educational edition

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