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Medical Aspects of Emergency Rescue Activities in Radiation Accidents

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***Abstract*— Radiation damage that can be caused to humans through exposure and ingestion (incorporation) of radioactive substances depends primarily on the amount and type of radiation and radioactive substances ingested. To exclude the possibility of radiation damage through the ingestion of radioactive substances, the maximum permissible concentrations (MPC) should be monitored as far as possible. This concept defines the limit values of the activity concentration of food products, drinking water and general consumption, after being exposed to radioactive contamination, which within a certain period of consumption does not cause serious damage to the population and people conducting emergency and rescue activities.**

Keywords*— biological effects, emergency and rescue activities, radiation accident and ionizing radiation, radioactive contamination.

I. Introduction

The occurrence of an accident in a nuclear power plant (*NPP*), radiochemical plants, etc. can lead to the release of radioactive substances (*RS*) into the atmosphere and contamination of the adjacent territory [1]. In such cases, one of the first actions that must be carried out is the dosimetric control of the external environment. It will provide information about the level and volume of radioactive contamination of the territory. The problem of changes in the system of education, training and scientific research in the sphere of security and the possibility for their management is particularly relevant and at the same time very complex [2].

The degree of radioactive contamination determines what sanitary and hygienic measures should be taken further.

The workers at the enterprise/nuclear power plant where the accident has occurred are subject to individual dosimetric control with individual dosimeters that are fixed to their clothing. In the second half of the twentieth century, the use of sources of ionizing radiation expanded significantly - nuclear power plants were built, medical diagnostics expanded, and radiation using these rays also entered industry [3].

In the event of a nuclear accident, the capabilities of the health care system are exceeded, local authorities and a number of central organizations are involved in the implementation of protective measures. Much of them are important as communication and transport hubs, and some are of great importance because of their proximity to certain sites or important stretches of the area [4]. The specificity of protective measures is such that measures are effective only when they are applied early - in the first hours and days [5]. This requires the program to provide, first of all, rapid dosimetric information, and secondly, determining the level of contamination. It is assumed that two main hazards are important as a criterion for decision-making:

- Danger of external radiation.
- Danger of incorporation of radioactive substances.

As the main pathways for radiation exposure to the population in the event of emergency contamination of the external environment:

- External exposure from the radiation cloud and contamination of the territory.
- Contact exposure due to contamination of skin and clothing.
- Internal exposure due to entry of PE into the respiratory system.
- Internal exposure due to consumption of contaminated food and water.

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The radiation hygiene measures that must be taken in general terms are the following:

- Temporary shelter of the population in homes and shelters.
- Elementary sealing of the premises.
- Restricting the movement of the population in the contaminated territory.
- Blocking the thyroid gland to prevent exposure to radioactive iodine through iodine prophylaxis.
- Temporary evacuation of the population from the contaminated territory.
- Sanitary treatment of exposed skin surfaces of persons contaminated with radioactive substances.
- Simple processing to remove surface radioactive contamination of food products by washing and separating the surface layer.
- Exclusion from use of contaminated exposed food products.
- Moving dairy animals to uncontaminated pastures.
- Exclusion from use of radioactively contaminated milk.
- Sanitary - hygienic control of drinking water.

II. Materials and methods

A radiation accident is an event that could have led to or has led to unplanned exposure of people or radioactive contamination of the environment above the values regulated by regulatory documents for controlled conditions, occurring as a result of loss of control over the source of ionizing radiation caused by equipment malfunction, incorrect actions of personnel, natural disasters or other causes.

A distinction is made between the source of the accident and the areas of radioactive contamination of the area:

- The source of the accident is the territory of the scattered structural materials of the emergency facilities and the action of α-, β- and ɣ- radiation.
- A radioactive contamination zone is an area in which radioactive isotopes have appeared.

The type of radiation accidents is determined by the sources of ionizing radiation used in the objects of the national economy. They can be conditionally divided into the following groups: nuclear, radioisotope and those creating ionizing radiation due to acceleration (*deceleration*) of charged particles in an electromagnetic field (*electrophysical*).

In nuclear power plants, as a result of an emergency release, the following factors of radiation pollution and impact on the population are possible:

- external exposure to a radioactive cloud and radioactively contaminated surfaces - land, buildings, structures, etc.;
- internal exposure from inhalation of radioactive substances in the air and consumption of food and water contaminated with radionuclides;
- contact radiation due to contamination of the skin with radioactive substances.

In order to increase the monitoring of the radioactive situation, the nuclear accidents in Chernobyl in 1986 and in Fukushima in 2011 played a major role [6]. The Chernobyl nuclear power plant accident [7] with the destruction of the fourth reactor occurred on 26 April 1986, during an experimental test (*training*) of the electronic control system, when the reactor was shut down for routine operation. The RBMK-1000 reactor (*powerful boiling reactor*) of slow neutrons, with nuclear fuel of 114.7 tons of uranium-238 dioxide, enriched with 2% uranium-235, water for cooling, with graphite moderators. The operators then, in violation of safety regulations, turned off important control systems and allowed the reactor to enter an unstable operating mode. Due to that, the uncontrolled increase in power and the subsequent increase in temperature, caused excessive overproduction of steam, which led to a steam explosion that tore the reactor vessel apart [8]. This caused the destruction of the core and the reactor building. Fortunately, a critical mass of uranium-235 was not formed, otherwise a nuclear explosion could have occurred. The Chernobyl reactor does not have a protective shell and therefore there were emissions of radioactive gases and large quantities of radioactive substances (*3.5% of the nuclear fuel and its decay products*). The release contains up to 20% isotopes of radioactive iodine, 23% isotopes of radioactive Cesium, 8% isotopes of radioactive strontium, 18% plutonium and neptunium, uranium-238, uranium-235 and other radionuclides. The highest emission intensity was observed in the period from April 26 to May 6. Subsequently, the emission intensity decreased. Radioactive gases and particles of radioactive substances (*RAW*) were carried by the wind first in the westerly and northern directions, and then in all directions. The deposition of radionuclides on the ground, buildings and other infrastructure occurs mainly through precipitation during the passage of the radioactive cloud. The resulting picture of radioactive contamination in the affected region is complex and variable. The total activity of emergency release products (*ESP*) during the Chernobyl accident in 1986 alone was 50 MKi. The accident contaminated with radioactive substances more than 150,000 square kilometers of territory in several regions of Belarus, the Russian Federation and Ukraine, and deposits of the released radionuclides have been recorded in Sweden, Finland, Poland, Germany, France, Belgium, the Netherlands, England, Bulgaria, Greece, Israel, Kuwait, Turkey, Japan, China, Canada and the USA.

As a result, an immediate evacuation began in 1986 of about 116,000 people from the area adjacent to the plant, and the resettlement of about 220,000 people to permanent residence after 1986. The Chernobyl accident led to the deaths of 30 workers over several days and weeks and to radiation injuries to more than 100 other workers. On the morning of April 26, 1986, out of 600 workers, 134 received large doses (*0.7–13.4 Gy*) and developed radiation sickness. 28 of which died within three months, and two others soon after. In 1986–1987, about 200,000 people involved in the restoration work received doses ranging from 0.01 to **0.5 Gy** [9]. They were at potential risk of late effects of radiation, such as cancer or other diseases. Radiation exposure was highest in the areas surrounding the reactor. The radiation dose from **iodine-131 was 1–10%, from caesium-137 was 65–75%**. In the first year after the accident, the highest average annual radiation doses for any region in Europe outside the former USSR were less than **50%** of the dose received from the natural radiation background. Subsequently, radiation exposure rapidly decreased. The radiation level in the area contaminated with radioactive substances from the Chernobyl accident decreased by a factor of 2 in the first ***24* hours**, and by a factor of 90 in the first year. Areas of hazardous contamination of food products with an exposure dose rate of **1 mR/h** and higher are considered to be the territories of the Chernobyl Nuclear Power Plant Emergency Release Zone (*ES*). After the decay of radioactive iodine isotopes and the reduction of the iodine hazard, the area of dangerous contamination with radioactive waste is considered a territory with an exposure dose rate of **1 to 2 mR/h**. The population is evacuated from the area contaminated with radioactive waste if the exposure dose rate of gamma radiation constantly **exceeds 0.3 mR/h**. Special treatment with surfactants was carried out if the skin has been contaminated with levels above **0.1 mR/h** (*130 Bq/cm*^{2}). On April 26, the population began receiving iodine preparations for iodine prophylaxis. The consumption of milk and products contaminated with radioactive substances was strictly prohibited. Monitoring of the radiation situation was organized. Measures were taken to prevent a nuclear explosion in the reactor and stop the release of radionuclides into the atmosphere. The decontamination work on the territory and facilities of the NPP and in the 30-kilometer zone, and the preservation of the destroyed reactor, has been completed. Similar to the Chernobyl accident, significant releases of radionuclides occurred during two other reactor accidents: at Windscale (*United Kingdom*) in October 1957 and at Three Mile Island (*United States*) in March 1979.

An emergency situation in facilities for the storage of radioactive materials and waste poses a great danger, as it can lead to long-term radioactive contamination of vast territories with highly active radionuclides and require large-scale intervention. An accident is also possible during deep burial of liquid radioactive waste in underground horizons due to a sudden collapse of the bottom of the well.

An accident could occur at a radiochemical production facility, where the radionuclide composition and the magnitude of the accidental contamination (*discharge*) depend significantly on the technological part of the process and the structure of the radiochemical production facility. On April 7, 1993, an accident occurred at a radioactive waste processing plant in Tomsk. The trace of the radioactive cloud with a width of 9-10 km stretched for 100-120 km. Accidents with radionuclide sources are associated with their use in industry, gas and oil production, construction, scientific research and medical institutions. The peculiarity of an accident with a radioactive source is associated with the difficulty of establishing the fact of the accident. Unfortunately, the presence of such an accident is often established after severe radiation exposure is recorded.

Large-scale nuclear decommissioning activities and technologies for processing, conditioning and storing radioactive waste, as well as all nuclear activities, have a significant potential for major accidents that would pose a risk to society [10]. This has necessitated the adoption of international binding instruments with a global scope for nuclear risk prevention, emergency response and liability for nuclear damage [11] as well as a system for supervision and control of the use of nuclear materials, radioactive substances and other sources of ionizing radiation and relevant security measures in accordance with Euratom legislation [12].

Accidents during the transport of radioactive materials are also possible [13]. Based on the extent of the spread of radioactive substances and the possible consequences, radiation accidents are divided into **local, regional and general**.

Local accident - Local accident is an accident with the release of radioactive products into the sanitary protection zone in quantities exceeding the values standardized for normal operation, which may lead to exposure of personnel to doses exceeding permissible levels.

General accident - an accident with the release of radioactive products outside the sanitary protection zone in quantities exceeding the normal values for normal operation, which may lead to exposure of the population and pollution of the environment above the established norms. Accidents can occur either with or without the destruction of a nuclear reactor.

There are three-time phases of the accident: ***early, intermediate and late*** (*recovery*).

The early phase is the period from the beginning of the accident until the moment when the release of radioactive substances into the atmosphere and the formation of a radioactive trace on the ground ceases. The duration of this phase, depending on the nature, scale of the accident and meteorological conditions, can vary from several hours to several days.

The intermediate phase of the accident begins from the moment of completion of the formation of a radioactive trace and continues until all necessary measures are taken to protect the population and the necessary volume of sanitary-hygienic and medical and preventive measures are carried out. Depending on the nature and scale of the accident, the duration of the intermediate phase may vary from several days to several months after the accident occurs.

The late (recovery) phase can last from several weeks to several years after the accident (*until the moment when* *the need for implementing measures to protect the population disappears*), depending on the nature and degree of radioactive contamination. The phase ends simultaneously with the removal of all restrictions on the life of the population in the contaminated area and the transition to the usual sanitary-dosimetric control of the radiation situation, characteristic of the conditions of "*controlled irradiation*". In the late phase, the sources and paths of external and internal irradiation are the same as in the intermediate phase. The scale and degree of contamination of the area and air determine the radiation situation.

The radiation situation is a set of conditions that arise as a result of contamination of the terrain, the ground layer of the air and water sources with radioactive substances (*gases*), and which affect emergency response (*rescue operations and life support of the population*).

Identification of the ground radiation situation includes determining the scale and degree of radioactive contamination of the area and the ground layer of the atmosphere. The assessment of the ground radiation situation is carried out in order to determine the degree of impact of radioactive contamination on people involved in the elimination of the consequences of an accident and on the population inhabiting this territory.

The method for assessing the radiation situation based on radiation reconnaissance data is used after an accident at a radiation facility (*installation, technological process*) [14]. It is based on establishing the real (*current*) situation by measuring the degree (*dose rate*) of ionizing radiation and radioactive contamination of the area and objects.

The conclusions formulated by specialists (*experts*) in radiation intelligence and dosimetric control as a result of an assessment of the radiation situation must indicate the following facts:

- the number of people affected by ionizing radiation and the necessary health resources;
- the most correct actions of the NPP personnel/ radiochemical plants, liquidators and emergency medical personnel;
- additional measures to protect different groups of people.

The main guidelines for preventing and reducing losses and damages in radiation accidents are as follows:

- location of radiation-hazardous territories and facilities, taking into account the possible consequences of an accident;
- special measures to limit the spread of radioactive emissions outside the sanitary protection zone;
- measures to protect personnel and the population.

The doses of ionizing radiation that do not lead to acute radiation injuries, reduced working capacity, and do not worsen concomitant diseases are as follows:

- single (single dose) - up to 50 rad (0.5 Gy);
- repeated: monthly - up to 100 rad (1 Gy), annual- up to 300 rad (3 Gy).

III. Results and discussion,

A distinctive feature of the structure of damages occurring during radiation accidents is their diversity, which is associated with a large number of variants of the development of radiation situations.

The structure of radiation consequences (*damages*) for the affected population is represented by ***the following main forms of diseases*** [15]:

- acute radiation sickness from combined external γ-, β- radiation (γ-neutron) and internal irradiation;
- acute radiation sickness from extremely uneven exposure to γ-radiation; – local radiation damage (γ, β);
- radiation reactions;
- radiation sickness from internal radiation;
- chronic radiation sickness from combined irradiation.

Acute radiation sickness Acute radiation illness (ARS).

The modern classification of acute radiation sickness is based on the firmly established experimental and clinical dependence of the severity and form of damage on the received radiation dose.

Mild (I) grade. The primary reaction, if it occurs, is mild and occurs rapidly. Nausea and sometimes vomiting may occur. The duration of the primary reaction does not exceed 1 day and is usually limited to a few hours.

Medium (II) degree. The periodization of ARS is clearly expressed. The primary reaction lasts up to 1 day. Nausea and 2-3-fold vomiting, general weakness and subfebrile body temperature appear.

Severe (III) degree. Violent primary reaction up to 2 days, nausea, repeated vomiting, general weakness, subfebrile body temperature and headache.

Extremely severe (IV) degree. The primary reaction is violent, lasts 3-4 days and is accompanied by uncontrollable vomiting and severe weakness, reaching adynamia. General skin erythema, loose stools and collapse are possible.

Depending on the possible manifestations, cerebral, toxic, intestinal and bone marrow forms of ARS.

Cerebral form. When irradiated with a dose of more than ***50 Gy***, a cerebral form of acute radiation sickness occurs. In its pathogenesis, the leading role belongs to damage at the molecular level of brain cells and cerebral vessels with the development of severe neurological disorders. Death occurs from respiratory paralysis in the first hours or the first ***2-3 days***.

Toxic or vascular-toxemic form. At radiation doses in the range of ***20-25 Gy, ARS*** develops, which is based on toxic- hypoxic encephalopathy caused by a violation of the hemodynamic of the cerebral cerebrospinal fluid and toxemia. With hypodynamia, prostration, clouding of consciousness with the development of stupor and coma, the patient dies between the ***4th and 8th*** day.

Intestinal form. Irradiation in a dose of ***10*** to ***20 Gy*** leads to the development of radiation sickness, the clinical picture of which is dominated by signs of enteritis and toxemia, caused by radiation damage to the intestinal epithelium, disruption of the barrier function of the intestinal wall for microflora and bacterial toxins. Death occurs in ***the 2nd*** week or at the beginning of ***the 3rd***.

Bone marrow form. Irradiation at a dose of ***1-10 Gy*** is accompanied by the development of a bone marrow form of ARS, which, depending on the magnitude of the absorbed dose, varies in severity. When irradiated with a dose of up to ***250 rad, 25%*** of those irradiated may die (*without treatment*), with a dose of ***400 rad*** - up ***to 50%*** of those irradiated, a radiation dose of ***600 rad*** or more is considered absolutely lethal.

Chronic radiation sickness is a general disease of the body that occurs with prolonged, systemic exposure to small doses of ionizing radiation (*above safe levels*).

It is difficult to strictly distinguish the degrees of severity of the disease, but chronic radiation sickness is conditionally classified as ***mild (I), moderate (II), severe (III) and extremely severe (IV)***.

Chronic radiation sickness from external radiation of II, III and especially IV degree of severity is rarely diagnosed under modern conditions of strict radiation dose control. Its development is more likely with accidental inclusion of long-lived radioactive substances. The radiological parameters of soils, bottom sediments and waste materials are assessed through analysis [16].

IV. CONCLUSIONS,

Combined radiation damage will be observed relatively frequently in various radiation incidents, as they are usually accompanied by explosions, frequent fires, release of various harmful chemical substances into the atmosphere, etc.

The consideration of this problem is of interest because of its peculiar course. The practical experience gained by the survivors of such injuries in previous nuclear accidents is not sufficient to form general conclusions. This necessitates the use of experimental results obtained from animals, modelling different forms in type and degree of the relatively large range of combined radiation injuries. These experimental results are extrapolated to humans while observing the dependencies in the biological scale. Reasoned opinions are expressed that pure radiation injury will rarely be observed in accidents. A striking example, in addition to frequent injuries, is the combined injury of the body with a radiation factor and fire gases. In this regard, not only their in-depth scientific study is necessary, but also familiarization of medical personnel with the main features of their course.

In general terms, combined radiation damage to the body in accidents can be divided into two main groups:

- combined damage from radiation factor and mechanical or thermal trauma;
- combined damage from radiation and chemical factors.

Combined radiation damage and mechanical or thermal trauma are characterized by some common features that need to be paid ¬attention to. One of the characteristic features is that the damage occurs against the background of an altered reactivity of the organism. Lethality increases 1.5-3 times compared to pure radiation exposure. Early development of radiation sickness and a significant shortening of the latent phase are observed. This is important from a surgical point of view, because the time for surgical intervention is shortened.

Another feature is the frequent occurrence of shock. This explains the impact of radiation on the central nervous system and the disruption of its regulatory functions. In addition, hypoxia, which regularly accompanies radiation sickness, predisposes to rapidly manifesting and severe shock. In this regard, the severe psychological trauma that the radiation accident represents should not be ignored. Taken together, this leads to increased sensitivity of the body to various additional traumas.

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