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BIOLOGICAL CONSEQUENCES OF RADIONUCLIDES FOR THE ENVIRONMENT

Abstract *The review draws attention to the fact that man-made radionuclides enter the environment mainly in solid form. Information is briefly presented on the factors that determine the further behavior of radioactive particles in ecosystems, radiation doses and biological consequences of radioactive environmental pollution. Thanks to human activities, natural radionuclides of the earth's crust can enter the atmosphere. When coal is burned at TPPs, in addition to carbon dioxide (a result of the greenhouse effect) and sulfur compounds (a result of acid rain), radon gas enters the atmosphere and emits soot (a product of carbon condensation in the absence of oxygen), which contains radionuclides of the thorium series. Scientists from different countries have repeatedly compared the radiation pollution of TPPs and NPPs. Long-term studies have proven that coal-fired thermal power plants emit many times more radioactive substances into the atmosphere than conventional nuclear power plants. However, historical experience also shows that this optimistic situation changed dramatically due to the massive releases of radioactive materials caused by accidents at nuclear power plants. In connection with the wide practical use of uranium and plutonium, the emission of these elements into the environment has become one of the main problems of modern radiation ecology. Systematization of a large amount of data during the entire post-accident period allowed the Commission to develop a fairly clear assessment. According to the Scientific Committee, there were cases of thyroid cancer in children exposed to radiation during the accident. Trends observed among this group of victims suggest that the number of cancer cases is likely to increase over the next decade. Apart from the increased incidence of thyroid cancer among exposed children, there is no scientific* *evidence that increased overall cancer incidence or increased mortality is associated with radiation exposure. Leukemia is a cancer that occurs mainly after exposure due to its short incubation period (210 years), and the risk of leukemia may not be increased even among workers engaged in disaster recovery.*

Key words: *population exposure, ionizing radiation, natural radionuclides, radiation pollution.*

БІОЛОГІЧНІ НАСЛІДКИ РАДІОНУКЛІДІВ ДЛЯ НАВКОЛИШНЬОГО СЕРЕДОВИЩА

Анотація *В огляді звертається увага на те, що техногенні радіонукліди потрапляють у навколишнє середовище переважно у твердому вигляді. Коротко подано інформацію про фактори, що визначають подальшу поведінку радіоактивних частинок в екосистемах, дози опромінення та біологічні наслідки радіоактивного забруднення навколишнього середовища. Завдяки життєдіяльності людей в атмосферу можуть потрапляти природні радіонукліди земної кори. При спалюванні вугілля на ТЕС, крім вуглекислого газу (результат парникового ефекту) і сполук сірки (результат кислотних дощів), в атмосферу надходить газ радон і виділяє сажу (продукт конденсації вуглецю при нестачі кисню), який містить радіонукліди торієвого ряду. Вчені різних країн неодноразово порівнювали радіаційне забруднення ТЕС і АЕС. Багаторічними дослідженнями доведено, що вугільні ТЕС викидають в атмосферу радіоактивних речовин у багато разів більше, ніж атомні електростанції, що працюють звичайним способом. Однак історичний досвід також показує, що ця оптимістична ситуація різко змінилася через масові викиди радіоактивних матеріалів, спричинені аваріями на атомних електростанціях. У зв'язку з широким практичним використанням урану і плутонію викид цих елементів у навколишнє середовище став однією з головних проблем сучасної радіаційної екології. Систематизація великої кількості даних протягом усього післяаварійного періоду дозволила Комісії розробити досить чітку оцінку. За даними Наукового комітету, були випадки раку щитовидної залози у дітей, які зазнали опромінення під час аварії. Тенденції, які спостерігаються серед цієї групи жертв, свідчать про те, що кількість випадків раку, ймовірно, зросте протягом наступного десятиліття. Окрім збільшення захворюваності на рак щитовидної залози серед опромінених дітей, немає наукових доказів того, що збільшення загальної захворюваності на рак або підвищення смертності пов'язані з радіаційним опроміненням. Лейкемія – це рак, який з'являється в основному після впливу через короткий інкубаційний період (210 років), і ризик лейкемії може не підвищуватися навіть серед працівників, зайнятих ліквідацією наслідків аварії.*

Ключові слова: *опромінення населення, іонізуюче випромінювання, природні радіонукліди, радіаційне забруднення.*

Introduction. An important achievement of the second half of the last century is the practical development of nuclear energy. Unfortunately, humanity entered the nuclear age in the worst possible way - the creation of nuclear weapons and their use (Hiroshima, Nagasaki 1945). The subsequent numerous tests of nuclear weapons, as well as violations of the nuclear technological cycle for the production of electricity, led to multiple emissions of radionuclides into the environment. Society also grapples closely with the issue of storing and processing radioactive waste [47].

The circumstances listed above contributed to the formation of a negative attitude towards nuclear energy in society, up to its complete rejection [1,2]. Radioactive pollution is often imagined as some homogeneous substance that fills the environment, such as "thermal hydrogen" or "ether". This point of view contradicts the results of numerous studies, in which it has been proven beyond doubt that radionuclides of man-made origin enter the environment mainly in the form of microparticles, and environmental pollution is not homogeneous [3,32,33].

In our opinion, one of the reasons for misconceptions lies in ignorance or misunderstanding that the formation of radioactive pollution is associated with physico-chemical processes that occur at the atomic (or molecular) level, while radioactivity is a property of nuclear elements, i.e. belongs to another, deeper level of the structure of matter. The second reason is ignoring the influence of the natural environment itself on the formation, spread and transformation of pollution [34,35]. The goal is to study the adverse impact of radiation pollution on the environment.

Research materials and methods. Assessments of the global situation, as well as assessments at the regional level, can be found in many works [4, 5, 6, 7, 8, 9]. However, they are most fully described in the documents. Research materials

spoke: national regulatory and technical documents on radiation safety [26], legislation of Ukraine on radiation safety and human protection from ionizing radiation, materials of a normative nature; materials of radiation research by scientists of the Mykolayiv Scientific Research Laboratory on the Problems of Radiation Safety of the Population (NDL "LARANI") [25]. The Radiation Safety Standards of Ukraine (NRBU - 97), approved by the Resolution of the Chief Sanitary Doctor of Ukraine dated December 1, 1997 No. 62 (hereinafter referred to as the Standards), is the main document that establishes a system of radiation hygiene regulations to ensure the accepted levels of exposure, as for an individual person, as well as society. The requirements of international and European organizations regarding radiation safety and the state of the domestic system of state regulation of nuclear and radiation safety are analyzed. The problems in the national legislation on radiation safety that need to be solved in accordance with the current directive requirements of the EU are highlighted [10, 11, 12, 13].

Research results and their discussion. Physico-chemical properties of uranium and plutonium (currently the most important environmental pollutants), as well as a number of factors that determine their further behavior in the ecosystem, are presented in a short form.

Sources of natural radioactivity include nuclides with very long half-lives, which, together with their short-lived daughter products, have been present on Earth since its formation. Additionally, natural radioactivity arises from nuclides formed by cosmic radiation in the upper layers of the atmosphere [14, 15]. Acting together, these sources create a natural radioactive background, which is an integral part of the human habitat.

As a result of the practical activities of people, natural radionuclides in the earth's crust can be released into the atmosphere [23]. Important sources of direct atmospheric emissions that existed long before the development of artificial radioactivity are the processes of extraction, processing and use of minerals (coal, oil, phosphates, etc.). So, for example, emissions of radionuclides into the atmosphere during the production of phosphate fertilizers are estimated at 90 Bq^{238}U i 10^6 Bq^{222}Rn for each ton of processed ore [19].

When coal is burned at thermal power plants, in addition to carbon dioxide (a consequence of the greenhouse effect) and sulfur compounds (a consequence of acid rain), radon enters the atmosphere and soot (a product of carbon condensation under conditions of lack of oxygen or too low temperatures) containing radionuclides is emitted thorium series.

Scientists from different countries have repeatedly compared the radiation pollution created by thermal and nuclear power plants (TPP and NPP). As a result of many years of research, it has been proven that the amount of radioactive substances emitted into the atmosphere by TPPs operating on coal is many times greater than the emissions of NPPs operating in regular mode [4]. However, historical experience also demonstrates that this optimistic picture can change dramatically due to accidents at nuclear power plants, which often result in significant emissions of radioactive substances.

Sources of radioactive contamination with artificial radionuclides. Artificial radionuclides are an important class of environmental pollutants that can enter the environment through various technological processes. During the hydrometallurgical processing of uranium ores, useful components are extracted from the initial raw materials in the amount of 0.2% of the total mass, and 99.8% goes to production waste containing radioactive elements. A large number of radionuclides of 36 chemical elements enter the atmosphere, among which more than 20% are radionuclides of iodine. The most common sources of environmental pollution with artificial radionuclides are [18, 4, 11] - fallout from nuclear weapons tests; emissions from nuclear fuel cycle enterprises (NFC); emissions as a result of nuclear accidents; leaks as a result of violation of nuclear waste storage conditions.

Tests of nuclear weapons. Since 1945, more than 2,000 military nuclear explosions have been carried out in the atmosphere, on the ground, underground and underwater. In addition, a number of underground tests were conducted for peaceful purposes[30,31]. Most of the plutonium released into the atmosphere ended up in sea bottom sediments [20]. During a nuclear explosion in conditions of high temperatures and pressure occurring in a confined space, a significant amount of uranium and plutonium instantly evaporates and is in an atomic, ionized state. Favorable conditions are created for further condensation of radioactive substances. Therefore, after the nuclear tests, in all cases without exception, highly active microparticles, which were called "hot particles", were detected in the atmosphere and on the surface of the earth. The size and shape of the particles, their chemical composition, and activity ratio (y/β) depended on the design and power of the explosive device, as well as on the conditions of the explosion [4,18].

As a rule, dense spherical particles of small size with a uniform distribution of activity were detected at high altitudes. Significant radioactivity (90-95%) appears to be associated with particles larger than 200 μm.

Emissions from nuclear fuel cycle enterprises. Currently, nuclear power plants produce about 17% of the world's electricity production [11]. The nuclear fuel cycle is the predominant source of radionuclide emissions following the cessation of nuclear weapons testing. Especially dangerous in this regard are emergency situations at nuclear facilities, which are accompanied by a leak of radioactivity [21]. As a result of numerous studies, it has been established that during accidents at nuclear industry enterprises, the emission into the environment occurs mainly in the form of hot particles. Moreover, radioactive particles can enter the environment both as a result of high-temperature (fire, explosion) and low temperature emergency processes (leakage in the event of a leak) [40-42]. The properties of particles (size, shape, chemical composition, activity, etc.) depend on the nature and scale of the accident. Among accidents at nuclear fuel cycle enterprises, events at the Chernobyl Nuclear Power Plant hold a special place [9,22,29].

Storage and processing of spent nuclear fuel. Reactor operation is accompanied by fuel depletion (decrease in 235U concentration) and accumulation of fission products. After several years of operation, exhausted fuel elements are replaced with new ones, and those removed from the reactor are stored for some time for cooling and deactivation, and then moved to storage facilities for long-term storage.

Spent fuel is a valuable raw material that, after its decontamination, can be removed from storage and reprocessed. Processing of spent fuel at a specialized enterprise allows you to isolate uranium and plutonium, separate them, and then to reuse them in reactors.

Due to the wide practical use of uranium and plutonium, emissions of these elements into the environment have become one of the main problems of modern radiation ecology [14].

Biological consequences of radioactive pollution of the environment. Assessments of the global situation, as well as assessments at the regional level, can be found in many works [4, 5, 6, 7, 8, 9, 43-46]. However, they are most fully set forth in the documents of the United Nations Scientific Committee on the Effects of Ionizing Radiation (UNSCEAR) [10, 11, 12, 13], which is the Scientific Committee of the General Assembly with the right to assess and report on the levels and effects of atomic radiation.

According to estimates made by the Scientific Committee at the turn of the 20th and 21st centuries [11, 13], the range of individual doses determined by the level of the natural radioactive background is 1-10 mSv. This range depends on factors such as the concentration of radionuclides in the environment, the latitude and altitude of the area, as well as various other influencing factors. The largest contribution of artificial sources was associated with the tests of nuclear weapons in the atmosphere[36-39].

The annual contribution to exposure from electricity production at nuclear power plants of nuclear states is estimated to be no more than 2 μSv, and the average international annual dose due to medical diagnostics is 0.4 mSv.

Special attention (in separate documents of the Scientific Committee [12]) is given to consideration of the doses that occur as a result of the accident at the Chornobyl NPP.

The systematization of numerous data for the entire post-accident period allowed the Committee to formulate a fairly categorical assessment. The average doses were 100 mSv for 240,000 workers engaged in liquidation of the consequences of the accident, 30 mSv - for 116,000 evacuated people, 10 mSv during the first decade after the accident - for those who continued to live in contaminated areas. Maximum dose values can be 10 times higher.

Residents of European countries received doses of no more than 1 mSv in the first year after the accident, with a progressive reduction of doses in subsequent years.

According to data available to the Scientific Committee, there have been about 1800 cases of thyroid cancer in children irradiated during the accident. Trends observed among this group of victims suggest that the number of cancer cases is likely to increase over the next decade. [15,24].

There were widespread psychological reactions to the accident, which arose from fears about radiation, but were in fact in no way related to radiation doses. The committee also notes that there is a recent tendency to associate the increase in the number of all cancers with the consequences of the accident at the Chernobyl nuclear power plant, ignoring the fact that these increases were noted in the affected areas before the accident[28]. In addition, when interpreting the consequences of the Chernobyl accident, it is necessary to concider information about the general increase in mortality observed in recent years in most areas, including those not related to the consequences of the accident.

Conclusions. At the end of the review, we note once again that radionuclides of man-made origin enter the environment mainly in the form of microparticles. Due to the wide practical use of uranium and plutonium, emissions of these elements into the environment have become one of the main problems of modern radiation ecology. Radionuclides tend to accumulate in soils and bottom sediments of water reservoirs, are easily adsorbed on the surfaces of plants and microorganisms, thus becoming incorporated into food chains. Living organisms are exposed to radionuclides mainly via surface contact, inhalation and food.

For situations similar to the accident at the Chernobyl NPP, the assessment of the radiological consequences of environmental pollution should be differentiated (liquidation professionals, the population living in contaminated areas, etc.).

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