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QUANTITATIVE ASSESSMENT OF THE BIOLOGICAL EFFECTS OF IONIZING RADIATION

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Annotation: This scientific article comprehensively examines the biological effects of ionizing radiation on living organisms and the methods for their quantitative assessment. The study determines the level of biological damage based on key physical quantities such as absorbed dose, equivalent dose, and effective dose. Deterministic and stochastic types of radiobiological effects are analyzed, and their dependence on dose is substantiated through mathematical models. The effectiveness of physical and biological dosimetry methods is evaluated, and their prospects for application in medical practice are highlighted. The results are of great importance for radiation protection and ensuring radiation safety.

Keywords: ionizing radiation, absorbed dose, equivalent dose, effective dose, radiobiology, dosimetry, deterministic effects, stochastic effects, radiation safety

Introduction

This article provides a scientific analysis of the effects of ionizing radiation on living organisms, its physical basis, and biological consequences. The direct and indirect effects of ionizing radiation at the cellular level, damage to DNA structure, and pathological changes occurring at the organism level are discussed.Ionizing radiation is an integral part of modern science and technology and is widely used in medicine, industry, and energy sectors. Ionizing radiation refers to radiation capable of ionizing atoms and molecules as it passes through matter. It includes alpha and beta particles, gamma rays, and X-rays.While widely used in modern medicine (radiology, radiotherapy), industry, and scientific research, ionizing radiation also poses a risk to living organisms.The biological effects of ionizing radiation are the main subject of study in radiobiology. These effects manifest from the cellular level to the whole organism and are largely dependent on dose and radiation type.Ionizing radiation has sufficient energy to remove electrons from atoms, forming ions. This process occurs through the following stages:ionization,excitation ,formation of free radicals.Particularly, free radicals (OH·, H·) formed during the radiolysis of water are highly dangerous for biological systems.The biological effects of ionizing radiation occur via two mechanisms:

a) Direct effect. Radiation directly affects DNA molecules, disrupting their structure. As a result:DNA strand breaks occur,genetic mutations arise ,cell division is impaired.

b) Indirect effect. Free radicals formed during water radiolysis damage DNA and other biomolecules. This mechanism is more common, as living cells are largely composed of water.Ionizing radiation has a dual role for living organisms: on one hand, it is an important tool in medicine and science, and on the other hand, improper use can cause serious biological damage. Its effects begin at the DNA level and extend to the cellular and whole-organism levels.Therefore, adherence to safety regulations when working with ionizing radiation is essential. This is especially important in diagnostic and radiotherapy procedures.Due to its high-energy nature, ionizing radiation is a potential hazard for biological systems.The effects of ionizing radiation on living organisms primarily manifest at the cellular level. Radiation damages DNA, leading to mutations, cell death, or uncontrolled cell proliferation. Therefore, quantitative assessment of radiation effects is one of the key задач of radiobiology.The following main dose quantities are used in biological assessment:

Absorbed dose (Gray) – the amount of energy absorbed by matter

Equivalent dose (Sv) – accounts for the biological effectiveness of radiation type

Effective dose (Sv) – considers the sensitivity of different tissues.The purpose of this study is to scientifically analyze methods for quantitative assessment of the biological effects of ionizing radiation and to demonstrate their practical applications.The following methods were used to assess the biological effects of ionizing radiation:

Physical dosimetry:

Ionization chamber – determines dose by measuring the number of ions produced

Geiger–Müller counter – used to detect and count ionizing particles

Thermoluminescent dosimetry (TLD) – measures stored energy in crystals

Mathematical modeling:

The dose–effect relationship is expressed as:

$E=\alpha D+\beta D^2$

where:E – biological effect

D – radiation dose

α,β – empirical coefficients

The conducted research led to the following conclusions:There is a clear relationship between dose and biological effect .Low doses may cause long-term genetic changes.High doses lead to rapid cell death.**Deterministic effects have a threshold dose:**

0.5–1 Gy – changes in blood composition

2–5 Gy – radiation sickness

5 Gy – severe biological damage

Even small doses increase the risk of cancer development.The combined use of physical and biological methods provides the most accurate results.The results indicate that the biological effects of ionizing radiation are complex and multifactorial. Deterministic effects depend on dose thresholds, while stochastic effects occur probabilistically.In modern radiobiology, the Linear No-Threshold (LNT) model is widely used. According to this model, even the smallest dose carries some level of risk.In medical practice, this requires:Application of the ALARA principle (As Low As Reasonably Achievable) .Use of protective equipment.Continuous dosimetric monitoring.In radiotherapy, however, high effective doses are intentionally applied while protecting healthy tissues.Quantitative assessment of biological effects is essential for accurately evaluating radiation exposure and its consequences. Nuclear radiation, when passing through matter, causes various chemical changes. Radiation can ionize, excite, and dissociate molecules or atoms. Regardless of the type of primary radiation particles (X-rays and gamma rays, electrons, alpha particles, protons, fast neutrons), the chemical changes in molecules are mainly caused by their interaction with secondary particles generated by radiation (such as secondary electrons, fission fragments, recoil nuclei, and gamma quanta).The products of such interactions—ions, free radicals, and excited particles—usually enter into chemical reactions with other molecules. As a result, the chemical composition and the physical and chemical properties of the substance may change.For example, under the influence of radiation, the properties of polymers change due to radiation-chemical reactions occurring within them. Nuclear radiation induces a number of chemical reactions that alter the structure of polymer molecules, including the formation of chemical bonds between molecules (cross-linking), breaking of molecular chains (destruction), formation and disappearance of double bonds, and the release of gaseous products (such as hydrogen). These processes, in turn, lead to changes in the physical properties of polymers.For instance, when polymers such as polyethylene, natural rubber, and nylon are irradiated with gamma rays, their tensile strength, heat resistance, and hardness increase, and their solubility changes. On the other hand, some polymers such as Teflon,

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cellulose, and butyl rubber deteriorate under irradiation: the fiber length and average molecular length decrease, viscosity decreases, and so on.The study of radiation-chemical changes occurring in matter under the influence of nuclear radiation is important in two aspects:

1. Radiation-chemical changes occur in radiation fields found in nuclear technology and in nature. The main goal here is to protect materials (such as coolants in nuclear reactors, polymers and lubricants used in radiation fields, etc.) from degradation and damage as much as possible.
2. To obtain new materials with valuable properties and to develop highly efficient chemical-technological processes.Radioactive substances possess specific properties and can pose serious hazards to the human body. One of the most dangerous aspects of radioactive substances is that their effects are not detectable by human sensory organs. That is, a person may be exposed to radiation for a long time without feeling its harmful effects. However, the consequences can be severe. Therefore, it is essential to exercise extreme caution when working with radioactive materials.Radiation exposure of the human body can be external or internal. External exposure occurs due to radiation from an external source, and the penetration ability of the radiation plays a crucial role. The higher the penetration power, the more harmful the effect on the body.Internal exposure occurs when radioactive substances enter the body's internal systems—for example, through damaged skin into the bloodstream, via the respiratory system into the lungs and mucous membranes, or through the digestive system. In such cases, radiation continues as long as the radioactive substance remains in the body. Therefore, substances with long half-lives and strong radiation are especially dangerous.The biological effect of radioactive radiation is characterized by the ionization of atoms and molecules in the body. This leads to changes in the composition of chemical compounds and the breaking of normal molecular bonds. As a result, metabolic processes in living cells are disrupted, and biochemical processes in the body fail.If exposure to high-intensity radiation continues for a long time, it can lead to the death of certain cells, which may result in the failure of individual organs or even the entire organism. Radiation exposure also disrupts the circulatory system: the rhythm of blood circulation slows down, blood clotting ability decreases, and blood vessels, especially capillaries, become fragile. The functioning of the digestive system is impaired, the person loses weight, and the body's ability to resist infectious diseases weakens.The effect of radioactive substances on the hands may not be noticeable at first. Over time, the skin becomes dry, cracks appear, and nails may fall off. Alpha and beta radiation, when acting externally, can be partially resisted by the skin. However, if these radioactive particles enter the digestive system, their harmful effects increase significantly.Many radioactive substances tend to accumulate in certain parts of the body. For example, accumulation in the liver, kidneys, and bones can quickly disrupt the entire organism. Some radioactive substances are highly toxic, and their toxicity may exceed that of the most dangerous chemical poisons.

Conclusion

Quantitative assessment of the biological effects of ionizing radiation is an important field in radiobiology and medical physics.Based on absorbed, equivalent, and effective doses, the level of damage to the organism can be determined.Research shows that radiation effects are directly related to dose: high doses cause deterministic effects, while low doses lead to stochastic effects.Modern dosimetry methods and mathematical models play a crucial role in assessing and reducing radiation risks. Scientifically grounded approaches to radiation safety are essential for protecting human health.

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