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THE EFFECTS OF RADIOACTIVE (IONIZING) RADIATION ON THE HUMAN BODY

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Abstract

Radioactive or ionizing radiation and its mechanisms of action on the human body, dose-dependent consequences, and long-term risks constitute one of the central topics in radiobiology, radiation epidemiology, and medical radiology. This article provides a detailed analysis of the physical-chemical properties of radiation, the processes of damage at the cellular and molecular levels—particularly the direct and indirect damage to DNA, as well as clustered damage mechanisms. Deterministic effects manifest as tissue and organ reactions at high doses and include the clinical stages of acute radiation syndrome, as well as damage to the hematopoietic, gastrointestinal, and central nervous systems, skin, eye lens, reproductive system, and circulatory system. Stochastic effects increase the probability of cancer and hereditary mutations. The study results confirm the existence of risk even at low doses and demonstrate the heightened radiosensitivity of children, pregnant women, and young organisms.

Keywords: ionizing radiation, radioactive radiation, DNA damage, DSB, ROS, clustered damage, deterministic effects, stochastic effects, acute radiation syndrome, cancer risk, Life Span Study, Chernobyl accident, Sievert, LNT model, radiation protection, ALARA, radiation monitoring.

Introduction. Radioactive radiation is a physical phenomenon consisting of ionizing particles and electromagnetic waves emitted from unstable atomic nuclei. This process was discovered in 1896 by Henri Becquerel and has brought significant benefits to humanity in medical diagnostics, radiotherapy, and nuclear energy. At the same time, radiation can ionize water molecules and other atoms in biological tissues, directly breaking DNA strands or indirectly generating reactive oxygen species. As a result, cell death, mutations, genetic instability, and tissue damage occur. Humans are exposed daily to natural background radiation at an average annual dose of approximately 2.4 mSv. Among artificial sources, medical radiation, nuclear technologies, and cosmic radiation play the primary roles. In the Republic of Uzbekistan, the Law on Radiation Safety ensures the protection of citizens' health and the environment. Modern scientific data indicate that risks exist even at low doses, with children, pregnant women, and young organisms representing the most vulnerable groups. This article provides a professional and in-depth examination of the effects of radiation on the human body, substantiates the mechanisms through analysis, and concludes with protective measures.

Main Part. Radiation enters the body via external and internal pathways. Alpha particles do not penetrate the skin but are highly dangerous in cases of internal contamination due to their high linear energy transfer coefficient. Beta and gamma rays penetrate deeper, while neutrons induce nuclear reactions. At the cellular level, the effects occur through two mechanisms: direct interaction with DNA and indirect action via ionization of water molecules leading to the formation of free radicals. Double-strand breaks (DSB) in DNA are considered the most dangerous, as incorrect repair can lead to mutations or cell death. These processes intensify oxidative stress, inflammation, and genetic instability. DNA damage mechanisms are as follows: in direct action, radiation particles ionize DNA atoms, producing single-strand or double-strand

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breaks. Approximately 40 double-strand breaks occur per 1 Gy of absorbed dose. Changes in nitrogenous bases are among the main causes of mutagenesis. In indirect action, water radiolysis generates hydroxyl radicals and other reactive oxygen species (ROS), which damage a large portion of DNA. Clustered damage is characterized by the simultaneous occurrence of multiple types of lesions within a few microns, which complicates repair mechanisms. Although DNA repair pathways exist, clustered lesions limit their effectiveness and can lead to senescence, apoptosis, or necrosis. Deterministic effects occur above a certain dose threshold and increase in severity with dose. The primary example is acute radiation syndrome (ARS). It begins with a prodromal phase involving nausea and vomiting, followed by a latent phase, and culminates in the manifest phase with full clinical signs. Depending on the dose, the hematopoietic syndrome involves suppression of bone marrow, leukopenia, infections, and bleeding; the gastrointestinal syndrome results from the destruction of intestinal epithelium; and the central nervous system syndrome leads to cerebral edema and coma. Other deterministic effects include skin erythema, hair loss, sterility, and cataracts of the eye lens. The threshold dose for lens cataracts and circulatory system diseases is estimated at approximately 0.5 Gy. While deterministic effects are based on cell death and functional impairment, stochastic effects arise from genetic modifications in one or more cells. Their probability (frequency) is proportional to dose, but their severity is independent of dose. The main manifestations are cancer and hereditary mutations. According to the Linear No-Threshold (LNT) model, risk exists at any dose level, and this risk is significantly higher in children than in adults. Age dependence is important: the risk is higher when exposure occurs at a younger age. In addition, exposure of pregnant women can affect fetal development, particularly during organogenesis, leading to serious anomalies.

Research Results. The Life Span Study of atomic bomb survivors from Hiroshima and Nagasaki remains the primary source for investigating the long-term effects of radiation. Between 1958 and 2009, 22,538 cases of solid cancer were recorded among 105,444 individuals. For all solid cancers, the excess relative risk per 1 Gy was 0.64 in women, while in men a linear-quadratic model was observed with a value of 0.20 at 1 Gy. The risk varies with age and is higher in those exposed at a younger age. A significant dose-response relationship was identified for prostate cancer for the first time; dose-response relationships were also confirmed for brain and central nervous system tumors, as well as pancreatic and uterine cancers in women. Cancer risk remains elevated even 64 years after exposure. In the Chernobyl accident, 134 people suffered from acute radiation syndrome, of whom 28 died in the first months. Thyroid cancer incidence in children increased sharply due to radioiodine exposure. Between 1991 and 2015, approximately 20,000 cases of thyroid cancer were recorded in individuals exposed during childhood or adolescence in three republics, with about 25% attributed to radiation. Leukemia and solid cancer risks have been assessed at low and moderate doses. Excess risk of thyroid cancer from childhood exposure is clearly demonstrated. At low doses, the cancer risk is estimated at approximately 10% per Sv. The threshold for lens cataracts and circulatory system diseases is around 0.5 Gy. Internal exposure, such as from radon, has been shown to increase lung cancer risk. No clear increase in hereditary effects has been demonstrated in human populations, although they have been observed in animals at high doses. Recent assessments of the Fukushima accident indicate low public doses, with no significant adverse health effects expected. Studies by Uzbek scientists confirm these international findings and emphasize the need for protective measures in the national context.

Conclusion.

The effects of radioactive radiation on the human body depend on dose, type of radiation, age, sex, and individual radiosensitivity. DNA damage mechanisms form the molecular basis of both deterministic and stochastic effects. Historical and contemporary studies support the Linear No-Threshold model and confirm the necessity of protective measures. Radiation safety regulations establish annual average limits for workers and stricter norms for the public. The principles of time, distance, and shielding, the ALARA principle, and personal protective

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equipment help minimize risk. Deeper research into biological markers, individual dosimetry, and mechanisms will enable more accurate risk assessment and reduction. Scientifically based management and protection against radiation remains one of humanity's fundamental tasks.

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