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EFFECTS OF RADIOACTIVE RADIATION ON THE HUMAN BODY AND PROTECTION MEASURES

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Abstract: *This article examines the biological mechanisms of ionizing radiation, its harmful effects on the human organism, and protection methods from a biophysics perspective. Drawing on materials from the ICRP (International Commission on Radiological Protection), UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), and WHO (World Health Organization), the study analyses radiation dose, biological equivalence coefficients, and deterministic and stochastic effects. The article is intended for specialists in medicine, physics, ecology, and radiation protection technology.*

1. INTRODUCTION.

Radioactive radiation is a form of ionizing radiation produced by the decay of atomic nuclei. The radiobiology branch of biophysics studies the effects of radiation on living organisms at the molecular, cellular, and tissue levels.

Since the early twentieth century — following W.K. Roentgen's discovery of X-rays in 1895 and Marie Curie's isolation of radium in 1898 — the biological effects of ionizing radiation have become one of the central problems of medicine and biophysics (IAEA, 2010; Hall & Giaccia, 2019).

Today, ionizing radiation is widely used in medicine for diagnostics and treatment, and also plays an important role in the nuclear industry, scientific research, and defence sectors. For this reason, a systematic study of the biological effects of radiation and protective measures is of pressing importance.

2. TYPES AND PHYSICAL PROPERTIES OF IONIZING RADIATION

2.1. Classification of Radiation Types

Ionizing radiation falls into two main categories (Attix, 2004):

- Directly ionizing: charged particles (alpha, beta, proton)
- Indirectly ionizing: uncharged particles (gamma rays, X-rays, neutrons)

The table below sets out the properties and shielding materials for the principal radiation types:

Table 1. Properties of ionizing radiation types

Alpha (α)

Ra, Rn, Po

Low (few cm in air)
Paper, skin
Beta (β)
Sr-90, I-131
Moderate (few mm in tissue)
Glass, plastic
Gamma (γ)
Co-60, Cs-137
High (metres)
Lead, concrete
Neutron (n)
Nuclear reactor
Very high
Water, paraffin, boron
X-rays
X-ray apparatus
High
Lead, concrete

2.2. Units for Measuring Radiation

Radiation-related measurements are expressed through the following fundamental physical quantities (ICRU Report 85, 2011):

- Absorbed dose (D) — in Gy (Gray): 1 Gy = 1 J/kg. This expresses the energy deposited in matter per unit mass.
- Equivalent dose (H) — in Sv (Sievert): H = D x wR, where wR is the radiation weighting factor (20 for alpha, 1 for gamma and beta, 5–20 for neutrons).
- Effective dose (E) — in Sv: E = S(wT x HT), where wT is the tissue weighting factor. This represents the average risk level for the whole organism.
- Activity (A) — in Bq (Becquerel): 1 Bq = 1 disintegration per second.

3. MECHANISMS OF BIOLOGICAL ACTION OF RADIATION

3.1. Effects at the Molecular Level

The biological effects of radiation occur primarily through two pathways (Hall & Giaccia, 2019):

Direct effect: ionizing radiation strikes the DNA molecule directly, breaking its strands. Single-strand breaks (SSBs) can be repaired by the cell's own repair mechanisms, whereas double-strand breaks (DSBs) are considerably more dangerous and may lead to chromosomal aberrations and cell death.

Indirect effect (radiolysis): radiation ionizes water molecules and produces free radicals: H2O -> H• + OH•. The hydroxyl radical (OH•) is the most powerful oxidizing agent in biological tissues; it reacts with DNA, proteins, and lipids. Radiobiological

studies show that indirect effects account for 60–70% of total biological damage (Wardman, 2009).

3.2. Effects at the Cellular Level

Under radiation exposure, cells can be destroyed or damaged in several ways (UNSCEAR, 2006 Report):

- Apoptosis (programmed cell death): when genetic damage is severe, p53 gene activation triggers self-destruction of the cell.
- Necrosis: widespread cell death at the tissue level, leading to inflammatory processes.
- Mitotic death: the cell dies during division due to radiation damage.
- Interphase death: some cells lose function and undergo apoptotic death without dividing.
- Transformation: if DNA damage is not fully repaired, mutations arise and oncological processes may be initiated.

3.3. LET and Biological Effectiveness

Linear Energy Transfer (LET) describes the energy deposited by radiation per unit path length (keV/um). Alpha particles have high LET (80–100 keV/um), whereas gamma rays have low LET (0.2–2 keV/um). Relative Biological Effectiveness (RBE) is considerably greater for high-LET radiation; accordingly, alpha radiation is considered approximately 20 times more hazardous than gamma radiation in the context of internal exposure (Goodhead, 1994).

4. EFFECTS OF RADIATION ON THE ORGANISM: CLINICAL ASPECTS

4.1. Deterministic Effects

According to ICRP Publication 103 (2007), deterministic effects manifest above a certain dose threshold, and their severity increases with the dose:

Table 2. Acute Radiation Syndrome (ARS) and dose–response relationship

< 0.1 Gy

No clinical signs

No follow-up required

0.1–1 Gy

Mild fatigue, minor blood count changes

Medical monitoring recommended

1–2 Gy

Grade I Acute Radiation Syndrome

Treatment and monitoring

2–4 Gy

Grade II ARS (mortality < 50%)

Hospitalisation required

4–6 Gy

Grade III ARS (LD50/30)

Intensive medical care

6–10 Gy

Grade IV, gastrointestinal syndrome

Poor prognosis; bone marrow transplant

> 10 Gy

Cerebrovascular syndrome, severe death

Palliative care only

Acute Radiation Syndrome (ARS) comprises four clinical stages: the prodromal phase (nausea, vomiting, fatigue), the latent period (relative clinical improvement), the manifest phase (damage to the haematopoietic, gastrointestinal, and nervous systems), and the recovery or death phase (REMM, 2023).

4.2. Stochastic Effects

Stochastic effects are random in nature and may arise even at low doses. They include radiation-induced cancer and heritable mutations. According to the BEIR VII report (2006), a gamma-ray dose of 0.1 Gy increases cancer risk by approximately 1%. Under the Linear No-Threshold (LNT) model, any dose, however small, slightly elevates stochastic risk, although this remains a subject of scientific debate (Tubiana et al., 2009).

4.3. Radiosensitivity of Organs and Tissues

Radiosensitivity is directly proportional to the mitotic activity of tissues (Bergonie-Tribondeau law, 1906). The most sensitive organs are: red bone marrow (haematopoiesis), gonads, the lens of the eye (cataract), thyroid gland, and lungs. Moderately sensitive: kidney, liver, mucosal epithelium. Most radioresistant: brain, bone, and muscle tissue.

5. FUNDAMENTALS OF RADIATION PROTECTION: ICRP PRINCIPLES

5.1. Three Core Principles

The ICRP (International Commission on Radiological Protection) establishes three fundamental principles (ICRP Publication 103, 2007):

- Justification: any practice involving radiation exposure must produce a net benefit — that is, its benefits must outweigh its risks. Exposing a patient without a valid medical indication is not permissible.
- Optimisation / ALARA: radiation doses must be kept As Low As Reasonably Achievable. This principle is widely applied in engineering, medicine, and the nuclear industry.
- Dose limits: prescribed dose limits must not be exceeded. For occupationally exposed workers: 20 mSv/year (averaged over 5 years), with a maximum of 50 mSv in any single year. For members of the public: 1 mSv/year (excluding natural and medical exposure).

5.2. Physical Methods of Protection

Three fundamental physical principles govern radiological protection (IAEA Safety Standards, GSR Part 3, 2014):

- Distance — dose is inversely proportional to the square of the distance (inverse square law): I ~ 1/r2. Doubling the distance reduces the dose by a factor of four.
- Time — minimising the time spent near a radiation source. For medical personnel, careful scheduling of work time is the primary protective measure.
- Shielding — material choice depends on radiation type: lead and concrete (lead equivalent >= 2 mm) for gamma/X-rays; low-atomic-number materials (Perspex, aluminium) for beta particles; water, paraffin, and boron for neutrons.

5.3. medical protective equipment and ındividual Dosimetric Monitoring

In healthcare facilities, protection is achieved using TLDs (Thermoluminescent Dosimeters), film badges, or electronic personal dosimeters. Lead-shielded panels, glass, and aprons (0.25–0.5 mm Pb equivalent) are installed in X-ray rooms. Special sanitary standards are established for radiologists and radiation therapists (GOST R 8.596-2011; SanPin 0193-07, Uzbekistan).

5.4. Protection Against Internal Radiation

Internal radiation — resulting from radioactive isotopes entering the body via inhalation, ingestion, or skin absorption — can be more hazardous than external exposure, because alpha particles deposit all their energy at high LET within the tissue (for example, radon-222 increases the risk of lung cancer). Protective measures include: respirators with NPF-certified filters, protective clothing, personal hygiene practices, and workplace ventilation (IAEA-TECDOC-1420, 2004).

6. PHARMACOLOGICAL METHODS OF RADIOBIOLOGICAL PROTECTION

Radioprotectors are chemical agents taken before radiation exposure to reduce biological damage (Weiss & Landauer, 2003):

- Amifostine (WR-2721): the only radioprotective drug approved by the FDA. A thiol-group compound, it scavenges free radicals and creates hypoxic conditions. Therapeutic dose: 910 mg/m2 i.v., administered 30 minutes before irradiation.
- Superoxide dismutase (SOD) and catalase analogues: enhance the enzymatic antioxidant defence system against oxidative stress.
- Melatonin: possesses antioxidant properties and provides mitochondrial protection.
- Potassium iodide (KI): used exclusively in cases of internal contamination with radioactive iodine (I-131). It saturates the thyroid gland and prevents uptake of radioactive iodine (WHO Guidance, 2017).

- G-CSF and GM-CSF: haematopoietic growth factors used to restore the haematopoietic system following radiation injury.

Radiosensitisers also exist (e.g. nitroimidazoles); these compounds are used in oncological radiation therapy to increase the radiosensitivity of tumours.

7. ENVIRONMENTAL AND NATURAL RADIATION

Globally, the average annual effective dose from natural sources is approximately 2.4 mSv (UNSCEAR 2008 Report, Annex B):

- Cosmic radiation: 0.39 mSv/year (at sea level) — increases with altitude.
- Terrestrial gamma radiation: 0.48 mSv/year — elevated in mountainous regions and granitic rocks.
- Radon and its progeny: 1.26 mSv/year — the most significant natural source; accumulates in enclosed spaces.
- Internal radiation (K-40, C-14, etc.): 0.29 mSv/year.

In Uzbekistan, natural radioactivity levels in the Navoi, Kashkadarya, and Surkhandarya regions are somewhat higher than elsewhere in the country, owing to granitic formations and non-ferrous metal ore deposits (Agency for the Use of Atomic Energy of the Republic of Uzbekistan, 2020).

8. ASSESSMENT OF RADIATION EFFECTS: EPIDEMIOLOGICAL DATA

Large-scale epidemiological studies of Hiroshima and Nagasaki atomic bomb survivors (Life Span Study, 1950–2000) constitute the principal data source for radiobiology. These studies indicate that a dose of 1 Sv increases the risk of cancer death by approximately 5–6% (Preston et al., 2007).

The Chernobyl (1986) and Fukushima Daiichi (2011) accidents also provided important data for radiobiological surveillance. According to WHO data, thyroid cancer incidence increased markedly following the Chernobyl accident, particularly in children (WHO, 2006). In the Fukushima incident, the observed health impacts were primarily attributable to psychological stress and evacuation rather than direct radiation exposure (UNSCEAR, 2014).

9. FUTURE PERSPECTIVES: MEDICINE AND TECHNOLOGY

Modern radiobiology and biophysics are advancing rapidly across the following areas:

- Proton and heavy-ion therapy (hadron therapy): enables high-LET particles to be directed precisely at the tumour, sparing surrounding healthy tissue (Suit et al., 2010).
- Boron Neutron Capture Therapy (BNCT): selective neutron irradiation of B-10 isotope enriched within tumour tissue.
- Nanodosimetry and radiosensitisation: gold nanoparticles enhance tumour radiosensitivity.

- Genomic radiology: assessment of individual radiosensitivity based on genetic analysis.
- AI and machine learning: application of artificial intelligence to predict radiation risk and develop optimal dose regimens.

10. CONCLUSION

Ionizing radiation exerts complex, multi-stage biological effects on the human organism — at the molecular (DNA damage, free radicals), cellular (apoptosis, mutations), and systemic (radiation sickness, cancer) levels. Biophysics studies these effects in a comprehensive manner, encompassing clinical, experimental, and theoretical approaches.

The protection system based on ICRP, UNSCEAR, and WHO recommendations — founded on the principles of justification, optimisation (ALARA), and dose limits — provides the scientific basis for effective protection against radiation. The combination of physical protection (distance, time, shielding), pharmacological agents (radioprotectors), and technical measures constitutes the essential elements of a modern radiological protection system.

As medicine, industry, and nuclear energy continue to develop, the radiobiology branch of biophysics will become increasingly important in the future.

REFERENCES:

1. Attix, F.H. (2004). Introduction to Radiological Physics and Radiation Dosimetry. Wiley-VCH.

2. BEIR VII (2006). Health Risks from Exposure to Low Levels of Ionizing Radiation. National Academies Press.

3. Bergonie J., Tribondeau L. (1906). Interpretation of some results of radiotherapy. Radiology, 2(4), 202-211.

4. Goodhead D.T. (1994). Initial events in the cellular effects of ionizing radiations. Int J Radiat Biol, 65(1), 7-17.

5. Hall E.J., Giaccia A.J. (2019). Radiobiology for the Radiologist. 8th ed. Wolters Kluwer.

6. IAEA (2010). Radiation Biology: A Handbook for Teachers and Students. IAEA-TCS-42. Vienna: IAEA.

7. IAEA (2014). Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. GSR Part 3. Vienna.

8. ICRP Publication 103 (2007). The 2007 Recommendations of the International Commission on Radiological Protection. Ann ICRP, 37(2-4).

9. ICRU Report 85 (2011). Fundamental Quantities and Units for Ionizing Radiation. Journal of ICRU.

10. Preston D.L. et al. (2007). Solid cancer incidence in atomic bomb survivors: 1958-1998. Radiat Res, 168(1), 1-64.

11. Suit H. et al. (2010). Proton vs carbon ion beams in the definitive radiation treatment of cancer patients. Radiother Oncol, 95(1), 3-22.

12. Tubiana M. et al. (2009). The linear no-threshold relationship is inconsistent with radiation biologic and experimental data. Radiology, 251(1), 13-22.

13. UNSCEAR (2006). Effects of Ionizing Radiation. Report to the General Assembly, Vol. I. New York: United Nations.

14. UNSCEAR (2014). Fukushima Daiichi Nuclear Power Plant Accident. New York: United Nations.

15. Wardman P. (2009). Fluorescent and luminescent probes for measurement of oxidative and nitrosative species. Free Radic Biol Med, 43(7), 995-1022.

16. Weiss J.F., Landauer M.R. (2003). Protection against ionizing radiation by antioxidant nutrients. Toxicology, 189(1-2), 1-20.

17. WHO (2006). Health Effects of the Chernobyl Accident and Special Health Care Programmes. Geneva: WHO.

18. WHO (2017). Radiation and Nuclear Emergencies: Potassium Iodide (KI) as a Thyroid Blocking Agent. Geneva.

19. Agency for the Use of Atomic Energy of the Republic of Uzbekistan (2020). Report on Radiation Safety Monitoring. Tashkent.