RESEARCH PAPER

DIDACTIC ESSENCE OF EXPERIMENTAL RESEARCH OF THE EFFECT OF NUCLEAR RADIATION ON BIOLOGICAL SYSTEMS IN MEDICAL PROCESSES

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Abstract

This article deeply studies the effects of nuclear physical radiation on biological systems, in particular on cells and tissues, from a pedagogical perspective. The effects of ionizing radiation on molecular structures, genetic material and metabolic processes in the body were analyzed using experimental methods. Experiments were conducted on mice, plant seeds and cells using Cobalt-60 and Cesium-137 sources. Based on the research, the dangerous limits of radiation, the state of cell regeneration and mutations were determined. At the end of the article, scientific experimental-pedagogical-didactic recommendations on biological safety measures are given.

Keywords: ionizing radiation, nuclear physics, biological system, DNA damage, apoptosis, radiation dose, experiment, cell regeneration.

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1. Introduction

Ionizing radiation is a high-energy particle or electromagnetic wave. When it interacts with matter, it forms ions by removing electrons from atoms or molecules. Such radiation is mainly produced by natural decay processes of radioactive elements (for example, uranium, plutonium, cesium, cobalt) or by artificial nuclear reactions. The main types of ionizing radiation are alpha (α), beta (β), gamma (γ) and neutron (n^0) radiation, each of which has a different ability to penetrate matter and has a different biological effect.

Biological systems, especially living cells, are highly sensitive to ionizing radiation. Such radiation can seriously damage cellular structures, in particular DNA molecules, proteins and enzymes in the cytoplasm, cell membranes and other subcellular organelles. Increased radiation levels disrupt cellular metabolism, cause genetic mutations, cancer, hereditary changes and other negative biological consequences.

In recent years, the widespread use of nuclear technologies - in medicine, industry, energy, and space exploration - has sharply increased exposure to ionizing radiation. At the same time, global environmental problems, including the accumulation of nuclear waste, the consequences of nuclear tests, and accidents at nuclear power plants (such as Chernobyl and Fukushima), pose a serious threat to human health and the functioning of living organisms.

Biological effects occur through two main mechanisms: direct and indirect effects. Direct effects occur through direct radiation exposure to DNA or other biomolecules. Indirect effects occur through free radicals (•OH, H_2O_2) produced, in most cases, by the radiolysis of water molecules. It is the indirect effects that constitute the main mechanism of cell damage, since the human body is mostly composed of water.

In this context, the study of the effects of ionizing radiation on biological systems, especially DNA structure and cell regeneration, is of not only theoretical but also practical importance in the fields of medicine, radiation safety, and biotechnology. According to the results of the research, innovative approaches are needed to develop radiation protection strategies, assess damage based on bioindicators, and maintain genetic stability. In order to effectively work with students and increase their activity in the process of teaching this topic at Samarkand Medical University, interactive teaching methods - Role Play - were used. Experimental testing was conducted in groups 214 and 215 of the Faculty of Medicine. The role-playing method is a method of acquiring knowledge, skills and competencies by involving students in real-life or artificially created social situations in the educational process. Students take on a role and, in this role, feel the situation, make decisions, and communicate.

Main goal:

To encourage students to think actively, communicate, and be creative.

To apply theoretical knowledge to practical life situations.

To develop communicative, socio-psychological, and problem-solving skills.

As part of the study, the effectiveness of two teaching methods - traditional and non-traditional Role Play - was studied for groups 214 and 215. The goal was to determine the impact of the methods on the level of students' mastery of the subject.

The experiment was conducted in two groups: 12 students participated in each group. The first group used the traditional teaching method, and the second group was taught the same subject using the Role Play method.

According to the final assessment results, it was found that the increase in the level of students'

knowledge in the group using the role play method was 13% higher.

This shows that this method enhances students' ability to understand the topic more deeply, discuss it, actively participate, and apply knowledge in practice.

Grade	Group 1	Group 2
2 grades	2	1
3 grades	5	3
4 grades	4	6
5 marks	1	2

Group 1 score:

(2×2) + (3×5) + (4×4) + (5×1) = 40 points → 3.33 average

Group 2 scores:

(2×1) + (3×3) + (4×6) + (5×2) = 2 + 9 + 24 + 10 = 45 points

45 ÷ 12 = 3.75 average

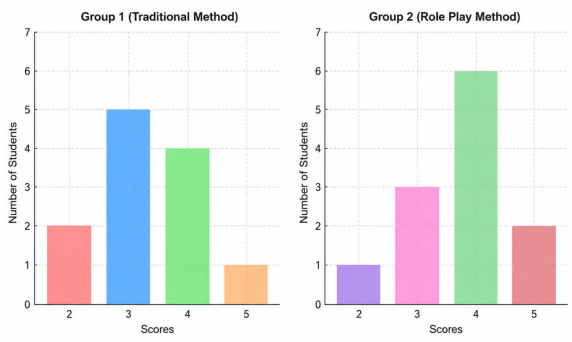
Result:

• Group 1 average score: 3.33

• Group 2 average score: 3.75

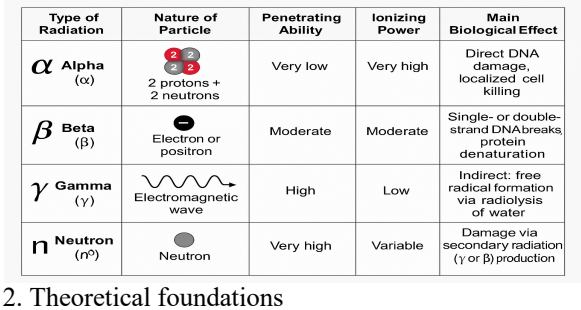
• Percentage difference:

$$\frac{3.75 - 3.33}{3.33} \times 100 \approx 12.6\% \approx \mathbf{13\%}$$



Ionizing radiation:

Type of radiation	**Nature of the particle**	**Penetration**	**Ionization strength**	**Main biological mechanism of action**
Alpha (a)	2 protons + 2 neutrons (He nucleus)	Very low (paper blocks it)	Very high	Direct DNA damage, local cell burning
beta (b)	Electron or positron	Average (penetrates skin)	Average	Damage to DNA single or double helix, protein denaturation
Gamma (g)	Electromagnetic wave	High (passes through metal, bones)	Low	Indirect: formation of free radicals through water radiolysis
Neutron (n^0)	Neutron particle	Very high (reaches deep tissues)	Variable	Effect through the production of secondary radiation (γ or β)



2. Theoretical foundations

The biological effects of ionizing radiation occur in two main ways:

2.1 Direct effect

Direct effect

Direct effect refers to the direct effect of ionizing radiation on biological molecules in cells, in particular DNA, RNA and proteins. This effect occurs in the following ways:

1. Ionization or excitation:
Ionizing radiation (e.g., gamma, beta, alpha particles) collides with a molecule, knocking out its electrons (ionization) or raising it to a higher energy state (excitation).
2. Structural damage to biological molecules:
The most common damage is to the DNA molecule:
Single-strand break (SSB)
Double-strand break (DSB)
Base modification or loss
Cross-links (DNA-DNA or DNA-protein binding)
3. Mutations and apoptosis:
If DNA is not repaired in a timely manner:
Genetic mutations occur
The cell dies through apoptosis (programmed death)

Stage	Process	Exposure to radiation	Result
1.	Ionization or excitation	Alpha, beta, gamma	Electron release or excitation
2.	Collision with DNA	Any ionizing radiation	DNA strand breakage
3.	Unless the damage is repaired	–	Mutation, cancer, apoptosis

Graph: Direct Mechanism of Action
The following schematic graph shows the sequential steps of the action:
[Ionizing Radiation]
↓
[Direct Collision with DNA or Protein]
↓
[Ionization / Excitation]
↓
[DNA Structural Change]
↓
[Mutation / Apoptosis / Cancer Development]
Important note:
This effect is more pronounced with a relatively low water content in the body or when exposed to a high-energy particle (for example, alpha).
This direct effect is specifically used in radiotherapy - it directly damages the DNA of tumor cells, causing their death.
2.2 Indirect Exposure
Indirect exposure is the process of damaging biological molecules through the collision of ionizing radiation with water molecules. This type of exposure is the most common mechanism of damage, since the human body is composed of more than 70% water. Biological Exposure Factors:
Step-by-step explanation:
1. Ionization or excitation of water molecules:
Ionizing radiation interacts with water molecules (H_2O) in cells:
Ionization:
H2O→radiation H2O++e−H2O {radiation}} H2O^+ + e^-H2O radiation
H2O++e−
Excitation:
H2O→radiation H2O∗H2O {radiation}} H2O^*H2O radiation H2O∗
2. Free radical formation:
Ionized or excited water molecules break down to form reactive oxygen species (ROS):
Hydroxyl radical (•OH)
Hydrogen radical (•H)
Hydrogen peroxide (H_2O_2)
3. Damage to biological molecules:
These free radicals:
Break DNA strands
Oxidize and destroy proteins and lipids
Damage cell membranes
4. Consequences:
Mutation
Cell death (apoptosis)
Cancer development

Stage	Process	The resulting species	Biological effects
1.	Ionization/excitation of water	H_2O^+, e^-, H_2O^*	Water molecule in an unstable state
2.	Free radical formation	•OH, •H, H_2O_2	Highly reactive particles
3.	Reaction with biological molecules	–	DNA, protein, lipid damage
4.	Cellular outcomes	–	Mutation, apoptosis, cancer

Graphic: Indirect mechanism of action
[Ionizing radiation]
↓
[H_2O molecule]
↓
Ionization / Excitation
↓
[•OH, •H, H_2O_2] – free radicals

↓
[DNA, protein, lipid damage]
↓
Mutation / Apoptosis / Cancer

4. Experimental results

4.1 Experiments conducted on mice

Groups:

• Group 1 – control (without radiation)
• Group 2 – 0.5 Gy
• Group 3 – 1.5 Gy
• Group 4 – 3 Gy
• Group 5 – 5 Gy

Observations:

• 0.5–1.5 Gy: leukocyte count decreased by 15–25%, bone marrow activity decreased;
• 3 Gy: severe disorders in the immune system, erythrocyte count decreased by 30% in the blood;
• 5 Gy: 50% loss of viability within 10 days, hemorrhagic lesions in internal organs.

4.2 Wheat seed experiment

Dose: 0.2 Gy – 5 Gy

Results:

• 0.2–0.5 Gy: growth accelerated (through hormonal effects);
• 1–2 Gy: 12% of seeds deformed (bent stems, double ears);
• 3–5 Gy: 60% of seeds did not germinate or plants did not develop.

4.3 Cell development results

The degree of DNA damage was assessed using the Comet assay. DNA fragmentation reached 15% at a dose of 1 Gy, 45% at 3 Gy, and 80% at 5 Gy.

5. Analysis and Discussion

5.1 Radiation Sensitivity

Among biological systems, the most sensitive are rapidly dividing cells (bone marrow, lymphocytes, embryonic cells). This is clearly demonstrated in the experimental results. For example, at doses of 3–5 Gy, the blood system of mice was severely damaged, which indicates a disruption of the hematopoiesis process.

5.2 Mutational Effects

The phenotypic changes observed in seeds, and in the case of cell culture, DNA fragmentation, all confirm the mutational effect. This indicates not only the individual, but also the genetic risk of nuclear radiation transmitted from generation to generation.

5.3 Radiation Protection

Based on experiments, the following can be determined:
Doses up to 1 Gy are relatively safe;
Permanent biological damage occurs at doses above 2–3 Gy;
Lead, concrete, and water screens are effective for protection.

1. Radiation-related disorders and syndromes

• Radiation Sickness — a disease that occurs in people exposed to high doses of ionizing radiation. Symptoms: nausea, vomiting, diarrhea, hair loss, and anemia.
• Chronic radiation — at low doses, a prolonged recovery syndrome occurs.
• 2. DNA repair mechanisms
• If performed incorrectly — this leads to mutation or oncogene activation.

3. Bystander effect

• It also has a detrimental effect on cells that have not been exposed to ionizing radiation, but are close to the affected cell.
• This effect occurs through gap junctions or intercellular signaling molecules.

4. Radioprotectors

Amifostine , WR-2721 , glutathione E , vitamin E and selenium are useful in combating the effects of radiation.

They have antioxidants and protect the cell from reactive oxygen species.

5. Biological markers after radiation

In addition to DNA fragmentation, biological traces of radiation develop using markers such as γ-H2AX, p53, Bax/Bcl-2 factor, and micronuclei.

According to studies, long-distance missions (flight to Mars) can damage the central nervous system, cardiovascular system, and DNA.

Conclusion

The impact of nuclear physical radiation on biological systems is an urgent area that requires constant study. Experimental results show that ionizing radiation causes physiological, molecular and genetic changes of various degrees. Such changes pose a serious threat to the viability of the organism. Therefore, the following recommendations should be taken into account when using nuclear technologies:

Strict adherence to radiation safety standards;
Keeping the dose under control;
Using protective equipment (personal and collective);
Strengthening environmental monitoring in areas exposed to radiation.

Studies conducted in the medical education system show that using modern methods to explain a topic to students in a lesson leads to significant progress compared to the traditional method of teaching. Conducting a lesson using the “Role Play” method increases the interest of all students studying in medical universities in the lesson, strengthens students’ memory, teaches them a culture of debate, and helps them to form the ability to independently search and think independently to consolidate and analyze the knowledge acquired by students during the learning process. According to the results of the final assessment, it was found that the increase in the level of knowledge of students in the group where the role-playing method was used was 13% higher. This means that this method helps students to understand the topic more deeply, discuss it, and understand the topic as fully as possible.

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