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Radiation Safety: Medical and Biological Aspect

Manual for training

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2023-2026





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Radiation Safety: Medical and Biological Aspect

As a result of mastering the **lecture course**, students will gain competences:

- ✓ **Instrumental competences:** ability to analyze and synthesize; basic general knowledge; information management skills (the ability to find and analyze information from different sources).
- ✓ **Interpersonal competences:** the ability to criticize; self-criticism; ethical obligations.
- ✓ **System competences:** ability to learn; environmental care.

As a result of the **training**, students will gain competences:

- ✓ **Instrumental competences:** ability to organize activities and manage time; ability to use knowledge in practice; information management skills (the ability to find and analyze information from various sources); solving complex problems.
- ✓ **Interpersonal competences:** interaction (teamwork); interpersonal skills and abilities; ability to work in an interdisciplinary team; ability to communicate with experts from other fields; ability to work in an international environment; ethical obligations.
- ✓ **System competences:** research skills and abilities; ability to generate new ideas (creativity); leadership skills; ability to work independently; planning and management of projects; environmental care.

Basic Concepts and Units in Dosimetry

Radiation can be classified into two main categories: ionizing and non-ionizing.

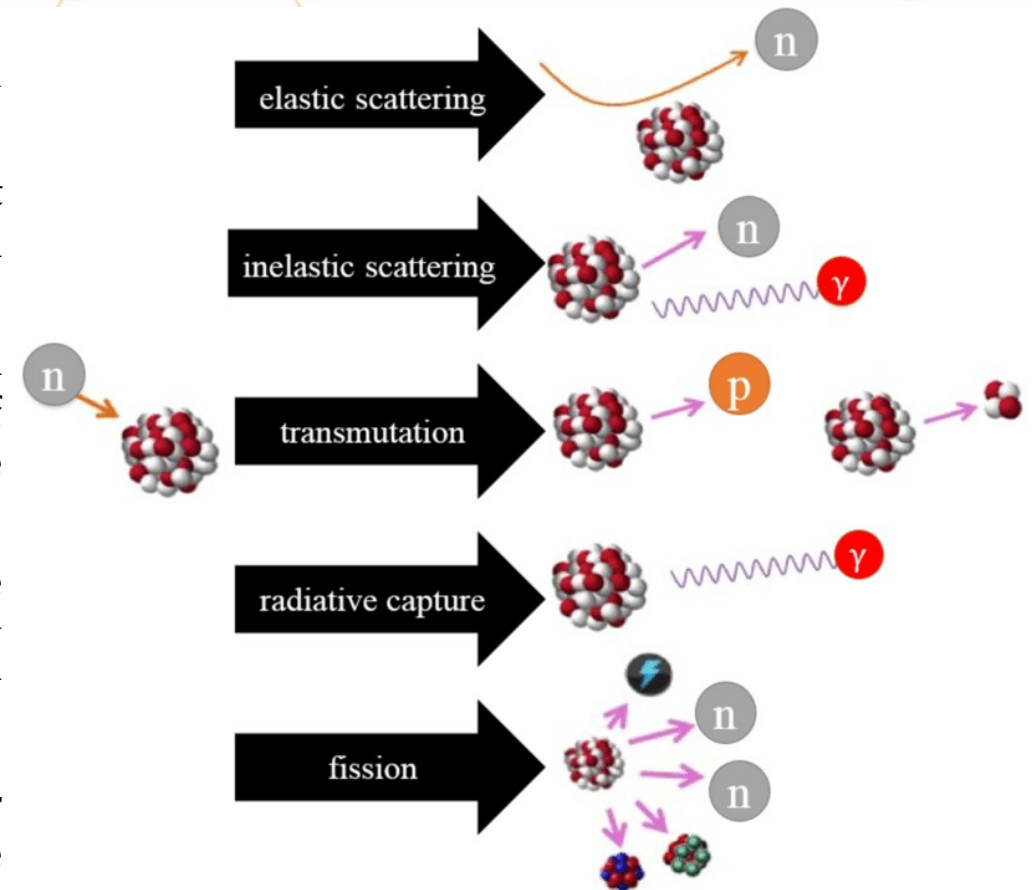
Ionizing radiation carries enough energy to remove tightly bound electrons from atoms and molecules, forming charged particles or ions.

Non-ionizing radiation, on the other hand, does not possess sufficient energy to cause ionization but can still produce thermal and photochemical effects.

Ionizing radiation is further divided into directly ionizing and indirectly ionizing radiation. Directly ionizing radiation consists of charged particles, such as alpha and beta particles, which can ionize atoms and molecules in their path due to their inherent electric charge.

Alpha particles are heavy, positively charged particles emitted from the nucleus of heavy elements during radioactive decay. They have low penetration power and can be stopped by a sheet of paper or a few centimeters of air.

Beta particles are lighter, negatively charged particles (electrons) or positively charged particles (positrons) also emitted during radioactive decay. Their penetration power is higher than alpha particles but can be stopped by thin plastic, glass, or aluminum.



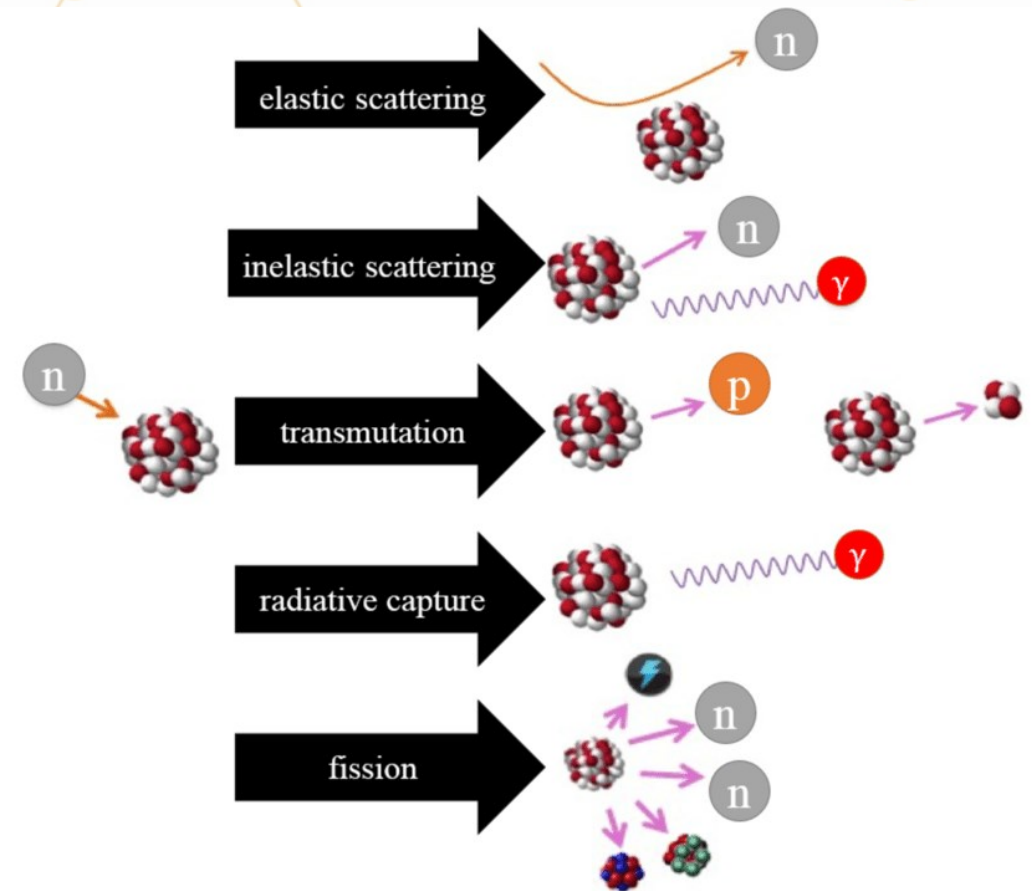
Basic Concepts and Units in Dosimetry

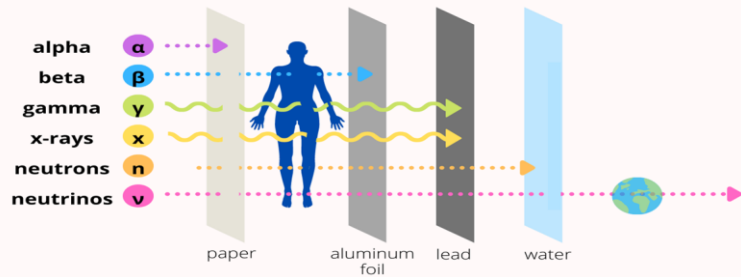
Gamma rays are high-energy electromagnetic radiation emitted during nuclear reactions or radioactive decay. They are highly penetrating and require dense materials, like lead or concrete, for effective shielding.

X-rays are similar to gamma rays in nature but are produced through different mechanisms, such as the interaction between high-energy electrons and matter.

Neutrons are uncharged particles that can cause ionization indirectly by interacting with atomic nuclei, causing the emission of charged particles. Neutrons can be highly penetrating, and their shielding requires materials rich in hydrogen, like water or polyethene.

These various types of radiation possess different energies and interaction properties with matter. Understanding their characteristics is essential for effective radiation protection, dosimetry, and the development of radiation-based technologies in medicine, industry, and research. Knowing the energy levels and properties of each radiation type makes it possible to design appropriate shielding, monitoring, and control strategies to minimize potential health risks and optimize the beneficial applications of radiation in numerous fields.





Dosimetric Quantities

In dosimetry, two key quantities are essential for understanding and assessing the impact of ionizing radiation on matter and living organisms: the absorbed dose (D) and the equivalent dose (H). These quantities provide a standardized way to quantify the potential biological effects of different types of radiation, allowing for informed decision-making in medical, industrial, and research settings.

The absorbed dose (D) represents the mean energy imparted by ionizing radiation per unit mass of matter. It is typically expressed in Gray (Gy) units, where 1 Gy equals the absorption of 1 joule of radiation energy per kilogram of matter. The absorbed dose indicates the amount of energy deposited in a material or tissue, which can cause ionization and potential biological damage in the case of living organisms. However, the absorbed dose does not account for the varying effectiveness of different radiation types in causing harm.

The equivalent dose (H) considers the biological effectiveness of the radiation by accounting for the type and energy of the radiation. The absorbed dose is multiplied by a radiation weighting factor (wR) to calculate the equivalent dose, reflecting the specific radiation type's relative biological effectiveness (RBE). The unit for equivalent dose is sievert (Sv), and 1 Sv equals 1 Gy multiplied by the radiation weighting factor.

Radiation Type and Energy Range	Radiation Weighting Factor, W_R
X and γ rays, all energies	1
Electrons positrons and muons, all energies	1
Neutrons:	
< 10 keV	5
10 keV to 100 keV	10
> 100 keV to 2 MeV	20
> 2 MeV to 20 MeV	10
> 20 MeV	5
Protons, (other than recoil protons) and energy > 2 MeV,	2-5
α particles, fission fragments, heavy nuclei	20

$$\text{Equivalent dose (H)} = \text{Absorbed dose (D)} \times \text{Radiation weighting factor (wR)}$$

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The radiation weighting factors account for the differences in the ionizing potential and the density of ionization events caused by various types of radiation. For example, alpha particles have a higher radiation weighting factor than beta particles, gamma rays, or X-rays because of their greater ability to cause biological damage.

Creating a comprehensive table of dosimetry values for the human body is challenging due to the factors involved, such as the type of radiation, energy, and individual tissue sensitivities. However, a simplified table illustrating the organ and tissue weighting factors (wT), used for calculating the effective dose (E) from the equivalent dose (H) in radiation protection, is provided:

Organ/Tissue	Weighting Factor (wT)
Gonads (Testes, Ovaries)	0.20
Red Bone Marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone Surface	0.01
The Remainder (Other Organs/Tissues)	0.12

<https://openmedscience.com/dosimetry-calculating-radiation-dose-for-medical-applications/>



The **effective dose (E)** can be calculated by summing the product of the equivalent dose (H) and the weighting factor (wT) for each organ or tissue:

$$E = \Sigma [wT * H(T)]$$

This calculation allows for the comparison of radiation exposure across different organs, tissues, and radiation types, accounting for the varying sensitivities of different organs to ionizing radiation.

Attenuation is a critical concept in understanding the behavior of radiation as it interacts with and passes through matter. As radiation traverses a medium, it loses intensity due to attenuation, including absorption (energy transfer to the medium) and scattering (deflection of radiation in different directions). Understanding attenuation is vital for designing effective shielding, radiation protection, and dosimetry strategies in various applications, including medicine, industry, and research.

The intensity of the radiation (I) after passing through a given thickness (x) of material can be determined using the Beer-Lambert law:

$$I(x) = I_0 * e^{-\mu x}$$

Here I_0 is the initial intensity, μ is the linear attenuation coefficient, and x is the thickness of the material. The linear attenuation coefficient (μ) is a property of the material and the type and energy of the radiation. It quantifies the likelihood of interaction between the radiation and the material, with higher values indicating greater attenuation.

The linear attenuation coefficient (μ) varies depending on the type and energy of radiation and the composition of the specific tissue in the human body. Here is a simplified list of approximate linear attenuation coefficients for some common tissues and materials in the human body at a photon energy of 100 keV:

Tissue / Material	Linear Attenuation Coefficient (μ) (cm ⁻¹)
Air	0.0002
Water	0.17
Fat	0.19
Muscle	0.20
Lung Tissue	0.23
Blood	0.21
Bone	0.35 – 0.6

<https://openmedscience.com/dosimetry-calculating-radiation-dose-for-medical-applications/>



Linear Energy Transfer (LET)

Linear energy transfer (LET) is critical in [radiation physics and dosimetry](#). It quantifies the energy a charged particle deposits per unit length of its path through a medium. It is typically expressed in units of keV/ μm (kilo-electron volts per micrometer) or MeV/cm (mega-electron volts per centimeter). The LET of radiation significantly impacts its biological effects and interaction properties with matter.

High LET radiation, such as alpha particles, is characterized by a dense ionization pattern along the particle's track, causing more ionizations and excitations per unit length than low LET radiation, such as gamma rays or X-rays. Due to the high ionization density, high LET radiation has a greater probability of causing severe and clustered DNA damage in living cells, which is less likely to be accurately repaired by cellular repair mechanisms. Consequently, high LET radiation is generally considered more biologically effective than low LET radiation of the same absorbed dose.

Low LET radiation, such as gamma rays and X-rays, has a sparse ionization pattern and deposits its energy over a longer distance in the medium. This type of radiation typically causes less severe and more isolated DNA damage, which is more likely to be repaired by cellular mechanisms. However, low LET radiation can still cause significant biological effects, especially at high doses or dose rates.

Below is a table summarizing the [properties of alpha, beta, and gamma radiation](#), including their LET values and other relevant information:

Radiation Type	Symbol	Particle / Photon	Charge	Mass (amu)	LET (keV/ μm)	Penetrating Power	Shielding Material
Alpha	α	Helium nucleus	+2	4	50-200	Low	Paper, clothing
Beta	β	Electron	-1	~ 0	0.1-10	Moderate	Plastic, glass
Gamma	γ	Photon	0	0	< 0.1	High	Lead, concrete



Linear Energy Transfer (LET)

Alpha (α) radiation consists of helium nuclei (2 protons and 2 neutrons) and has a high LET value, which means it causes many ionizations and excitations per unit length. Due to its high LET, alpha radiation has low penetrating power and can be stopped by paper or clothing.

Beta (β) radiation consists of electrons, which are much lighter and have a negative charge. Beta particles have a lower LET value than alpha particles, indicating fewer ionizations and excitations per unit length. Beta radiation has moderate penetrating power and can penetrate materials like plastic or glass but can be shielded by denser materials.

Gamma (γ) radiation is a type of electromagnetic radiation consisting of photons with no charge or mass. Gamma rays have the lowest LET values, implying minimal ionizations and excitations per unit length. However, they have high penetrating power and can pass through many materials, requiring lead or concrete to provide effective shielding.

It is important to note that these values are approximate and may change on the specific radionuclide and energy of the radiation.

Understanding the LET of radiation is essential for various applications, including radiation protection, medical imaging, and radiotherapy. Knowing the LET can guide the choice of appropriate shielding materials and designs to minimize exposure to radiation protection. In medical imaging, the knowledge of LET can help balance image quality and patient dose by optimizing imaging parameters. In radiotherapy, considering the LET can help design treatment plans that maximize the radiation dose to tumors while minimizing the dose to healthy tissues.



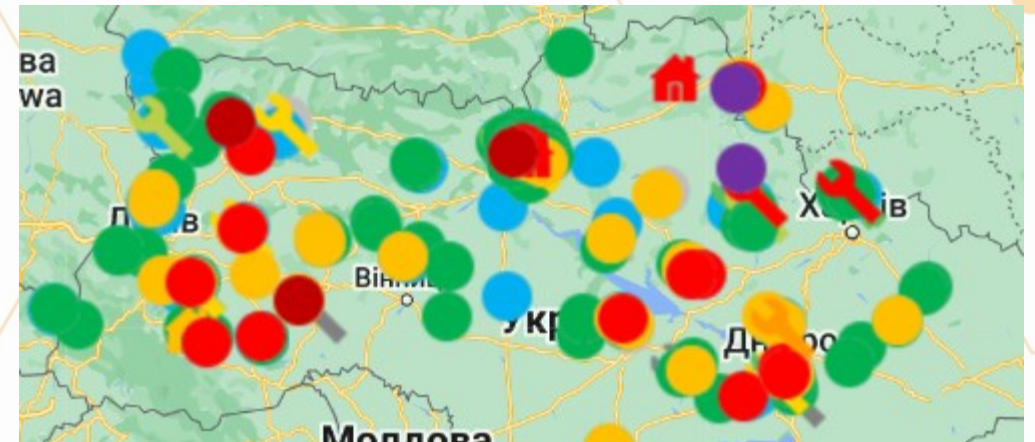
Sequence of Execution

1. <https://eco-city.org.ua/>

Familiarize yourself with the EcoCity website. Consider the characteristics of different levels of environmental pollution.

2. Find five monitoring points on the map of Ukraine, where the radiation background is determined.

3. Calculate the absorbed, equivalent, and effective doses for one day at different points in Ukraine.





Sequence of Execution

4. Fill in the table (5 times):

Organ / Tissue	Effective dose (E)
Gonads (Testes, Ovaries)	
Red Bone Marrow	
Colon	
Lung	
Stomach	
Bladder	
Breast	
Liver	
Oesophagus	
Thyroid	
Skin	
Bone Surface	



Sequence of Execution

5. Visit the website

<https://www.xrayrisk.com/calculator/calculator-normal-studies.php?id=13>

Calculate the risk of cancer from radioactive radiation for yourself or others.





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Tests





Radiation Safety: Medical and Biological Aspect. Tests

1. Which process occurs when a chemical bond is broken due to radiation?

- a) Oxidation
- b) Excitation
- c) Ionization
- d) Hydrolysis

2. Free radicals formed by radiation primarily interact with which cellular component?

- a) Proteins
- b) Lipids
- c) DNA
- d) Ribosomes

3. Which of the following is an indirect influence of radiation on DNA?

- a) Formation of free radicals
- b) Direct ionization
- c) Formation of thymine dimers
- d) Cleavage of phosphodiester bonds

4. What is the consequence of unrepaired DNA damage caused by radiation?

- a) Apoptosis
- b) Necrosis
- c) Mutagenesis
- d) Translocation

5. Which of the following is NOT a type of radiation-induced cell death?

- a) Apoptosis
- b) Necrosis
- c) Autophagy
- d) Hyperplasia

6. Chromosomal aberrations are commonly used as a biological indicator of

- a) cell sensitivity
- b) radiation dosage
- c) DNA repair efficiency
- d) cell cycle progression

7. The overall dose-response curve for total body irradiation typically exhibits

- a) linear response
- b) exponential response
- c) threshold response
- d) biphasic response

8. Which of the following organs is MOST sensitive to radiation-induced damage?

- a) Skin
- b) Thyroid gland
- c) Lungs
- d) Gonads





Radiation Safety: Medical and Biological Aspect. Tests

9. What term describes the concept of reducing radiation dose per fraction while maintaining the total dose?

- a) Fractionation
- b) Dose rate modulation
- c) Radioprotection
- d) Radiosensitization

10. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) primarily focuses on

- a) environmental effects of radiation
- b) health effects of radiation
- c) radiological protection guidelines
- d) radiation therapy advancements

11. What type of radiation-induced damage involves the removal of an electron from an atom?

- a) Excitation
- b) Ionization
- c) Oxidation
- d) Hydrolysis

12. The threshold response in the dose-response curve indicates

- a) linear relationship between dose and response
- b) no observable effect below a certain dose
- c) response that increases with decreasing dose
- d) maximum response at a specific dose

13. Which cellular component is particularly vulnerable to radiation-induced damage due to its high lipid content?

- a) Nucleus
- b) Cell membrane
- c) Mitochondria
- d) Golgi apparatus

14. The process of repairing damaged DNA by reattaching broken ends is known as

- a) transcription
- b) DNA ligation
- c) translation
- d) replication

15. Which type of cell death is characterized by cell shrinkage and fragmentation into apoptotic bodies?

- a) Apoptosis
- b) Necrosis
- c) Autophagy
- d) Hyperplasia

16. Fractionation of radiation therapy helps in

- a) minimizing damage to healthy tissues
- b) increasing the total dose delivered
- c) reducing the effectiveness of treatment
- d) accelerating tumor growth



Radiation Safety: Medical and Biological Aspect. Tests

17. Which of the following is a direct consequence of ionizing radiation interacting with DNA?

- a) Formation of free radicals
- b) Inhibition of DNA replication
- c) Activation of repair enzymes
- d) Promotion of cell division

18. The formation of chromosomal aberrations, such as translocations and deletions, is a result of

- a) DNA repair
- b) incorrect chromatin packaging
- c) DNA replication
- d) ribosomal synthesis

19. Which of the following organs is LEAST sensitive to radiation-induced damage?

- a) Bone marrow
- b) Brain
- c) Muscle
- d) Liver

20. The concept of radioprotection involves

- a) enhancing the effects of radiation
- b) minimizing exposure to radiation
- c) promoting radiation-induced mutations
- d) maximizing DNA damage

21. Which international organization provides guidelines for radiological protection?

- a) International Commission on Radiological Protection (ICRP)
- b) World Health Organization (WHO)
- c) United Nations Development Programme (UNDP)
- d) International Atomic Energy Agency (IAEA)

22. Which type of mutation results from a single nucleotide substitution?

- a) Deletion
- b) Point mutation
- c) Insertion
- d) Frameshift mutation

23. The double dose concept suggests that

- a) mutations occur twice as frequently in diploid organisms
- b) the effect of radiation doubles with an increase in dose
- c) mutations are more severe in haploid organisms
- d) radiation doses should be halved for safety

24. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) evaluates

- a) global climate change
- b) health effects of ionizing radiation
- c) effects of chemical pollution
- d) geological phenomena



25. Radiation sensitivity varies depending on the stage of cell development due to differences in

- a) cell size
- b) metabolic activity
- c) chromosome number
- d) DNA repair capacity

26. Developmental delay due to radiation exposure primarily affects

- a) motor skills
- b) brain development
- c) language acquisition
- d) social interaction

27. Which type of cancer is most commonly associated with radiation exposure?

- a) Melanoma
- b) Leukemia
- c) Breast cancer
- d) Prostate cancer

28. Epidemiological studies on radiation effects require

- a) large sample sizes and long follow-up periods
- b) small sample sizes and short follow-up periods
- c) laboratory-controlled experiments only
- d) exclusion of statistical analysis

29. The concept of collective dose refers to

- a) individual radiation exposure
- b) summation of doses received by a population
- c) average radiation dose per exposure
- d) maximum permissible dose

30. The approach adopted by the ICRP prioritizes

- a) preventing stochastic effects of radiation
- b) promoting deterministic effects of radiation
- c) encouraging non-occupational radiation exposure
- d) maximizing radiation dose limits

31. Which of the following is NOT a common chromosomal aberration observed after radiation exposure?

- a) Translocation
- b) Deletion
- c) Duplication
- d) Crossing over

32. Radiation-induced damage to the lens of the eye can result in

- a) cataracts
- b) glaucoma
- c) macular degeneration
- d) retinal detachment



33. Threshold doses are defined as the
- minimum dose required to cause a specified effect
 - maximum dose that can be safely administered
 - optimal dose for therapeutic purposes
 - total dose received over a specific period
34. The fractionation effect in radiation therapy refers to
- increased effectiveness of each fractionated dose
 - reduced damage to normal tissues with fractionated doses
 - enhanced repair mechanisms with fractionated doses
 - decreased overall treatment time with fractionated doses
35. The concept of effective dose takes into account
- total radiation exposure
 - individual radiation sensitivity
 - radiation weighting factors for different tissues and organs
 - the linear no-threshold model
36. The comparison of risks from different types of radiation exposure involves consideration of
- biological half-life of isotopes
 - chemical properties of radiation sources
 - relative biological effectiveness (RBE)
 - dose rate modulation
37. Which of the following is NOT a principle of radiological protection?
- Justification
 - Optimization
 - Limitation
 - Maximization
38. Which of the following is a radioprotective factor?
- Antioxidants
 - Mutagens
 - Radiosensitizers
 - Carcinogens
39. The ICRP risk tolerances focus on
- limiting the risk of stochastic effects
 - maximizing deterministic effects
 - ignoring genetic risks
 - excluding non-radiation-related risks
40. The modern approach to epidemiological studies of radiation effects emphasizes
- minimal statistical analysis
 - robust statistical methods
 - qualitative data only
 - exclusion of cohort studies



Radiation Safety: Medical and Biological Aspect. Tests

41. What is the primary mechanism by which radiation interacts with proteins?

- a) Formation of hydrogen bonds
- b) Induction of conformational changes
- c) Cleavage of peptide bonds
- d) Inhibition of enzymatic activity

42. Which of the following is an example of a radiosensitizer?

- a) Cisplatin
- b) Vitamin C
- c) Antioxidants
- d) Aspirin

43. What term describes the phenomenon where a cell's sensitivity to radiation increases as it progresses through the cell cycle?

- a) Radioprotection
- b) Cell cycle checkpoint
- c) Radiosensitization
- d) Fractionation

44. The hematopoietic syndrome is characterized by

- a) nausea and vomiting
- b) diarrhea and dehydration
- c) decreased production of blood cells
- d) cognitive impairment

45. Which of the following organs is MOST affected by the gastrointestinal syndrome?

- a) Brain
- b) Liver
- c) Intestines
- d) Kidneys

46. The main mechanism of radiation-induced thyroid damage is

- a) direct DNA damage
- b) incorporation of radioactive iodine
- c) formation of free radicals
- d) inhibition of hormone synthesis

47. Which of the following is a consequence of radiation damage to the lens of the eye?

- a) Cataracts
- b) Macular degeneration
- c) Retinal detachment
- d) Glaucoma

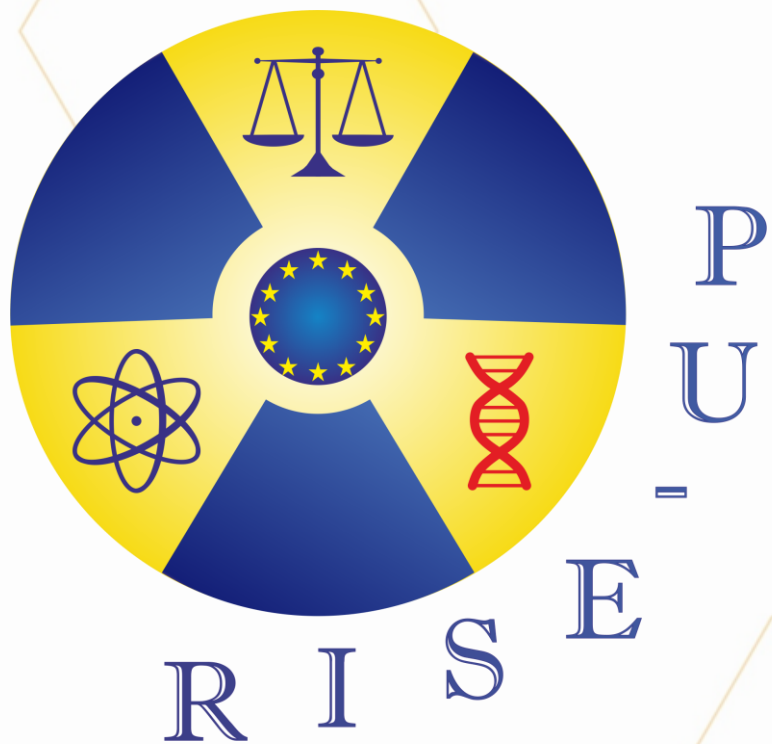
48. The concept of linear no-threshold (LNT) model suggests that

- a) there is no safe threshold for radiation exposure
- b) the risk of radiation exposure decreases linearly with dose
- c) radiation exposure below a certain threshold is beneficial
- d) radiation effects are purely deterministic in nature



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