Abstract

Self-preparation guide for 2gr students.

Subject: “Safety science”

Topic 1.4 -2 “Identification of harmful habitat factors. Ionizing radiation”

Ionizing radiation

1. Types of ionizing radiation

Ionizing radiation - is any type of particle or electromagnetic wave that carries enough energy to ionize or remove electrons from an atom.

There are officially two types of ionizing radiation:

- Particulate radiation (alpha, beta, and neutron particles);
- Electromagnetic. (X-rays and gamma-rays) Gamma radiation is produced by interactions within the nucleus, while X-rays are produced outside of the nucleus by electrons.

Non-ionizing radiation is the term given to radiation in the part of the electromagnetic spectrum where there is insufficient energy to cause ionization. It includes electric and magnetic fields, radio waves, microwaves, infrared, ultraviolet, and visible radiation (light).

Particulate radiation.

Alpha particle radiation (alpha radiation).

- The alpha particle is composed of two protons and two neutrons, or a helium nucleus.
- Alpha particles are composed of two neutrons with no charge and two positively charged protons, traveling at very high speed. When alpha particles penetrate solid material, they interact with many atoms within a very short distance. They create ions and use up all their energy in that short distance. Most alpha particles will use up their energy while traveling through a single sheet of ordinary notebook paper. The primary health concern associated with alpha particles is that when alpha-emitting materials are ingested or inhaled, energy from the alpha particles is deposited in internal tissues such as the lungs.
- Alpha decay: a nucleus ejects an alpha particle which is identical to an ionized helium nucleus.

- Alpha radiation: The emission of an alpha particle from the nucleus of an atom.

BetaRadiation

- Beta particles are high-speed electrons that are not attached to atoms. They are small - over 7,000 times lighter than alpha particles. The beta particles travel farther through solid material than alpha particles. For example, a very high-energy beta particle will travel about half an inch through plastic before it uses up all its energy. Like alpha particles, beta particles lose energy with every interaction and no longer produce ions once all their energy is spent. Health concerns associated with beta particles arise primarily when beta - emitting materials are ingested or inhaled.
- Beta radiation: The emission of a beta particle from the nucleus of an atom.
- Beta radiation takes the form of either an electron or a positron (a particle with the size and mass of an electron, but with a positive charge) being emitted from an atom.

Neutron ionizing radiation

- Neutron radiation: The emission of a neutron from the nucleus of an atom.
- Neutron radiation consists of a free neutron, usually emitted as a result of spontaneous or induced nuclear fission. Able to travel hundreds or even thousands of meters in air, they are however able to be effectively stopped if blocked by a hydrogen-rich material, such as concrete or water. Neutrons are, in fact, the only type of radiation that is able to turn other materials radioactive.

Electromagneticionizingradiation.

- Gamma radiation;
- X-rays

Table 1-1. Properties of electromagnetic ionizing radiation.

Common with properties of visible radiation.	Differentfromvisibleradiation.

-propagated in straight lines; -don’t deviate in magnetic or electric fields.	- invisible to the naked eye; -penetrate in matter; -absorbed by different materials and tissues depending on their density; -don’t reflect from mirror surfaces; -are not focused by optical lenses,are not refracted by optical prisms; -ionize gases, change colors of glasses, minerals

Gamma radiation:

- The emission of a high-energy wave from the nucleus of an atom.
- Gamma radiation, unlike alpha or beta, does not consist of any particles, instead consisting of a photon of energy being emitted from an unstable nucleus. Having no mass or charge, gamma radiation can travel much farther through air than alpha or beta, losing (on average) half its energy for every 500 feet. Gamma waves can be stopped by a thick or dense enough layer material, with high atomic number materials such as lead or depleted uranium being the most effective form of shielding.

One source of gamma rays in the environment is naturally occurring potassium-40.

X-Rays

- The emission of a high energy wave from the electron cloud of an atom.
- X-rays are similar to gamma radiation, with the primary difference being that they originate from the electron cloud. This is generally caused by energy changes in an electron, such as moving from a higher energy level to a lower one, causing the excess energy to be released. X-Rays are longer-wavelength and (usually) lower energy than gamma radiation, as well.

2. Doses.

The main aim of radiological safety is health protection from harmful impact of ionizing radiation. It is necessary to estimate environmental, occupational, medical, military exposure.

There is the system of dosimetry quantities:

1) Physical quantities (the impact of ionizing radiation on the material):

   -Exposure ionizing radiation dose (radiation exposure);

   - Absorbed dose.

2) Normalized quantities (the hazard of ionizing radiation):

   - Equivalent Dose;
   - Effective Dose.

Table 1-2. SI and traditional units used in radiation dosimetry, with conversion factors

Quantity	Units		Conversionfactor (SI/traditional)
	SIunit	Traditional unit	
Absorbeddose (D)	gray (Gy) 1 Gy = 1 J per kg	rad	1 Gy = 100 rad 1 rad = 0.01 Gy
Equivalentdose (H)	sievert (Sv) 1 Sv = 1 J per kg	rem	1 Sv = 100 rem 1 rem = 0.01 Sv
Radiation exposure (X)	coulomb per kilogram of air (C per kg)	roentgen (R)	1 R = 2.58 × 10^{-4} C per kg of air 1 C per kg = 3,876 R
Effectivedoseдоза (E)	sievert (Sv)	-	1 Sv = 100 rem

Physical quantities

1.Exposure ionizing radiation dose (radiation exposure) - is a measure of the ionization of the air due to ionizing radiation from photons; that is, gamma rays and X-rays.

The SI unit of exposure is the coulomb per kilogram (C/kg), which has largely replaced the roentgen (R). One roentgen equals 0.000258 C/kg; an exposure of one coulomb per kilogram is equivalent to 3876 roentgens.

Exposure is not applicable to particulate radiation.

As a measure of radiation damage exposure has been superseded by the concept of absorbed dose which takes into account the absorption characteristic of the target material.

2. Absorbed dose (D) - is a dose quantity which is the measure of the energy deposited in matter by ionizing radiation per unit mass. Absorbed dose is used in the calculation of dose uptake in living tissue in both radiation protection (reduction of harmful effects), and radiology (potential beneficial effects for example in cancer treatment).

The SI unit of measure is gray (Gy), which is defined as one Joule of energy absorbed per kilogram of matter.The older, non-SI (traditional) unit is rad (sometimes also used).

- 1 Gy = 1 J per kg
- Rad (radiation absorbed dose) is a traditional unit of absorbed dose.
- 1 rad = 0.01 Gy

Dose (D) can be expressed as $D = d\varepsilon/dm$,

where $d\varepsilon$ is energy imparted to a finite volume of matter of mass dm.

The absorbed dose alone is not a sufficient indicator of the risk of deleterious effects to humans from ionizing radiation, in particular when delayed effects are of concern.So, there are such concepts for quantitative estimationof absorbed dose:

- Equivalent dose. The equivalent dose (H) to an organ or tissue is obtained by weighting the absorbed dose in an organ or tissue by a radiation weighting factor (described below).
- The radiation weighting factor (Wr) reflects the biological effectiveness of the particles that produce damage in the tissue.

Normalized quantities

There are normalized quantities for biological effects assessment of ionizing radiation.

1. Equivalent Dose($H_{T,R}$):

- Equivalent doseis calculated for individual organs.
- It is based on the absorbed dose to an organ, adjusted to account for the effectiveness of the type of radiation.
- Equivalent dose is expressed in millisieverts (mSv) to an organ.

The equivalent dose in tissue (H_T) may be defined as:

$$H_T = \sum_R * W_R * D_{T,R}$$

where: W_R = radiation weighting factor for radiation R.

$D_{T,R}$ = absorbed dose in tissue T associated with radiation R.

$\sum_R$ = the sum of all radiation types that impart ionizing tissue in tissue T.

The SI unit for the equivalent dose is the sievert (Sv), where 1 Sv = 1 J/kg.
The traditional unit is rem: 1 rem=0.01 sV.

Historically, X rays were used as the reference radiation; however, gamma radiation is now frequently used as the reference radiation of choice. Based on some biological endpoints and on the physical characteristics of the deposition of energy, there is evidence that X rays are about twice as effective as gamma rays at very low doses. However, ICRP has given a weighting factor (WR) of 1 to all energies of all photon radiations.

Weighting factor (WR) of beta particles is 1;

Weighting factor of protons is 2;

Weighting factor of alpha particles, fission fragments, heavy nuclei – 20;

Weighting factor of neutrons – from 5 to 20 depending on their energy.

2. Effective Dose (E) - The effective dose (E) is the overall biological injury associated with radiation, which takes into account variations in equivalent dose

among different organs and tissues. This value is calculated by multiplying the equivalent doses for a number of different organs by tissue weighting factors.

The effective dose is defined as:

$$E= \sum_T * W_T * H_T$$

Where: W_T = tissue weighting factor that reflects the contribution of the tissue to the total detriment to human health when the body is uniformly irradiated.

H_T = the equivalent dose in tissue T.

The standard unit for effective dose is sievert (Sv).

Tissue weighting factors are based on studies of rates of cancer production in different organ systems after exposure to radiation. These factors are updated periodically by the International Commission on Radiological Protection (ICRP). ValuesofdifferenttissueweightingfactorsaregiveninTable1-3.

Table 1-3. Tissueweightingfactors.

Tissue	Tissueweightingfactor, W_T
Gonads	0,2
Bonemarrow (active)	0,12
Colon	0,12
Lungs	0,12
Stomach	0,12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0,1
Bonesurface	0,1
Remainder	0.05

Altogether	1.0

W_T = tissue weighting factor that reflects the contribution of the tissue to the total detriment to human health when the body is uniformly irradiated.

3. Sources of ionizing radiation:

There are 2 main sources of ionizing radiation:

1) Natural sources of radiation (background radiation, cosmic radiation, radon gas)
2) Artificial sources of radiation (medical x-rays, generating electricity from nuclear power, testing nuclear weapons, and producing a variety of common products such as smoke detectors which contain radioactive materials, can cause additional exposure to ionizing radiation)

The meaning of natural and anthropogenic sources of ionizing radiation:

- Naturalbackground – 70%
- Diagnostic medical examinations – 29%
- Nuclear Weapons Testing – 0.3%
- occupational exposure – 0.06%
- nuclear-power engineering– 0.006%

The largest contribution for radiation exposure (all types) to the population is from natural sources (two thirds); the other one-third is from anthropogenic sources, such as radiation from medical procedures, consumer products, and other (< 1%), which includes occupational exposures, nuclear fallout, and the nuclear fuel cycle. Natural background exposure may range from 1 to 10 mSv with some populations exposed to 10 to 20 mSv.

Medical use of ionizing radiation in both diagnosis and therapy has been widespread since the discovery of X rays by Wilhelm Conrad Roentgen in 1895. Advances in the latter half of the twentieth century brought about an increase in the uses of medical radiation, with some techniques, particularly radiotherapy, computed tomography, positron emission tomography, and interventional radiation involving fluoroscopy, involving higher doses than for standard diagnostic X rays.

Diagnostic X rays vary in exposure level but are generally low. In more developed countries, the use of rare-earth screens and fast film has significantly reduced the dose from many procedures. Plain film examinations of the chest and extremities involve relatively low doses (effective doses of perhaps 0.05 to 0.4 mSv), whereas studies involving the abdomen and lumbar spine or pelvis may result in higher doses (effective doses of around 1 to 3 mSv).

Fluoroscopic procedures involve much higher exposures, as the X-ray beam is energized for longer periods of time to allow observation of the movement of material, placement of catheters, and other processes. The effective dose may reach 1 to 10 mSv.

Use of computed tomography has become widely available in many developed countries. In contrast to plain-film radiography, tomographic techniques provide excellent visualization of soft tissue and good spatial resolution. The scans involve significantly higher doses of radiation (effective doses of perhaps 2.5 to 15 mSv) than plain film techniques. In contrast to plain film techniques, higher exposures always result in better quality images, so care is needed to optimize techniques to obtain the best diagnostic information possible while maintaining radiation doses as low as reasonably achievable.

In radiation therapy, the goal is to deliver high doses of radiation to cancer cells while minimizing doses to normal tissues. For some patients, such as those with limited survival potential, the goal is not to cure the disease but merely to palliate pain.

Doses of radiation used in therapeutic nuclear medicine are of course much larger than those used in diagnosis.

Occupational exposure:

According to IARC (2000), approximately 5 million workers worldwide are exposed to natural sources of radiation at levels above background. About 75% are coal miners, about 13% are underground miners in non-coal mines, and about 5% are crews on airlines.

Workers involved in the production of nuclear weapons are exposed to a large number of radionuclides and types of radiation. Workers in reactors are exposed primarily to gamma radiation and beta radiation from fission products and neutron activation products. Fuel reprocessing and separation of weapons materials results in workers being exposed first to gamma radiation from the fission products and then to alpha radiation from plutonium, uranium, and americium during fuel reprocessing.

There are maximum permissible radiation doses (according to the IARC)

- For the staff (for professional employees, who have permanent contact with the sources of ionizing radiation) – 20 mSv, but not more than 50 mSv per year;
- For other people – 1 mSv, but not more than 5 mSv.

What concerning ordinary people, which occupation doesn't associate with ionizing radiation, annual approximate per capita dose from natural and anthropogenic sources for them is about 3-4 mSv.

Table 1-4. Average annual doses from different sources (natural and artificial) of ionizing radiation.

The source of ionizing radiation	The dose, mSv (per year)
Background radiation	2
Builder's supplies	1,4
Nuclear-power engineering	0,002
Medical examinations	1,4

Nuclear tests	0,025
Plain flight	0,005
Utility (household) devices	0,04
TV-set and PC	0,001
Altogether (common dose)	5

Table 1-5. Approximate mean effective doses from diagnostic radiological procedures

Medical procedure	Average dose (mGy) per examination
Chestradiography	1
Chest fluorography	5
Chest fluoroscopy	5 – 10
AbdominalX-rayexamination	10 - 20
Radiationtherapy	2000 - 10000

Questions for self-control.

1. Types of ionizing radiation.
2. Particulateionizingradiation.
3. Electromagneticradiation.
4. Radiation exposure. Characteristic and SI unit.
5. Absorbed dose. Characteristic and SI unit.
6. Equivalent Dose. Characteristic and SI unit.
7. Effective Dose. Characteristic and SI unit.
8. Maximumpermissibleradiationdoses.

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