

# Ionising Radiation

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## Definition

Ionizing radiation is a term used for radiation whose quanta have energy to directly or indirectly ionize (one or more electrons are released from the atom of the given substance) molecules or atoms while passing through matter, hence the name ionizing radiation.

## Characteristics of Ionizing Radiation

Ionizing radiation has been classified as follows:

- **X-radiation** - These are photons with low energy, in the range 120 eV to 120 keV. They have a shorter wavelength than UV rays and longer than gamma rays. X-radiation is also called Röntgen radiation. Named after Wilhelm Conrad Röntgen, the discoverer of its existence, and the man who named it X-radiation. The "X" standing for an unknown type of radiation.
- **Gamma radiation** - Photons with higher energy than x-rays. Gamma, or  $\gamma$ -radiation is electromagnetic radiation of high frequency (very short wavelength). It consists of frequencies above 10 exahertz (or  $>10^{19}$  Hz), and therefore have energies above 100 keV and wavelength less than 10 picometers, less than the diameter of an atom.
- **Alpha radiation** - This type of radiation does not consist of photons but rather, particles. More specifically  $\text{He}^{2+}$  particles, i.e. Helium nuclei.
- **Beta radiation** - This consists of a stream of electrons or positrons
- **Neutron radiation** - This consists of a neutron stream (free neutrons). The stream of free neutrons reacts with nuclei of other atoms forming new isotopes resulting in a chain reaction. Nuclear fission or fusion, consists of the release of free neutrons from atoms in the first place. The chain reaction makes radiation this dangerous and harmful over great areas of space.

## Basic Terminology and Units

The quantity determining the amount of radioactive substance is "Activity" (characterized by the mean number of radioactive decays per unit time) Becquerel = 1 decay per second. However, the basis for the description of the biological effects of ionizing radiation and the fundamental dosimetric quantity in radiological protection, is the "Absorbed dose". The absorbed dose is measured in Gray ( $\text{Gy} = \text{J/Kg}$ ). The dose is defined for any substance and any type of radiation. On the other hand, even when the dose is equal, the response after irradiation with different types of IR may differ, depending in particular of the density of ionization. These differences are designated as relative biological effectiveness of radiation and are taken into account in the definition of the quantity, "Equivalent dose" (H), the unit of which is 1 Sievert ( $\text{Sv} = [\text{J/Kg}] \times \text{quality factor}$ )

## Main Sources of Ionizing Radiation

- Nature, background;
- Medical exposure (x-ray examination, radio-therapy);
- Nuclear energetic and liquidation of radio-active waste;
- Mining of radio-nuclides;
- Objects of common usage (very old TV and computer tubes, some types of phosphorescent matters);
- A special type of exposure of a mammalian organism is internal exposure (contamination), i.e. entry of radioactive material into the body via inhalation, ingestion or injured skin.

## Biological and Health Effects of Ionizing Radiation (IR)

IR interacts with living matter in the same way as with matter in general. However one of the striking differences is the high level of hierarchy organization of living systems. Another characteristic feature of living matter is its capability of self-reparation that modifies the significance primary injury.

## Direct Vs Indirect Effects of Ionizing Radiation

Random distribution of energy may damage vital parts of dsDNA or other important macromolecules in the cells in several ways. Chromosomal aberrations are a result of DNA damage.

The direct effects of IR result from the ability of IR to cause DNA breaking through direct ionization of genetic material. On the other hand, the indirect effects result from the ability of IR to ionize water into free radicals ultimately leading to a chain of events that are deleterious to the cells.

## **Long Term Effects**

### **Somatic Mutations**

Cell modifications can affect only the progeny of the dividing cells of those tissues. These are related to malignant transformation (potential capability of unlimited cellular proliferation). The interval between exposure and detection of radiation-induced cancer is referred to as latency period. This period varies with type of cancer and age at exposure. The reason why the frequency of radiation induced neoplasia is considerably low is due to the fact that cells have the capability to self repair DNA damage.

Cancer: There is a long latency period. For leukemia the peak of incidence is between 5-15years, for lung cancer in uranium miners between 15-25years. It is assumed that a malignancy might appear as late as 40years after exposure.

### **Germline mutations**

Germline mutations of the reproductive tissues result in a variety of transmissible lesions. They may manifest as hereditary disorders.

## **Acute Effects**

The cellular basis of the effects of acute radiation in man is cell killing as applied to successive populations of the cell renewal system. The main feature of the cell renewal system can be best explained using the hematopoietic system as an example.

### **Acute Post-Irradiation Syndrome**

It manifests after a high dose whole-body irradiation greater than 1-2Gy delivered in a period between a few minutes and a few hours. Whatever the severity of injury or the clinical form, there will be an initial reaction characterized by nausea, vomiting, diarrhoea, a feeling of malaise and fatigue. This phase does not exceed a few hours. Then a latency period will follow which for doses less than 8Gy lasts from 5-14hours (in that time no symptoms). According to the dose received the symptoms occur either in the hematopoietic system, the GIT or the CNS.

### **The Hematopoietic Syndrome**

This results as a consequence of the attack on the medullary functions, halting the production of cells and leading to pancytopenia. (The first sign is regularly lymphocytopenia, which occurs already after  $>0,3\text{Gy}$ ; for a higher dose, from 4-5 Gy, granulocytopenia is observed followed by thrombocytopenia and finally even anaemia). The main clinical symptoms in fully developed disease are a tendency to bleed and sepsis as a result of the deterioration of defense mechanisms.

### **The Gastrointestinal Syndrome**

The most serious clinical form – the gastrointestinal syndrome – occurs after 6-8Gy and reflects radiation damage to intestinal mucosa and to small blood vessels in the submucosa. It is manifested after a short latency period of several days to one week by excessive depletion of liquids caused by vomiting diarrhea and hemorrhaging. Its prognosis is serious and it is always accompanied by irreversible medullary damage and leads to death in 10-14 days.

### **Acute Side Effects Witnessed during Radiotherapy**

These include damage to epithelial tissue, such as skin and mucosa (oral, pharyngeal and bowel mucosa), as mentioned previously. Also, edema can be another side effect of radiotherapy as part of the general inflammation that occurs

### **Skin Injury**

The precondition for developing skin injury is exceeding the threshold on IR similarly as in ARS (Acute Radiation Syndrome). A transient mild erythema caused by local hyperemia can be found within hours and lasts no more than 12 days. An erythematous dermatitis ("late erythema") manifests itself after a latency period of 8-20days following radiation with doses of 3-5 Gy. It heals in most situations rapidly and frequently it leaves a permanent pigmentation. An exudative radio-dermatitis appears about 8 days following exposure of 10-20Gy. With doses more than 20-40Gy a necrotic radio-dermatitis can occur. Ulceration appears after a few days and is seldom fully cured.

The hair system is very sensitive, and the temporary shedding of hair can occur after a dose of 4 Gy. Relapses of the 2° ulcer often require surgery (amputation).

## Medium Term Effects

### Effects of radiation on embryo or fetus

Irradiation applied during the processes of fertilization, blastogenesis and embryogenesis can disrupt the course of events. The resulting effects depend strongly on the phase of development. Irradiation between 1-3weeks after conception can rarely cause serious damage because of the great reparative capacity of the cells in those stages. Irradiation between 4-8weeks affects organogenesis (congenital malformations might appear as a result of such exposure). If 8-15weeks may lead to mental retardation.

### Fibrosis

Usually occurs after radiotherapy. This is the consequence of irradiated tissue tending to become less elastic over time due to a diffuse scarring process.

### Dryness (Xerophthalmia, Xerostomia)

Again mostly after radiotherapy. The salivary glands and lacrimal glands, have a radiation tolerance of about 30Gy in 2Gy fractions (radiotherapy is applied in fractions to minimize the detrimental effects of high doses of radiation, used in radiotherapy, on non-neoplastic/healthy tissue, allowing them time to repair), a dose which is exceeded by most radical head and neck cancer treatments. Similar effects can occur in sweat glands.

Basic criteria and principles of radiation protection

- 2 types of effects in mammals are recognized: 1) Deterministic (incl. acute post irradiation syndrome and acute skin injury; the dose-effect relationship is demonstrated on a graph as a sigmoid curve) and 2) Stochastic
- Stochastic effects: incl. malignant tumors and genetic disorders; here a straight line passing through the intersection of co-ordinates represents the dose-effect relationship.
- In the case of deterministic effects health protection can be fully ensured by non-exceeding the maximum permissible equivalent dose (limit) at a level sufficiently lower than the threshold.
- In stochastic effects, it is not possible to set an equivalent dose which is fully safe, as we assume that each equivalent dose, even the smallest one, is connected with an increase of probability of late effects. The only alternative safeguard is to apply the criterion of an acceptable risk.
- The activities to which radiation safety provisions apply are defined as “practices” or “interventions”
- Practices: are those human activities involving radiation exposures, or the potential of radiation exposure, for which radiation safety provisions can be planned in advance
- Interventions: are those human activities that seek to reduce or avert radiation exposures, or likely of incurring exposure, in those situations in which the sources are not part of a currently controlled practice or are out of control as a consequence of an accident
- To achieve the objectives of the protection of individuals and public health as they relate to practices, a system of protection founded on basic principles is needed:
  1. The practice should be justified (i.e. it produces sufficient benefit to the exposed individual and to society to outweigh the radiation detriment it may cause)
  2. For justified practice, other than those involving medical exposures, dose limits (to the total exposure [incl. all different sources]) are required in order to ensure that no person be subject to an unacceptable risk attributable to radiation.
  3. The number of people exposed to and the likelihood of incurring exposures all be kept as low as reasonably achievable (ALARA)
  4. All reasonable practicable measures shall be taken to enhance operational safety and to prevent radiation accident and lessen their consequences should they occur (safety of sources).

Common principles of health protection To minimisation of medical ionising radiation load, we use two types of optimisation methods to X-ray diagnostic and therapy:

1. Technical arrangement – i) Limitation of entry field, shield of non-irradiation body parts; ii) Sufficiently sensitive film materials and correct combination with folio make shorter exposure time, today also computer transmission without film use.  
iii) Limitation of skiascopic examinations
2. Organisational arrangement – is based in minimisation of non-necessary X-ray examinations i.e. good record-keeping of x-ray examination and good access to x-ray medical report; collaboration with radiologists from different wards in hospitals; as well as high caution by examination of sexual organs

Principles of protection against IR

- Distance – with square of distance is lowering absorbed E of radiation
- Shielding – material containing lead, plasters with barium carbonate (also tungsten)
- Time – shorten of exposure time

Types of radio-nucleides divided into two groups:

1. Sealed source of ionizing radiation  
A type of radionuclide, whose arrangement eliminate a possibility elusion of radioactive materials out of one, by anticipate conditions - cobalt bomb (complete arrangement)
2. Opened radio-nuclide
  - A type of radionuclide, which don't answer to qualification of a sealed source of ionizing radiation – various radioisotopes, (radiopharmaceutical materials)
  - Work with liquid substances, not with powdered materials (danger of inhaling or spilling)
  - Work in small space – protection box, fume chamber
  - Work with minimum necessary quantity of substance

Basic quantities in ionising radiation problems:

- Absorbed dose (D)  
This is energy absorbed per unit mass and its unit is the joule per kilogram, which is given a specname Gray.
- Equivalent dose (H) – Even when the dose D is equal, the response after irradiation with different types of ionising radiation is differ. Relative biological effectiveness of radiation - definition of the quantity equivalent dose (H), the unit of which is one Sievert.
- Activity – Determining the amount of a radioactive substance. The mean number of radioactive decays per unit time determined it. Its dimension is  $s^{-1}$ . This unit has a special denotation Becquerel.

Health contraindication to work in external irradiation risk

- Pregnancy or lactation
- Age lower than 18years
- Blood diseases and bleeding diseases
- Skin carcinomas and skin precarcinomas
- Ovarian insufficiency
- Vascular disorders
- Organic disorders of nervous apparatus
- More serious neurosis
- Blood pressure above normal limits
- Skin disorders
- Cataract