Dosimetry

The dosimetry of ionizing radiation is based on the basic property of this radiation, which is to create negative and positive ions in the substance through which it passes (ionize) or to cause physical phenomena in the substance that are measurable and in some way dependent on the amount of radiation to which the given substance was exposed (e.g. change in conductivity, temperature, color, emergence of thermoluminescence etc.).

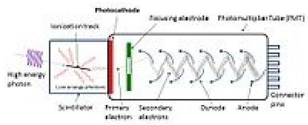
Using different methods of dosimetry, we can characterize **the properties of the radiation source**, the radiation field or the effects of radiation on the substance it passes through - including tissues and living organisms. The quantity that characterizes the source of radiation is the *activity* given in **Bq** (becquerel). The radiation field can be described by *particle fluence* (the number of particles incident on a unit area). The basic quantity by which we characterize the effect of radiation on the substance through which it passes is the *absorbed dose*. The absorbed dose is the amount of energy transferred to the substance by radiation, the dose unit is 1 **gray** (Gy) with the dimension $J.kg^{-1}$.

There are many types of dosimeters, which can be divided into two basic groups, depending on whether they provide information **continuously** – this mainly includes ionization chambers, Geiger-Müller computers, semiconductor detectors, scintillation detectors, electronic dosimeters − or the information about the amount of energy is accumulated in them somehow and is evaluated with the help of some suitable evaluation device − these are **integral** dosimeters - this mainly includes film, thermoluminescent or photoluminescent dosimeters. These dosimeters are also the most commonly used nowadays in personal dosimetry. The use of electronic personal dosimetry is also expanding.

Ionization chamber

The ionization chamber consists of two electrodes (anode and cathode) placed in a gaseous environment. Under normal circumstances (without the presence of radiation) no current flows through the system - the gas between the electrodes is non-conductive, the circuit is not closed. However, if ionizing radiation penetrates the space between the electrodes, it knocks out electrons from the initially neutral gas atoms and turns them into positive ions. Negative electrons travel in the electric field immediately to the positive anode, positive ions move to the negative cathode - a weak electric current starts to flow through the circuit caused by the ionic conductivity of the ionized gas between the electrodes. The current is directly proportional to the intensity of the ionizing radiation.

Scintillation detectors



Scintillator

Scintillation detectors convert the absorbed energy of ionizing radiation into the energy of photons usually belonging to the visible short-wave or near-ultraviolet region of the spectrum. Scintillation detectors are among the most widely used ionizing radiation detectors. Their advantage, in addition to good spectrometric properties, also lies in the fact that the detection medium, the scintillator, can have different dimensions and almost any shape. At the same time, the weight of the scintillating substances is large enough so that a relatively high detection efficiency can be achieved, especially for gamma radiation. The scintillation detector also gives an output signal, whose further processing usually does not require the use of sensitive amplifiers.

Ionization chambers in the dosimeter

Semiconductor detectors

Semiconductor detectors are based on **ionization effects in solids**. If an ionizing particle penetrates a suitable semiconductor, it creates an electron − hole pair by ionizing it, while most of the primary electrons have such a high energy that they cause further impact ionization of the environment. There is an avalanche-like release of electrons into the conduction band and the formation of holes in the valence band, so the number of released charge carriers depends on the energy of the primary particle. If we apply a voltage to this semiconductor, then due to the electric field, the free charge carriers (electrons and holes) will move in the appropriate direction and a current impulse will arise in the connected circuit, whose size depends on the energy of the incident particle of ionizing radiation. This makes it possible to use semiconductor detectors both for the detection of ionizing radiation and for spectrometric measurements.

Film dosimeters

Film dosimeters are based on the fact that the action of ionizing radiation produces a so-called *latent image,* which can be made visible by the developing process, and the resulting blackening (optical density), which can be measured, is dependent on the degree of film irradiation. The dosimetric film is covered on both sides with a set of filters, and thanks to this the radiation energy and direction of irradiation can be determined. The dose from photons, electrons and neutrons can be measured using a film dosimeter. Among the advantages of the film dosimeter is the permanent recording of radiation data with the possibility of re-analysis of the developed film. The disadvantage is sensitivity to light, high humidity, temperature and some chemicals.

Thermoluminescent dosimeters

Thermoluminescent dosimeters are **suitable substances** in which ionizing radiation causes the excitation of electrons from the valence to the conduction band with subsequent capture in capture centers. By heating, the electrons then gain sufficient energy to leave the capture center and recombine with the simultaneous emission of ultraviolet radiation or visible light, which is detected using a photocathode and photomultipliers. The total radiated energy is proportional to the energy of the ionizing radiation absorbed in the substance. For the production of thermoluminescent dosimeters, various types of thermoluminescent materials are used, e.g. LiF (lithium fluoride), CaF_2, $MgBeO_4$, $CaSO_4$(Dy), etc. with different energy dependence and sensitivity for different types of radiation. The advantage of thermoluminescent dosimeters is their high sensitivity, the possibility of accurate measurement of the response, a relatively wide range of linear dependence between the dose and the response of the dosimeter, the possibility of repeated use of the dosimeter and also the possibility of using substances with properties close to human tissue. The disadvantage of thermoluminescent dosimeters is their sensitivity to light and pollution.

Radiophotoluminescent dosimeters

The essence of the radiophotoluminescent dosimeter is **photoluminescence**, which is based on the principle of the formation of luminescence centers induced by ionizing radiation in certain substances (e.g. phosphate glasses doped with silver). Luminescence is excited by illuminating the irradiated detector with ultraviolet light. As with the thermoluminescent dosimeter, the emitted light is proportional to the dose of ionizing radiation absorbed in the detector. The advantage of the radiophotoluminescent dosimeter is the long-term stability of the response, constant and high sensitivity and low energy dependence. The disadvantage is the detectors' sensitivity to light.

Electronic personal dosimeters

Electronic personal dosimeters are gaining importance gradually with the development of miniaturization of electronics and the availability of computer technology. Generally, they work on the basis of **Geiger-Müller detectors or semiconductor** − Si-detectors. The disadvantage of electronic personal dosimeters is possible influence by electromagnetic radiation. Electronic personal dosimeters can be used autonomously or in conjunction with an evaluation device. All the mentioned dosimeters basically work in such a way that, based on calibration with a radiation source of known properties, they are calibrated in such a way that the size of the investigated response (e.g. luminescence) is related to the amount of applied radiation.

Radiation protection of workers with sources of ionizing radiation

When using ionizing radiation, it is necessary to establish certain rules so that there are no adverse effects of radiation on human health. These side effects are divided into two basic groups - **deterministic** and **stochastic**. Deterministic effects are effects that are acute and occur when a certain dose threshold is exceeded (this includes for example radiation sickness, burns, cataract etc.), the protection against them lies in preventing the threshold dose from being reached. Protection against stochastic effects is more complicated because we don't have such a threshold there (this includes different types of tumors, genetic damage).

Location of personal dosimeter

Limit values are set that must not be exceeded when using radiation sources. Determination of the absorbed dose in the case of living tissues and organisms does not yet tell us anything about the possible effect of the given radiation on this organism or tissue. It is necessary to take into account what **type of radiation** it is (alpha, beta, photons, neutrons, etc.), because individual types of radiation have **different effects** on the tissue − their so-called *biological effectiveness* differs. E.g. **alpha** particles are heavy charged particles and when they pass through matter they transfer their energy quickly on a relatively short section of their path− we say that they ionize densely − this is different for photons, which pass through matter easily and ionize sparsely − therefore it is also suitable to use them, for example, in imaging methods in medicine - radiodiagnosis. If we apply to the determined absorbed dose in a given tissue a coefficient that takes into account these properties of ionizing radiation and which we call the radiation weight factor, we arrive at the so-called **equivalent dose** If we want to evaluate the possible effects of whole-body irradiation, we must also take into account the sensitivity of individual organs and tissues to irradiation and the probability of the above-mentioned stochastic effects. This is taken into account in the so-called **tissue weight factor**. If we determine an equivalent dose for each tissue and weigh it by this factor and perform the sum over all tissues for which the factor is determined, we arrive at the so-called **effective dose**. The effective dose therefore also includes information about the severity of the amount of radiation to a living organism. The limit values for the exposure of workers are then determined in the equivalent dose for selected organs and tissues (thus limiting the occurrence of deterministic effects) or in the effective dose (reducing the probability of the occurrence of stochastic effects to an acceptable level).

The limit value of the effective dose or workers is given by legislation (Atomic Act) and is 100 mSv per 5 years and at the same time must not exceed 50 mSv per year. The limit value for e.g. the eye lens is 150 mSv per year, for limbs 500 mSv per year. Workers with sources of ionizing radiation (radiation workers) must be equipped with personal dosimeters or their dose is evaluated based on measurements at the workplace, so that it can be proven that they do not exceed the specified limits.

Links

Related Articles

- Ionizing radiation protection

References

- NAVRÁTIL LEOŠ, ROSINA JOSEF, ET AL,. *Medical biophysics.* 1 (reprint 2010) edition. Prague : Grada Publishing, a.s., 2005. 524 pp. ISBN ISBN 978-80-247-1152-2.