Radiation dosimetry

The unit of absorbed dose

- When ionizing radiation interacts with matter it deposits energy.
- Uncharged radiation like photons and neutrons perform this mainly in two steps where first charged particles are produced.
- Charged particles then deposit energy through excitations and ionizations.
- An important task in dosimetry is to determine the deposited energy both at the macroscopic and microscopic level.
- It is impractical to measure microscopic distribution and so a macroscopic assessment of absorbed energy is made quantified by the SI unit of absorbed dose – The gray.
- **The gray : is the SI unit for absorbed radiation dose**
- **The absorbed dose (*D*):**

  Is the energy deposited by a given radiation in a unit mass of matter .

  Mathematically, the absorbed dose (D) is the quotient of the mean energy imparted by ionizing radiation (d*e*) to matter of mass (d*m*) .

$$D = \frac{de}{dm}$$

1 gray = 1 joule per kilogram **(1 Gy = 1Jkg $^{-1}$).**

The unit of absorbed dose is the Gray (mGy , µGy)

How to measure the absorbed dose ?

Calorimetry

- ***Calorimetry* : is one method of measuring absorbed dose** whereby the precise quantification of minute temperature changes in irradiated samples are used to produce direct evidence of the energy absorbed during the process, because the heat energy absorbed by a sample is proportional to the absorbed dose.
- Calibration of local ionization detectors against a national calorimetric standard also exists for a range of megavoltage photon qualities; however, calorimetry is not always practicable because it suits the measurement of large absorbed quantities of radiation under very controlled conditions. **(تعليل)**
- Therefore there are other preferred methods for less energetic X - rays and electrons. The first step is to specify a unit of ionization that is compatible with absorbed dose.

Radiation Exposure

Radiation exposure (X) : it is the absorbing of radiation by the human body

It occurs in tow methods :

1 - External exposure , outside the body (like an X-ray)

2 - Internal exposure, Radioactive material inside the body (from inhaling, ingesting, or absorbing it through the skin or open wounds).

Mathematically, the Radiation Exposure (X) is the quotient of the absolute value of the total charge of the ions (dQ) to matter of mass (dm) .

$$X = \frac{dQ}{dm}$$

- The SI unit of exposure is coulombs per kilogram (Ckg^{-1}). This definition explicitly defines exposure for photons interacting with a defined mass of air and no other radiation particles or irradiated medium.
- To determine the exposure at some point within any other medium, it is necessary to replace a small part of that material with a volume of air small enough to prevent disruption of the photon field.
- The process covered by this definition thus comprises two stages.

- First, photons interact with the air to produce electrons (by photoelectric absorption or Compton scatter) or electrons and positrons (by pair production).
- Second, these electrons and positrons diffuse though the air causing more ionization. Exposure is thus the collection of all the ions of one sign when the energy of all subsequent particles has been completely dissipated.

Then, the absorbed dose in air (D_{air}) is :

$$D_{air} = X \frac{W}{e}$$

Where , X = The exposure , e = the charge electron ,
W = the mean energy expended in the formation of one ion – pair .

where W_{air} = average energy absorbed in the production of a single ion -pair in air (33.85 eV) , e = charge on each ion then .. W_{air} /e = 33.85JC $^{-1}$

A_{mat} = mass energy absorption coefficient for material

and A_{air} = mass energy absorption coefficient for air.

Although the concept of exposure satisfies the mathematical requirements of the derivation of dose, there are obvious practical problems when attempting to irradiate a defined mass of air while leaving a surrounding volume sufficient to attenuate the secondary particles, unirradiated.

External Dosimetry

- External dosimetry is the measurement of dose when the radiation source is outside of (or external to) the body. Therefore, in terms of dose to humans, external dosimetry is concerned with radiation that can penetrate the skin: beta, photon, and neutron radiation.
- Since photons and beta interact through electronic forces (interactions between charged particles) and neutrons interact through nuclear forces, their detection methods and dosimetry are substantially different.
- The fundamental basis of external dosimetry is the determination of the absorbed energy in matter and, more specifically, human tissue.

Dosimeters

A dosimeter: is a small radiation detection device worn by an individual, used to **measure doses** from ionizing radiation.

Radiation Units

Radioactivity – 1 Becquerel (Bq)= 1 radioactive decay per second

Absorbed dose – 1 Gray (Gy) = the absorption of one joule energy (in the form of ionising radiation) by one kilogram of matter

Equivalent dose (biological effect) – Sievert (Sv) the unit of absorbed dose equivalent for the body, based on the damaging effect for the type of radiation (W_R) and the biosensitivity of the exposed tissue (W_T). (Note: 1 Sv = 100 rem)

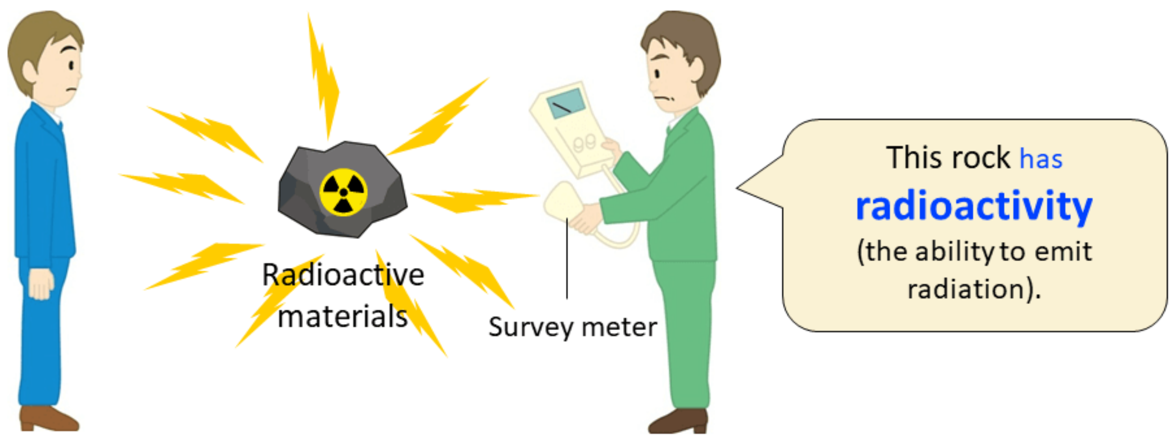
$$Sv = Gray \times W_R \times W_T$$

International Commission on Radiological Protection (ICRP):

Annual Dose Limit (public) = 1 mSv
Annual Dose Limit (workers) = 20 mSv

Radiation and Radioactivity

Units of Radiation and Radioactivity



General characteristics

Dosimeters are classified into two general categories, passive and active:

1. **A passive dosimeter** produces a radiation-induced signal, which is stored in the device. The dosimeter is then processed and the output is analyzed.

2. **An active dosimeter** produces a radiation-induced signal and displays a direct reading of the detected dose or dose rate in real time.

- Dosimeters used to estimate effective doses are typically worn between the waist and the neck, on the front of the torso, facing the radioactive source.
- Dosimeters worn on the torso are often called whole-body dosimeters.
- Dosimeters may also be worn on the extremities or near the eye to measure equivalent dose to these tissues.

Choosing a dosimeter

There are many types of dosimeters, and each type has limitations. Many factors influence the quality of a dosimeter's results.

Some key considerations when choosing a dosimeter include:

1. Energy dependence and angle dependence: A dosimeter's response will vary depending on the energy of the radiation and the angle(s) between the source and the dosimeter's detector.

2. Radiation type to be detected: Dosimeters vary in their abilities to detect different kinds of radiation (alpha, beta, photon or neutron).

3. Fading: A dosimeter's signal can be lost or fade over time. This can be caused by external factors such as temperature, light and humidity.

4. The ability to be re-read: Certain types of dosimeters lose their signals upon processing. Others retain their signals and can therefore be processed more than once.

5. Minimum measurable dose or limit of detection (the lowest dose that can be measured with a certain specified confidence level): Some dosimeters are more sensitive and can detect a lower quantity of radiation than others.

6. Ruggedness and ease of wear: Dosimeters differ in their ability to withstand severe environmental conditions, and some are smaller, lighter and more portable than others.

Dosimetry for photon and beta radiation

- Photon radiation has greater penetrating power than alpha and beta radiation. Alpha radiation cannot penetrate the outermost dead layer of human skin, so it poses no external human health hazard.
- Beta and photon radiation are hazardous to the skin and the eye, as they can deposit energy in the sensitive cells of these tissues. Beta radiation does not pose a significant risk to organs under the skin, since it typically cannot penetrate this deeply. The penetrating ability or probability of interaction of radiation is related to the radiation's energy.
- For example, tritium (H-3) is a nuclear substance that emits only beta radiation with an average energy of 6 kiloelectronvolts. This level of energy is too low to penetrate any more deeply than the dead layer of human skin. Therefore, external beta radiation from tritium is not a hazard; tritium presents solely an internal radiation hazard.
- **A typical dosimeter consists** of a detector inserted in a holder. Various dosimeters are configured differently; in general, **the detector contains the sensitive element(s)** and **the holder contains the filter(s)**.
- In a dosimeter that measures photon and beta radiation, it is mainly the filter/holder that permits the instrument to differentiate between the equivalent dose to the skin or eye and the effective dose. One part of the holder may have an open window (no filter or a very thin filter) to measure equivalent dose to skin, and the other part of the detector may have a thicker filter that allows for measurement of effective dose. The thicker filter or filters shield the low-energy photons and beta radiation and allow only the more penetrating radiation to deposit energy.
- Some dosimeters have several filters of different thickness and composition that allow them to discriminate among different energy levels.

Types of dosimeters for measuring beta and photon radiation

There are many types of dosimeters for measuring beta and photon radiation, as below:

1. Film dosimeters.
2. Thermoluminescent dosimeters (TLDs).
3. Optically stimulated luminescence dosimeters (OSLDs).
4. Direct reading dosimeters (DRDs).