Radiation Dosimeters

DOSE CONCEPTS

When ionizing radiation penetrates matter, such as the human body, it deposits energy. The energy absorbed per unit mass from exposure to radiation is called a dose. Three different radiation dose quantities are presented absorbed dose, equivalent dose, and effective dose. Figure 1 summarizes the relationship between these dose quantities.

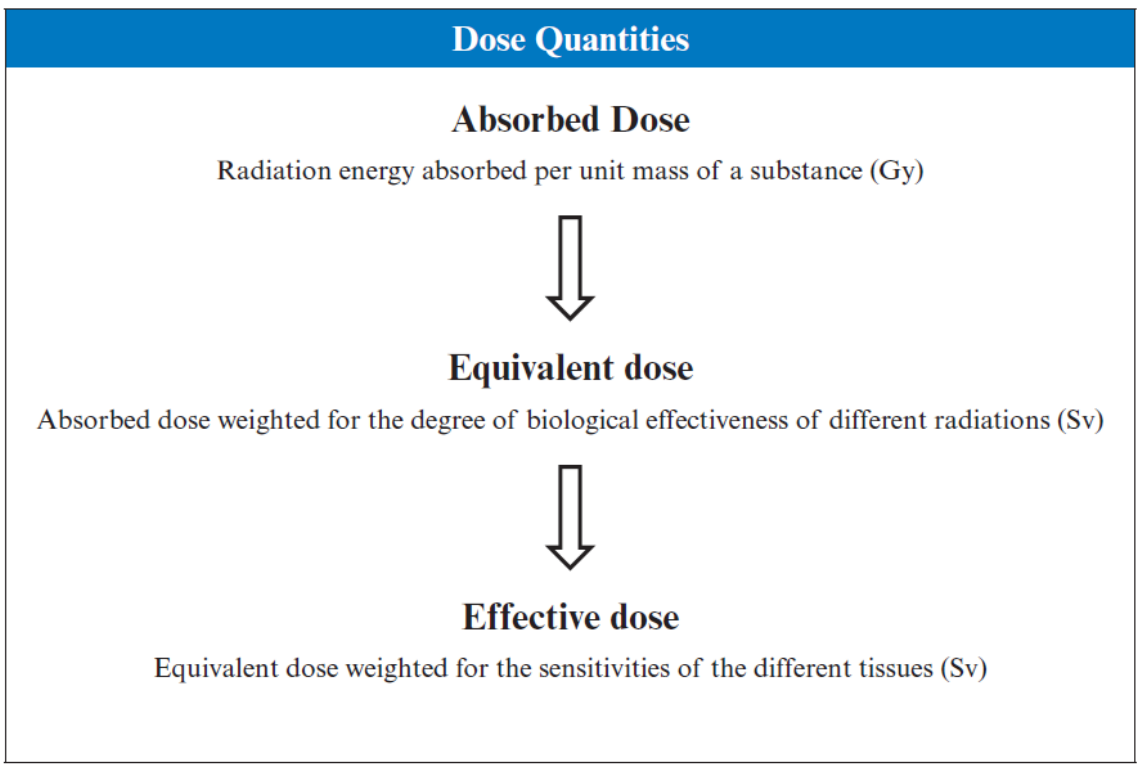

FIGURE 1. Relationship between absorbed dose, equivalent dose and effective dose.

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- **Absorbed dose**

Absorbed dose is the amount of energy deposited per unit mass in a substance (such as human tissue). It is measured in a unit called the gray (Gy). A dose of 1 gray is equivalent to 1 unit of energy (joule) deposited in 1 kilogram of a substance.

The gray is defined as: 'The absorbed dose (D) is the quotient of **de** by **dm,** where **de** is the mean energy imparted by ionizing radiation to matter of mass **dm** . '

$$D = de/dm$$

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

There are several methods for measuring absorbed dose, particularly in the context of ionizing radiation. The choice of method depends on factors such as the type of radiation, the energy range, the accuracy required, and the specific application. Here are some common methods:

1. Ionization chambers
2. Thermoluminescent Dosimeters (TLDs)
3. Film Dosimetry:
4. Solid-State Detectors
5. Calorimetry
6. Chemical Dosimeters

- **Equivalent dose**

When living matter absorbs radiation, the radiation can produce a biological effect. Since different types of ionizing radiation vary in how they interact with biological materials, absorbed doses of equal value do not necessarily have equal biological effects.

For example, 1 Gy of alpha radiation is more harmful to tissue than 1 Gy of beta radiation. This is because an alpha particle is more heavily charged and deposits its energy much more densely along its path.

The concept of equivalent dose allows different types of ionizing radiation to be considered equally with respect to their potential to cause harm. Equivalent dose is expressed in a unit called the sievert (Sv). It can therefore be stated that an equivalent dose of 1 Sv of alpha radiation will, on average, have the same biological effectiveness as an equivalent dose as 1 Sv of beta radiation.

- **Effective dose**

Different tissues and organs may vary in how they respond biologically to a given type of radiation. For example, a given equivalent dose (per sievert) has a higher risk of inducing fatal cancer in the lung than in the thyroid gland. Effects can be different both in type and magnitude and must be considered when assessing radiation exposure's overall detriment to human health. This is taken into account by multiplying the equivalent dose to an organ or tissue by its respective weighting factor (W_T).

Weighted doses can be calculated for each organ or tissue using their respective weighting factors, and then added together to provide a total effective dose to the body as a whole. Organ and tissue weighting factors consider the relative susceptibility of a body part to cancer, death and hereditary effects. Effective dose is also expressed using the sievert (Sv).

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.

About dosimeters

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

General characteristics

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

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

*****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.

While all dosimeters have advantages and disadvantages, an ***ideal*** instrument would have the following qualities:

1) Low energy dependence and angle dependence.

2) The ability to detect several radiation types.

3) High resistance to fading (stability when exposed to high temperatures and humidity levels).

4) A linear response to dose (response does not change with increasing dose).

5) A low minimum measurable dose.

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.

There are many types of dosimeters for measuring beta and photon radiation. These include film dosimeters, thermoluminescent dosimeters (TLDs), optically stimulated luminescence dosimeters (OSLDs), and direct reading dosimeters (DRDs).

Thermoluminescent dosimeters

Thermoluminescence is a form of light emission exhibited by certain materials. This phenomenon occurs when previously absorbed energy from radiation is re-emitted as light, when the material is heated.

Since the 1950s, there has been extensive research on thermoluminescence and its application in dosimetry. This research, which was only widely applied beginning in the 1970s, guided the development of the TLD – which is now the most commonly used type of dosimeter around the world.

*********The TLD system consists of a dosimeter and a reader, both of which play a key role in determining dose and dose accuracy.***

The following basic overview explains how a TLD works:

1. When ionizing radiation passes through the detector (chip), its atoms release some of their electrons.
2. The electrons eventually become trapped in impurities (also called doping centres) within the dosimeter, where they remain in their excited state (a state in which their energy is elevated relative to the ground state).

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3. The chip is then heated in a TLD reader (consisting mainly of a heater, a photomultiplier tube8 and a recorder), and the trapped electrons return to the ground state and emit photons of visible light. The amount of light emitted relative to the temperature is called the glow curve. This curve is analyzed to determine the dose.

There are many types of TLDs. These include lithium fluoride, calcium sulphate and lithium borate dosimeters, each of which has advantages and disadvantages.

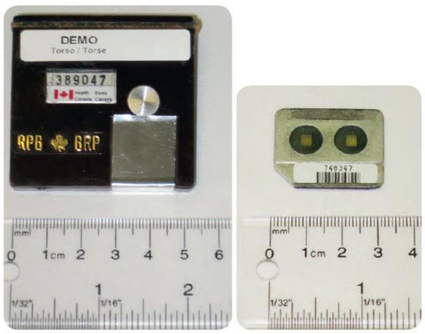

FIGURE 1. A whole-body thermoluminescent dosimeter badge (left), and the detector found inside (right).

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