

## 8.4: Radiation measurements

### Radioactivity measurement

Radioactivity is measured in terms of the rate of radioactive events. Nuclear radiations are ionizing radiations, i.e., they knock off electrons from atoms or molecules that come in their path, leaving behind cations. Geiger Muller counter is one of the radiations measuring instruments that counts the disintegration of radionuclide per second by registering the current produced by the ionization action of the radiation, as illustrated in Fig. 8.4.1. It is not just one ionization event; the nuclear particle keeps ionizing the atoms in its track until its energy is exhausted, as illustrated in Fig. 8.4.2. The instrument records the flash of electric current produced by the ionization of each radioactive disintegration.

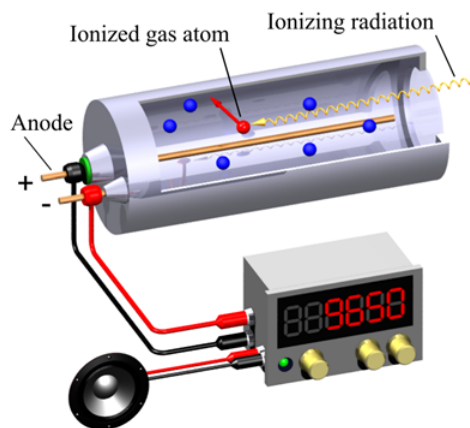


Figure 8.4.1: Geiger-Mueller counter. Source source Svjo-2 / CC BY-SA (<https://creativecommons.org/licenses/by-sa/3.0>)

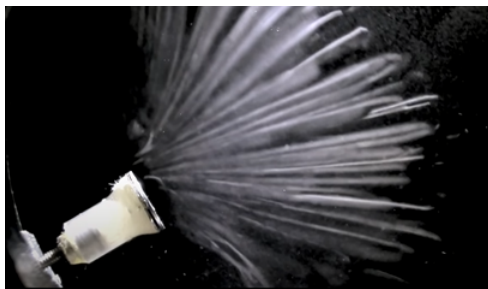


Figure 8.4.2: Tracks of  $\alpha$ -particles from americium-241 made visible in a cloud chamber. Source: <https://youtu.be/noP7HT-Uins>

#### Becquerel (Bq)

The SI unit of radioactivity is Becquerel (Bq), i.e., the number of nuclei that disintegrate per second.

The common unit of radiation intensity is Curie (Ci), i.e.,  $3.7 \times 10^{10}$  disintegrations per second. The relationship between Becquerel and Curie is the following.

$$1\text{Ci} = 3.7 \times 10^{10} \text{ Bq} = 3.7 \times 10^{10} \text{ disintegrations}$$

Often the radioisotope for medical use has the information of millicurie per milliliter (mCi/mL) from which the volume for the desired dose can be calculated.

#### ✓ Example 8.4.1

A patient must be given a 5.0 mCi dose of iodine-131 that is available as  $\text{Na}^{131}\text{I}$  solution containing 3.8 mCi/mL. What volume of the solution should be administered?

#### **Solution**

Use the reciprocal of 3.8 mCi/mL as a conversion factor:

$$5.0 \text{ mCi} \times \frac{1 \text{ mL}}{3.8 \text{ mCi}} = 1.3 \text{ mL dose}$$

## Radiation exposure measurements

### Absorbed dose

The ionizing radiation dose or called the absorbed dose is measured in terms of energy deposited by ionizing radiation in a unit mass of matter being irradiated, as illustrated in Fig. 8.4.3

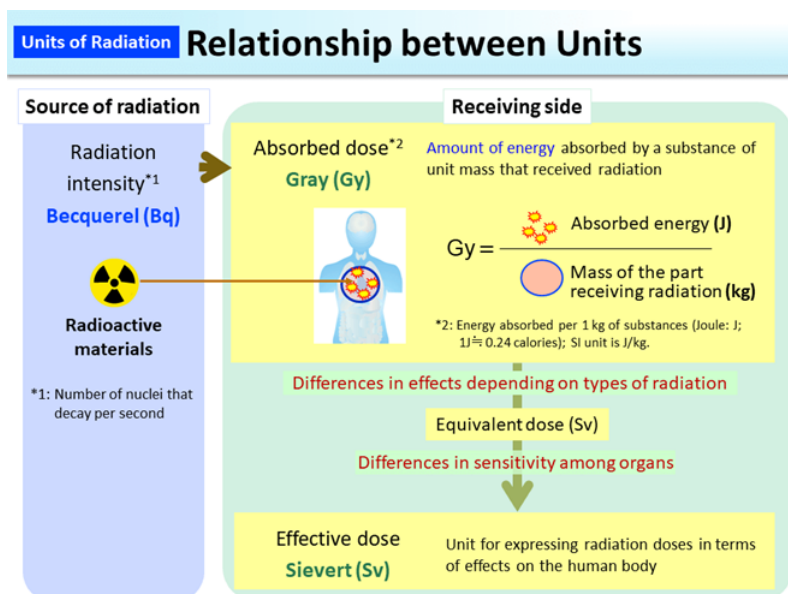


Figure 8.4.3: Source: Ministry of the Environment of Japan website, <https://www.env.go.jp/en/chemi/rhm/b...g-02-03-03.png>

#### Gray (Gy)

The SI unit of absorbed dose is gray (Gy) which is defined as the absorption of one joule of radiation energy per kilogram of matter (J/kg).

The common unit of absorbed dose is rad, which stands for radiation absorbed dose. The rad is one-hundredth of a gray, i.e.:

$$1 \text{ Gy} = 100 \text{ rad}$$

### Equivalent dose

The same amount of energy deposited in tissues by different types of radiation carries different levels of health risks in terms of causing cancer and genetic damage, expressed as a radiation weighting factor ( $W_R$ ), as illustrated in Fig. 8.4.4, and listed in Fig. 8.4.5. For example, 1 Gy of beta-particles carries a risk of 5.5% chances of eventually developing cancer, while 1 Gy of alpha-particles has 20 times more risk compared to the  $\beta$ -particle (ref.: <https://en.Wikipedia.org/wiki/Sievert>, accessed on 07/15/2020). The health risk of the ionizing radiation is measured in the units of equivalent dose. Sievert (Sv) is an SI unit of an equivalent dose of ionizing radiation that measures the health effects of low levels of ionizing radiation on the human body.

#### Sievert (Sv)

The equivalent dose in Sievert (Sv) is equal to the product of absorbed dose in grays (Gy) multiplied the radiation weighting factor ( $W_R$ ), i.e., The equivalent dose in Sv = Absorbed dose in Gy  $\times$   $W_R$

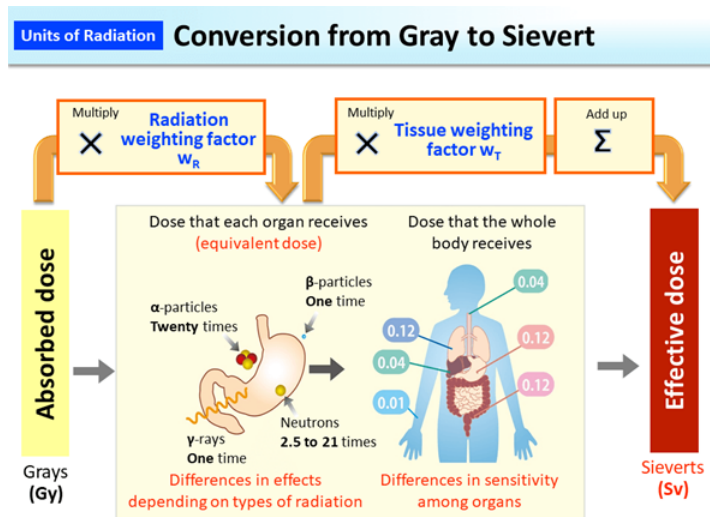


Figure 8.4.4: Illustration of radiation equivalent dose, effective dose, radiation weight factors ( $w_R$ ), and tissue weighting factors ( $w_T$ ). Source: Ministry of the Environment of Japan website, <https://www.env.go.jp/en/chemi/rhm/b...g-02-03-04.png>

| Radiation   | Energy (E)     | $w_R$ (formerly Q)                              |
|---|----------------|---|
| x-rays, gamma rays, beta particles, muons               |                | 1   |
| neutrons  | < 1 MeV        | $2.5 + 18.2 \cdot e^{-[\ln(E)]^2/6}$            |
|   | 1 MeV - 50 MeV | $5.0 + 17.0 \cdot e^{-[\ln(2 \cdot E)]^2/6}$    |
|   | > 50 MeV       | $2.5 + 3.25 \cdot e^{-[\ln(0.04 \cdot E)]^2/6}$ |
| protons, charged pions                                  |                | 2   |
| alpha particles, Nuclear fission products, heavy nuclei |                | 20  |

Figure 8.4.5: Radiation weighting factors  $w_R$  used to represent relative biological effectiveness according to ICRP report 103, Source of data: <https://en.Wikipedia.org/wiki/Sievert>, accessed on 07/16/2020

The common unit of equivalent dose is rem (rem stands for roentgen equivalent man), which is:

$$1 \text{ Sv} = 100 \text{ rem}$$

The personnel working in a radiation environment are required to wear film badges or electronic personal dosimeters, as shown in Fig. 8.4.6, that record the dose received. A record of each person's dose is usually maintained by the radiation facilities to comply with the allowed radiation exposure limits.



Figure 8.4.6: View of readout on an electronic personal dosimeter. The clip is used to attach it to the wearer's clothing. Source: Rama / CC BY-SA 2.0 FR (<https://creativecommons.org/licenses...2.0/fr/deed.en>)

### Effective dose

The equivalent dose is equal to the effective dose in sievert (Sv) when the whole human body is exposed equally to the radiation. If part of the body is exposed, then an effective dose in sievert (Sv) is calculated by the summation of the product of equivalent dose

in Sv with tissue weighting factor ( $W_T$ ) for each tissue exposed to the radiation, as illustrated in Fig. 8.4.4 and calculated with example in Fig. 8.4.7. The reason for this calculation is that the effect of the same equivalent dose is different in different tissues. The tissue weighting factors ( $W_T$ ) are listed in Table 1.

An effective dose takes the absorbed dose and adjusts it for radiation type and organ sensitivity, i.e.,:

$$\text{The effective dose in Sv} = \text{Equivalent dose in Sv} \times W_T$$

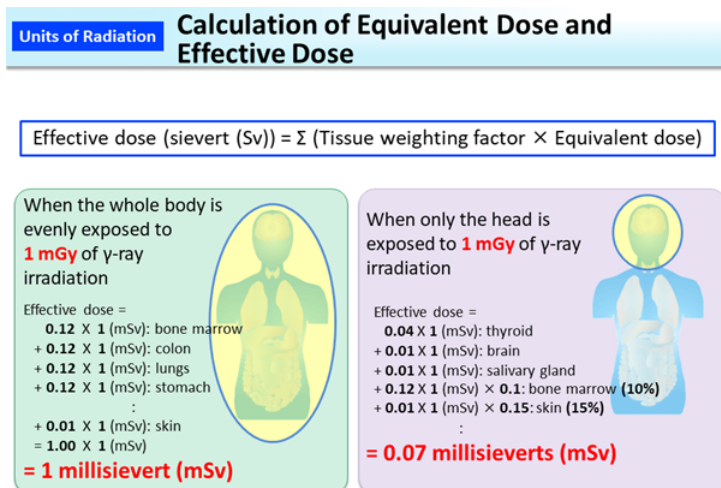


Figure 8.4.7: Example calculations of effective dose. Source: Ministry of the Environment of Japan website, <https://www.env.go.jp/en/chemi/rhm/b...g-02-03-06.png>

Table 1: Tissue weighting factors ( $W_T$ ) ICRP103 (2007), source of data: Source: <https://en.Wikipedia.org/wiki/Sievert>, accessed on 07/16/2020

| Organs            | $W_T$ |
|-------------------|-------|
| Gonads            | 0.08  |
| Red bone marrow   | 0.12  |
| Colon             | 0.12  |
| Lung              | 0.12  |
| Stomach           | 0.12  |
| Breasts           | 0.12  |
| Bladder           | 0.04  |
| Liver             | 0.04  |
| Oesophagus        | 0.04  |
| Thyroid           | 0.04  |
| Skin              | 0.01  |
| Bone surface      | 0.01  |
| Salivary glands   | 0.01  |
| Brain             | 0.01  |
| Remainder of body | 0.12  |
| Total             | 1.00  |

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