Canadian Centre for Occupational Health and Safety   Centre canadien d'hygiène et de sécurité au travail   Canada

> Radiation - Quantities and Units of Ionizing Radiation

Ask a Question
Feedback
Printer-friendly

What is ionizing radiation?
What are some examples of ionizing radiation?
What properties are considered when ionizing radiation is measured?
What units are used for measuring radioactivity?
What does half-life mean when people talk about radioactivity?
What units are used for measuring radiation energy?
What units are used for measuring radiation exposure?
What units are used for measuring radiation dose?
What effects do different doses of radiation have on people?
What are the limits of exposure to radiation?
What is the relationship between SI units and non-SI units?
What is a "committed dose"?
What is an "effective dose"?
What are "working level" and "working level month"?

What is ionizing radiation?

Ionizing radiation is radiation that has enough energy to remove electrons from atoms or molecules (groups of atoms) when it passes through or collides with some material. The loss of an electron with its negative charge causes the atom (or molecule) to become positively charged. The loss (or gain) of an electron is called ionization and a charged atom (or molecule) is called an ion.

What are some examples of ionizing radiation?

Forms of ionizing radiation include:

- Gamma rays
- X rays
- Alpha particles
- Beta particles
- Neutrons.

X rays refer to a kind of electromagnetic radiation generated when a strong electron beam bombards metal inside a glass tube. The frequency of this radiation is very high - 0.3 to 30 Ehz (exahertz or million gigahertz). By comparison FM radio stations transmit at frequencies around 100 MHz (megahertz) or 0.1 Ghz (gigahertz).

Some compounds like uranium are radioactive and give off radiation when the nucleus breaks down or disintegrates. The three kinds of radiation generated by radioactive materials or sources are alpha particle, beta particles and gamma-rays.

What properties are considered when ionizing radiation is measured?

Ionizing radiation is measured in terms of:

- the strength or radioactivity of the radiation source,
- the energy of the radiation,
- the level of radiation in the environment, and
- the radiation dose or the amount of radiation energy absorbed by the human body.

From the point of view of the occupational exposure, the radiation dose is the most important measure. Occupational exposure limits like the ACGIH TLVs are given in terms of the permitted maximum dose. The risk of radiation-induced diseases depends on the total radiation dose that a person receives over time.

What units are used for measuring radioactivity?

Radioactivity or the strength of radioactive source is measured in units of becquerel (Bq).

1 Bq = 1 event of radiation emission per second.

One becquerel is an extremely small amount of radioactivity. Commonly used multiples of the Bq unit are kBq (kilobecquerel), MBq (megabecquerel), and GBq (gigabecquerel).

1 kBq = 1000 Bq, 1 MBq = 1000 kBq, 1 GBq = 1000 MBq.

An old and still popular unit of measuring radioactivity is the curie (Ci).

1 Ci = 37 GBq = 37000 MBq.

One curie is a large amount of radioactivity. Commonly used subunits are mCi (millicurie), µCi (microcurie), nCi (nanocurie), and pCi (picocurie).

1 Ci = 1000 mCi; 1 mCi = 1000 µCi; 1 µCi = 1000 nCi; 1 nCi = 1000 pCi.

Another useful conversion formula is:

1 Bq = 27 pCi.

Becquerel (Bq) or Curie (Ci) is a measure of the rate (not energy) of radiation emission from a source.

What does half-life mean when people talk about radioactivity?

Radiation intensity from a radioactive source diminishes with time as more and more radioactive atoms decay and become stable atoms. Half-life is the time after which the radiation intensity is reduced by half. This happens because half of the radioactive atoms will have decayed in one half-life period. For example a 50 Bq radioactive source will become a 25 Bq radioactive source after one half-life.

Table 1 Radioactive Decay	
Number of half-lives elapsed	**Percent radioactivity remaining**
0	100
1	50
2	25
3	12.55
4	6.25
5	3.125

Half-lives widely differ from one radioactive material to another and range from a fraction of a second to millions of years.

What units are used for measuring radiation energy?

The energy of ionizing radiation is measured in electronvolts (eV). One electronvolt is an extremely small amount of energy. Commonly used multiple units are kiloelectron (keV) and megaelectronvolt (MeV).

6,200 billion MeV = 1 joule

1 joule per second = 1 watt

1 keV = 1000 eV, 1 MeV = 1000 keV

Watt is a unit of power, which is the equivalent of energy (or work) per unit time (e.g., minute, hour).

What units are used for measuring radiation exposure?

X-ray and gamma-ray exposure is often expressed in units of roentgen (R). The roentgen (R) unit refers to the amount of ionization present in the air. One roentgen of gamma- or x-ray exposure produces approximately 1 rad (0.01 gray) tissue dose (see next section for definitions of gray (Gy) and rad units of dose).

Another unit of measuring gamma ray intensity in the air is "air dose or absorbed dose rate in the air" in grays per hour (Gy/h) units. This unit is used to express gamma ray intensity in the air from radioactive materials in the earth and in the atmosphere.

What units are used for measuring radiation dose?

When ionizing radiation interacts with the human body, it gives its energy to the body tissues. The amount of energy absorbed per unit weight of the organ or tissue is called absorbed dose and is expressed in units of gray (Gy). One gray

dose is equivalent to one joule radiation energy absorbed per kilogram of organ or tissue weight. Rad is the old and still used unit of absorbed dose. One gray is equivalent to 100 rads.

1 Gy = 100 rads

Equal doses of all types of ionizing radiation are not equally harmful. Alpha particles produce greater harm than do beta particles, gamma rays and x rays for a given absorbed dose. To account for this difference, radiation dose is expressed as *equivalent dose* in units of sievert (Sv). The dose in Sv is equal to "absorbed dose" multiplied by a "radiation weighting factor" (W_R - see Table 2 below). Prior to 1990, this weighting factor was referred to as Quality Factor (QF).

Table 2 Recommended Radiation Weighting Factors	
Type and energy range	**Radiation weighting factor, WR**
Gamma rays and x rays	1
Beta particles	1
Neutrons, energy < 10 keV > 10 keV to 100 keV > 100 keV to 2 MeV > 2 MeV to 20 MeV > 20 MeV	5 10 20 10 5
Alpha particles	20

Equivalent dose is often referred to simply as "dose" in every day use of radiation terminology. The old unit of "dose equivalent" or "dose" was rem.

Dose in Sv = Absorbed Dose in Gy x radiation weighting factor (WR)

Dose in rem = Dose in rad x QF

1 Sv = 100 rem

1 rem = 10 mSv (millisievert = one thousandth of a sievert)

1 Gy air dose equivalent to 0.7 Sv tissue dose (UNSEAR 1988 Report p.57)

1 R (roentgen) exposure is approximately equivalent to 10 mSv tissue dose

What effects do different doses of radiation have on people?

One sievert is a large dose. The recommended TLV is average annual dose of 0.05 Sv (50 mSv).

The effects of being exposed to large doses of radiation at one time (acute exposure) vary with the dose. Here are some examples:

10 Sv - Risk of death within days or weeks

1 Sv - Risk of cancer later in life (5 in 100)

100 mSv - Risk of cancer later in life (5 in 1000)

50 mSv - TLV for annual dose for radiation workers in any one year

20 mSv - TLV for annual average dose, averaged over five years

What are the limits of exposure to radiation?

The Threshold Limit Values (TLVs) published by the ACGIH (American Conference of Governmental Industrial Hygienists) are used in many jurisdictions occupational exposure limits or guidelines:

20 mSv - TLV for average annual dose for radiation workers, averaged over five years

1 mSv - Recommended annual dose limit for general public (ICRP - International Commission on Radiological Protection).

What is the relationship between SI units and non-SI units?

Table 3 shows SI units (International System of Units or Systéme Internationale d'unités), the corresponding non-SI units, their symbols, and the conversion factors.

<table>
<tr><th colspan="4">Table 3
Units of Radioactivity and Radiation Dose</th></tr>
<tr><th>Quantity</th><th>SI unit and symbol</th><th>Non-SI unit</th><th>Conversion factor</th></tr>
<tr><td>Radioactivity</td><td>becquerel, Bq</td><td>curie, Ci</td><td>1 Ci = 3.7×10^{10} Bq
= 37 Gigabecquerels (GBq)
1 Bq = 27 picocurie (pCi)</td></tr>
<tr><td>Absorbed dose</td><td>gray, Gy</td><td>rad</td><td>1 rad = 0.01 Gy</td></tr>
<tr><td>"Dose" (Equivalent dose)</td><td>sievert, Sv</td><td>rem</td><td>1 rem = 0.01 Sv
1 rem = 10 mSv</td></tr>
</table>

What is a "committed dose"?

When a radioactive material is gets in the body by inhalation or ingestion, the radiation dose constantly accumulates in an organ or a tissue. The total dose

accumulated during the 50 years following the intake is called the committed dose. The quantity of committed dose depends on the amount of ingested radioactive material and the time it stays inside the body.

What is an "effective dose"?

The effective dose is the sum of weighted equivalent doses in all the organs and tissues of the body.

Effective dose = sum of [organ doses x tissue weighting factor]

Tissue weighting factors (Table 4) represent relative sensitivity of organs for developing cancer.

Table 4 Tissue Weighting Factors for Individual Tissues and Organs	
Tissue or Organ	**Tissue Weighting Factor (WT)**
Gonads (testes or ovaries)	0.20
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid gland	0.05
Skin	0.01
Bone surfaces	0.01
Remainder**	0.05
Whole body	1.00

** The remainder is composed of the following additional tissues and organs: adrenal, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus.

What are "working level" and "working level month"?

In underground uranium mines, as well in some other mines, radiation exposure occurs mainly due to airborne radon gas and its solid short-lived decay products, called radon daughters or radon progeny. Radon daughters enter the body with the inhaled air. The alpha particle dose to the lungs depends on the concentration of radon gas and radon daughters in the air.

The concentration of radon gas is measured in units of picocuries per litre (pCi/L) or becquerels per cubic metre (Bq/m^3) of ambient air. The concentration of radon daughters is measured in working level (WL) units this is a measure of the concentration of potential alpha particles per litre of air.

The worker's exposure to radon daughters is expressed in units of Working Level Months (WLM). One WLM is equivalent to 1 WL exposure for 170 hours.

1 WL = 130,000 MeV alpha energy per litre air

   = 20.8 μJ (microjoules) alpha energy per cubic meter (m^3) air

WLM = Working Level Month

   = 1 WL exposure for 170 hours

Often people use the concentration of radon gas (pCi/L) in the air to estimate the WL level of radon daughters. Such estimates are subject to error because the ratio of radon to its decay products (radon daughters) is not constant.

Equilibrium factor is ratio of the activity of all the short-lived radon daughters to the activity of the parent radon gas. Equilibrium factor is 1 when both are equal. Radon daughter activities are usually less than the radon activity and hence the equilibrium factor is usually less than 1.

Conversion of radon exposure units (equilibrium factor = 0.40)

---

1 WLM = 3.54 mJ-h/m^3

1 MBq-h/m^3 = 2.22 mJ-h/m^3

1 MBq-h/m^3 = 0.628 WLM

Annual exposure from measured radon concentration

(A) At home : assuming 7,000 hours spent indoors per year

1 Bq/m^3 = 0.0156 mJ-h/m^3

1 Bq/m^3 = 0.0044 WLM

1 WLM = 4 mSv

1 mJ-h/m^3 = 1.1 mSv

(B) At work : assuming 2,000 hours work per year

1 Bq/m^3 = 0.00445 mJ-h/m^3 = 0.00126 WLM

1 mJ-h/m^3 = 1.4 mSv

---

1 WLM = 5 mSv

Source: ICRP Publication 65, Protection Against Radon at Home and at Work

mJ-h/m^3 = millijoule hours/per cubic metre

MBq-h/m^3 = megabecquerel hours per cubic meter

Joule is unit of energy

1 J = 1 Watt-second = Energy delivered in one second by a 1 Watt power source

1 calorie = 4.2 J

MBq/m^3 = megabecquerel per cubic metre

WLM = Working Level Months

Document last updated on June 19, 2007

Date Modified: 2007-06-19