Units of Radiation

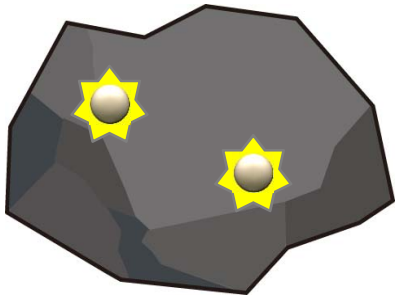
Becquerel and Sievert

Becquerel (Bq)

Unit indicating the amount of radioactivity

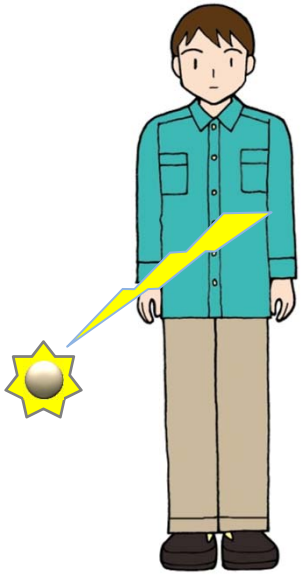
One nucleus decays per second = 1 becquerel (Bq)

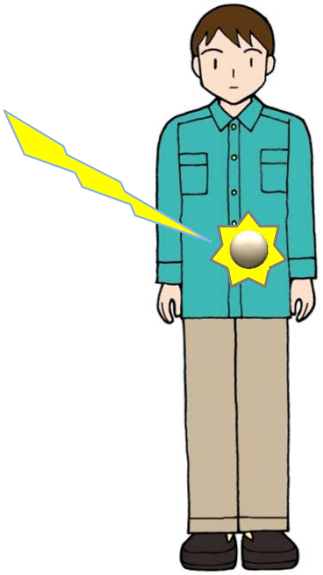
Radioactive materials



Sievert (Sv)

Unit of radiation exposure dose that a person receives
Associated with radiation effects





1 mSv from outside the body

1 mSv from within the body

Nearly equal effects on the human body

Origin of Sievert

Sievert is expressed by the symbol "Sv."

- 1 millisievert (mSv)
  = one thousandth of 1 Sv
- 1 microsievert (μSv)
  = one thousandth of 1 mSv

Rolf Sievert (1896-1966)
Founder of the physics laboratory at Sweden's Radiumhemmet
Participated in the foundation of the International Commission on Radiological Protection

Units of Radiation

Relationship between Units

Source of radiation

Radiation intensity*1

Becquerel (Bq)

Radioactive materials

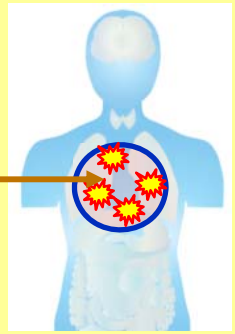
*1: Number of nuclei that decay per second

Receiving side

Absorbed dose*2

Gray (Gy)

Amount of energy absorbed by a substance of unit mass that received radiation



$$Gy = \frac{\text{Absorbed energy } \mathbf{(J)}}{\text{Mass of the part receiving radiation } \mathbf{(kg)}}$$

*2: Energy absorbed per 1 kg of substances (Joule: J; 1J≒0.24 calories); SI unit is J/kg.

Differences in effects depending on types of radiation

Equivalent dose (Sv)

Differences in sensitivity among organs

Effective dose

Sievert (Sv)

Unit for expressing radiation doses in terms of effects on the human body

Units of Radiation

Conversion from Gray to Sievert

Multiply × **Radiation weighting factor w_R**

Multiply × **Tissue weighting factor w_T**

Add up Σ

Absorbed dose

Grays **(Gy)**

Dose that each organ receives (equivalent dose)

α-particles **Twenty** times

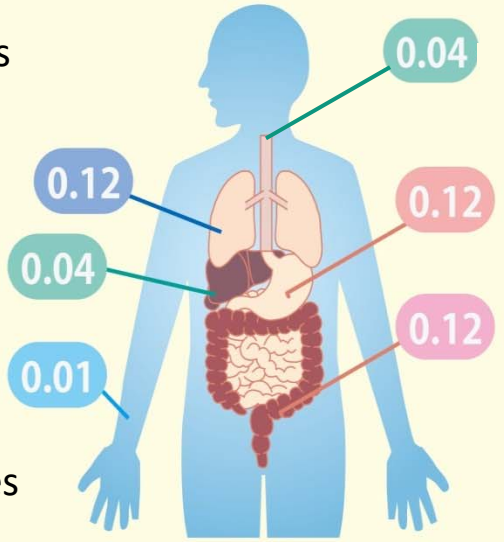
β-particles **One** time

γ-rays **One** time

Neutrons **2.5 to 21** times

Differences in effects depending on types of radiation

Dose that the whole body receives



Differences in sensitivity among organs

Effective dose

Sieverts **(Sv)**

Various Factors

Equivalent dose (**Sv**) = Radiation weighting factor w_R × Absorbed dose (**Gy**)

Type of radiation	Tissue weighting factor w_R
γ-rays, X-rays, β-particles	**1**
Proton beams	**2**
α-particles, heavy ions	**20**
Neutron beams	**2.5～21**

Effective dose (Sv) = Σ (Tissue weighting factor w_T × Equivalent dose)

Tissue	Tissue weighting factor w_T
Red bone marrow, colon, lungs, stomach, breasts	**0.12**
Gonad	**0.08**
Bladder, esophagus, liver, thyroid	**0.04**
Bone surface, brain, salivary gland, skin	**0.01**
Total of the remaining tissues	**0.12**

Sv: sieverts; Gy: grays

Source: 2007 Recommendations of the ICRP

Calculation of Equivalent Dose and Effective Dose

Effective dose (sievert (Sv)) = Σ (Tissue weighting factor × Equivalent dose)

When the whole body is evenly exposed to **1 mGy** of γ-ray irradiation

Effective dose =
0.12 X **1** (mSv): bone marrow
+ **0.12** X **1** (mSv): colon
+ **0.12** X **1** (mSv): lungs
+ **0.12** X **1** (mSv): stomach
:
+ **0.01** X **1** (mSv): skin
= **1.00** X **1** (mSv)

= 1 millisievert (mSv)

When only the head is exposed to **1 mGy** of γ-ray irradiation

Effective dose =
0.04 X **1** (mSv): thyroid
+ **0.01** X **1** (mSv): brain
+ **0.01** X **1** (mSv): salivary gland
+ **0.12** X **1** (mSv) × **0.1**: bone marrow **(10%)**
+ **0.01** X **1** (mSv) × **0.15**: skin **(15%)**
:

= 0.07 millisieverts (mSv)

Units of Radiation

Concepts of Doses: Physical Quantities, Protection Quantities and Operational Quantities

Physical quantities: directly measurable

Radiation intensity (Bq: becquerels)
Number of nuclei that decay per second

Radiation fluence ($s^{-1}m^{-2}$: fluence)
Number of particles incident on a unit area

Absorbed dose (Gy: grays)
Energy absorbed per 1 kg of substances

Irradiation dose (for X-rays and γ-rays) (C/kg)
Energy imparted to 1 kg of air

Defined based on physical quantity

Doses indicating the effects of exposure on humans: not directly measurable

Protection quantities

Equivalent dose (Sv: sievert)
indicates effects on individual human organs and tissues

Effective dose (Sv: sievert)
indicates effects on the whole body by combining effects on individual organs and tissues

≒

Operational quantities

Ambient dose equivalent (Sv: sievert)
Directional dose equivalent (Sv: sievert)
Approximate value for protection quantity used in environmental monitoring

Personal dose equivalent (Sv: sievert)
Approximate value for protection quantity used in personal monitoring

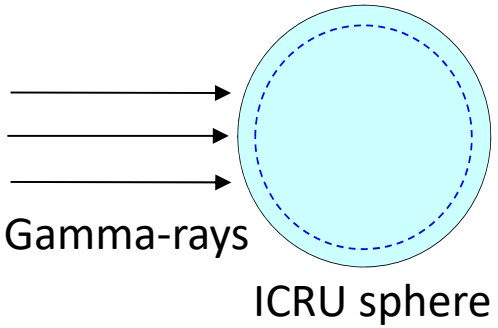
Dose Equivalents:
Measurable Operational Quantities for Deriving Effective Doses

Dose equivalent = Absorbed dose at a reference point meeting requirements × Quality factor

To substitute for "effective doses" that cannot be actually measured, "operational quantities" that can be measured as nearly the same values as effective doses, such as an ambient dose equivalent and personal dose equivalent, are defined under certain conditions.

Ambient dose equivalent (1cm dose equivalent)

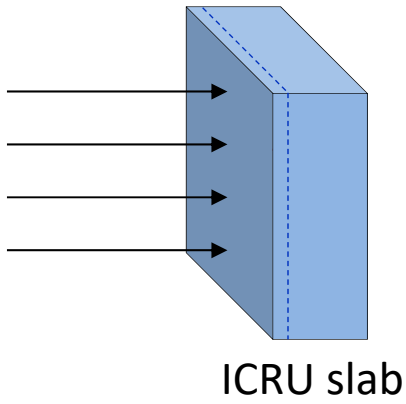
Dose equivalent occurring at a depth of 1cm from the surface of an ICRU sphere, which is 30 cm in diameter and simulates human tissue, placed in a field where radiation is coming from one direction; Ambient dose equivalent is used in measurements of ambient doses using survey meters, etc.



Personal dose equivalent (1cm dose equivalent)

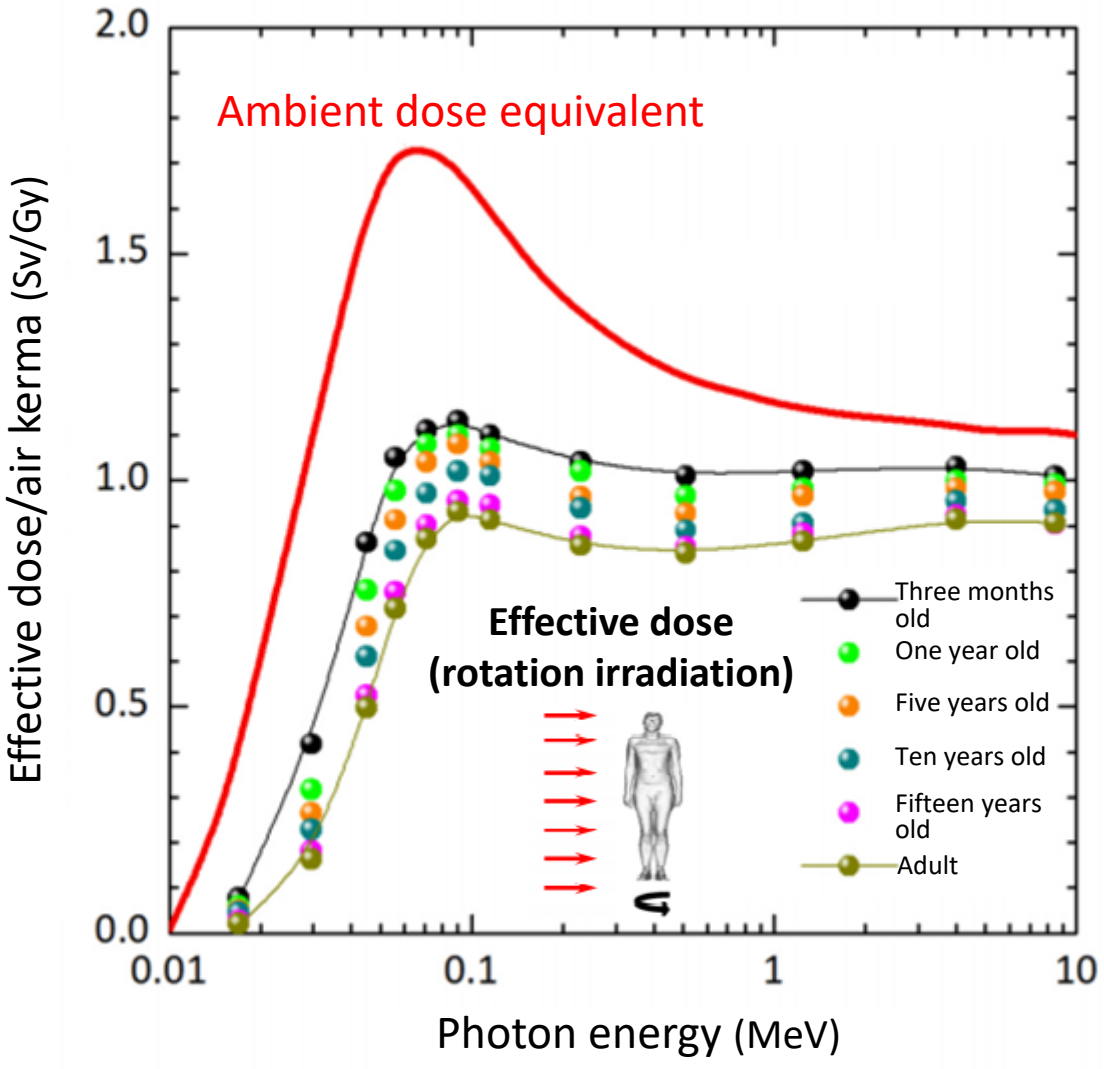
Dose equivalent at a depth of 1 cm at a designated point on the human body; Since measurement is conducted using an instrument worn on the body, exposure from all directions is evaluated while a self-shielding effect is always at work.

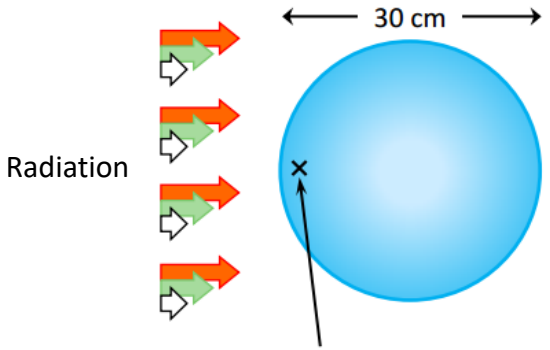
⇒ **Personal dose equivalents are always smaller than survey meter readings!**



Units of Radiation

Difference between Values of Effective Dose and Dose Equivalent





The ambient dose equivalent measured with a survey meter is defined as the dose equivalent at a depth of 1 cm from the surface of an ICRU sphere that is 30 cm in diameter. The ambient dose equivalent is also called 1 cm dose equivalent.

Extract from the 9th meeting of the Atomic Energy Commission of Japan in 2012 (a report by Akira Endo of JAEA)

Units of Radiation

Doses in Units of Sieverts