Units of Radiation

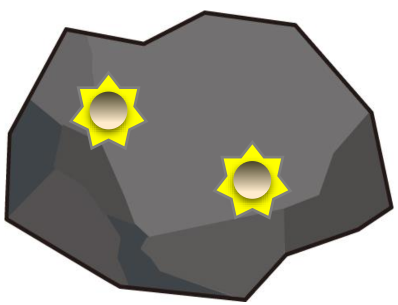
# Becquerel and Sievert

## Becquerel (Bq)

Unit indicating the amount of radioactivity

One nucleus decays per second = 1 becquerel (Bq)

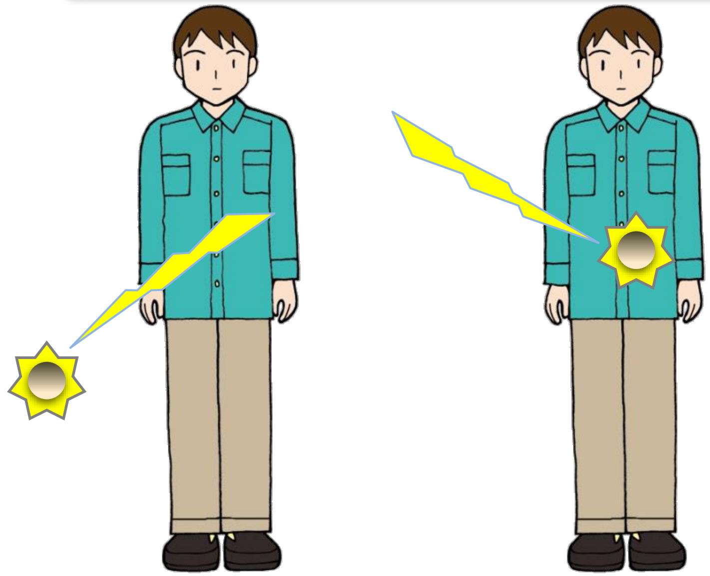
Radioactive materials



## 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

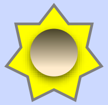
Units of Radiation

# Relationship between Units

## Source of radiation

Radiation intensity[*1]

**Becquerel (Bq)**



**Radioactive materials**

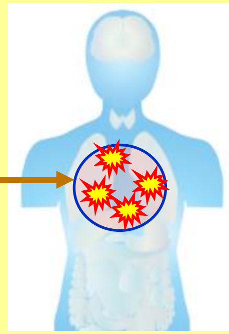
*1: Number of nuclei that decay per second

## Receiving side

Absorbed dose[*2]

**Gray (Gy)**

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



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

*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

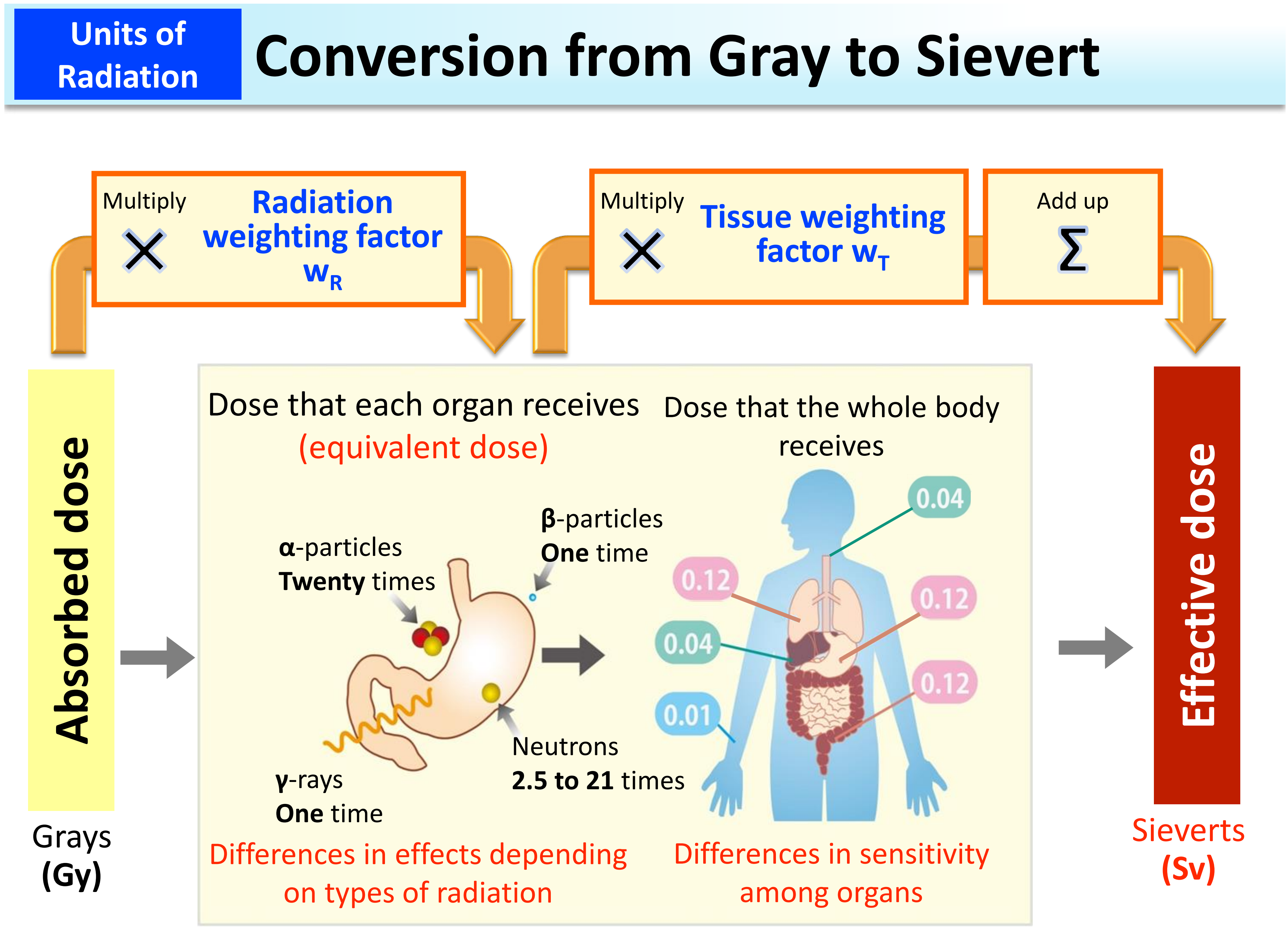
Equivalent dose (Sv)

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 wR
Multiply × Tissue weighting factor wT
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
0.04
0.12
0.12
0.04
0.12
0.01
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

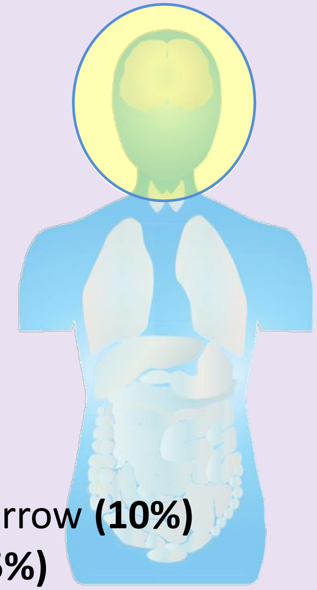
Effective dose (sievert (Sv)) = Σ (Tissue weighting factor × Equivalent dose)

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)**

# 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

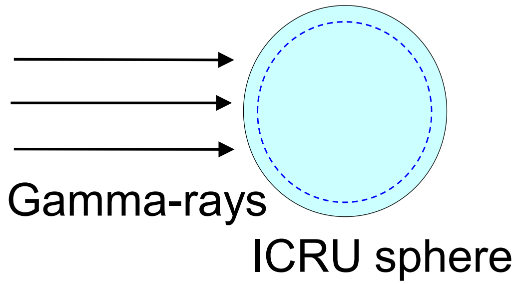
# Dose Equivalents: Measurable Operational Quantities for Deriving Effective Doses

Dose equivalent = Absorbed dose at a reference point that meets certain requirements × Quality factor

To substitute for "effective doses" that cannot be actually measured, "operational quantities" that can be measured as conservative values or 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)

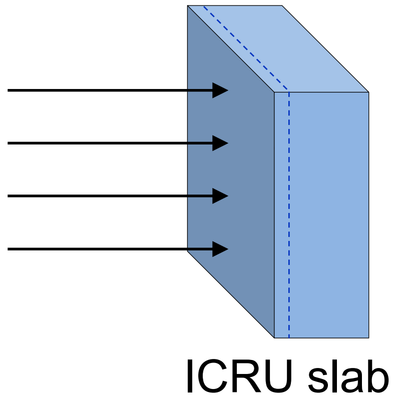
Dose equivalent is a dose that would be produced at a depth of 1 cm from the surface of an ICRU sphere, which is 30 cm in diameter and simulates human tissue, placed in a field where radiation is coming from one direction; Ambient dose equivalent is used in measurements of ambient doses using survey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



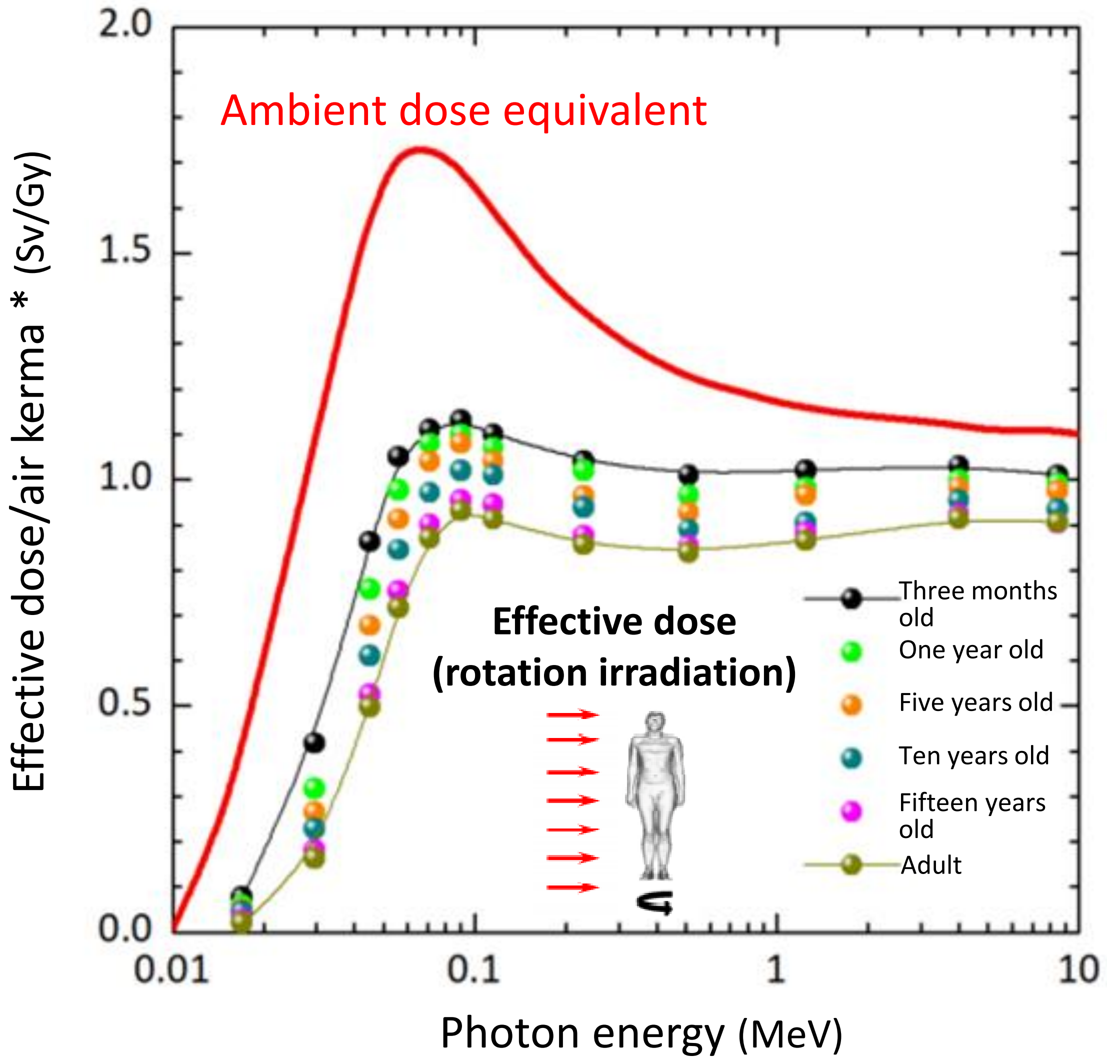

## Personal dose equivalent (1 cm dose equivalent)

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.

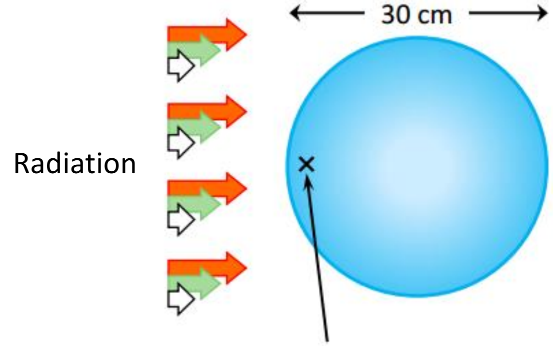
**⇒ Personal dose equivalents are always smaller than survey meter readings!**



# Difference between Values of Effective Dose and Dose Equivalent




* Air kerma is a unit of physical quantity.




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.

Source: Partially revised material 1 for 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