Becquerel (Bq)
Unit indicating the amount of radioactivity

One nucleus decays per second = 1 becquerel (Bq)

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


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

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

*²: Energy absorbed per 1 kg of substances (Joule: J; 1 J = 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

Relationship between Units
Units of Radiation

Conversion from Gray to Sievert

Multiply

Radiation weighting factor $w_R$

Multiply

Tissue weighting factor $w_T$

Add up

Effective dose

Dose that each organ receives (equivalent dose)

- $\alpha$-particles
  - Twenty times
- $\beta$-particles
  - One time
- $\gamma$-rays
  - One time
- Neutrons
  - 2.5 to 21 times

Differences in effects depending on types of radiation

Dose that the whole body receives

- $\alpha$-particles
  - 0.12
- $\beta$-particles
  - 0.04
- $\gamma$-rays
  - 0.01
- Neutrons
  - 0.12

Differences in sensitivity among organs

Absorbed dose

Grays (Gy)

Effective dose

Sieverts (Sv)
Equivalent dose ($Sv$) = Radiation weighting factor $w_R \times$ Absorbed dose ($Gy$)

<table>
<thead>
<tr>
<th>Type of radiation</th>
<th>Tissue weighting factor $w_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>γ-rays, X-rays, β-particles</td>
<td>1</td>
</tr>
<tr>
<td>Proton beams</td>
<td>2</td>
</tr>
<tr>
<td>α-particles, heavy ions</td>
<td>20</td>
</tr>
<tr>
<td>Neutron beams</td>
<td>2.5～21</td>
</tr>
</tbody>
</table>

Effective dose ($Sv$) = $\sum (Tissue$ weighing factor $w_T \times$ Equivalent dose)

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Tissue weighting factor $w_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red bone marrow, colon, lungs, stomach, breasts</td>
<td>0.12</td>
</tr>
<tr>
<td>Gonad</td>
<td>0.08</td>
</tr>
<tr>
<td>Bladder, esophagus, liver, thyroid</td>
<td>0.04</td>
</tr>
<tr>
<td>Bone surface, brain, salivary gland, skin</td>
<td>0.01</td>
</tr>
<tr>
<td>Total of the remaining tissues</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Sv: sieverts; Gy: grays

Source: 2007 Recommendations of the ICRP
Calculation of Equivalent Dose and Effective Dose

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

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

Effective dose =
  
  - 0.12 \times 1 \text{ (mSv)}: \text{bone marrow}
  + 0.12 \times 1 \text{ (mSv)}: \text{colon}
  + 0.12 \times 1 \text{ (mSv)}: \text{lungs}
  + 0.12 \times 1 \text{ (mSv)}: \text{stomach}

  : 

  + 0.01 \times 1 \text{ (mSv)}: \text{skin}

= 1.00 \times 1 \text{ (mSv)}

= 1 \text{ millisievert (mSv)}

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

Effective dose =
  
  - 0.04 \times 1 \text{ (mSv)}: \text{thyroid}
  + 0.01 \times 1 \text{ (mSv)}: \text{brain}
  + 0.01 \times 1 \text{ (mSv)}: \text{salivary gland}
  + 0.12 \times 1 \text{ (mSv)} \times 0.1: \text{bone marrow (10%)}
  + 0.01 \times 1 \text{ (mSv)} \times 0.15: \text{skin (15%)}

  :

= 0.07 \text{ millisieverts (mSv)}
### Physical quantities: directly measurable

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

- **Radiation fluence** *(s⁻¹m⁻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

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

- **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

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

- **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 equivalent = Absorbed dose at a reference point meeting requirements \(\times\) 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!
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)
Doses in Units of Sieverts

(i) Whole-body exposure
- Effective dose

(ii) Internal exposure
- Committed effective dose

(iii) Local exposure
- Equivalent dose

(iv) Survey meter readings

Radioactive materials
(radioactive iodine, radioactive cesium, etc.)

Personal dosimeter

Survey meter