Ge Semiconductor Detector
Used to measure radioactivity in foods or soil; Effective in measuring low levels of radioactivity concentrations

Nal (TI) Food Monitor
Suitable for efficient radioactivity measurement of foods, etc.

Whole-body Counter
Assess accumulation of γ-ray nuclides in the body using numerous scintillation counters or the like

Integrating Personal Dosimeter
Worn on the trunk of the body for 1-3 months to measure cumulative exposure doses during that period

Electronic Personal Dosimeter
Equipped with a device to display dose rates or cumulative doses during a certain period of time and thus convenient for measuring and managing exposure doses of temporary visitors to radiation handling facilities
Principles of Radiation Measurement

Measurements are carried out utilizing the interaction between radiation and substances.

**Ionization (with gas atoms)**

- Detectors are filled with gases such as inert gases or air.
- When radiation passes through gas, molecules are ionized, creating positive ions and electrons.
- Positive ions and electrons are drawn toward the electrodes and are converted into electric signals for measurement.

GM counter survey meters, ionization chambers, etc.

**Excitation**

- When radiation passes through a scintillator, molecules are excited, but they return to their original state (ground state).
- Light emitted in the process is amplified and converted into a current for measurement.

Nal (TI) scintillation survey meter, etc.
<table>
<thead>
<tr>
<th>Type</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GM counter survey meter (ionization)</strong></td>
<td>Contamination detection Has a thin entrance window and can detect β-particles efficiently; Suitable for detecting surface contamination</td>
</tr>
<tr>
<td><strong>Ionization chamber survey meter (ionization)</strong></td>
<td>γ-ray ambient dose rate Most accurate but unable to measure low dose rates like a scintillation type can</td>
</tr>
<tr>
<td><strong>NaI (Tl) scintillation survey meter (excitation)</strong></td>
<td>γ-ray ambient dose rate Accurate and very sensitive; Suitable for measuring γ-ray ambient dose rates from the environment level up to around 10μSv/h</td>
</tr>
<tr>
<td><strong>Personal dosimeter (light-stimulated luminescence dosimeter, luminescent glass dosimeter, electronic dosimeter, etc.) (excitation)</strong></td>
<td>Personal dose Cumulative dose Worn on the trunk of the body to measure personal dose equivalent of the relevant person's exposure while it is worn; A direct-reading type and types with alarm functions are also available.</td>
</tr>
</tbody>
</table>
Methods of Measuring Doses

Example: NaI (TI) scintillation survey meter (TCS-171)

(i) Background measurement
(ii) Field measurement
- Range (the reading is indicated near the center of the scale)
- Adjustment of time constant (the value is to be read when a period of time three times the time constant elapses)

(iii) Dose calculation
- Reading × Calibration constant = Dose (μSv/h)

How to interpret the readings
- 0.3, 3, 30 μSv/h in the upper row
- 1, 10 μSv/h in the lower row
- The photo shows a range of 0.3 μSv/h.
- Read the value in the upper row
- The needle pointing at 0.92

The reading at 0.092 μSv/h

For example, when the calibration constant is 0.95
Dose = 0.092 × 0.95 = 0.087 μSv/h

Prepared based on "How to Handle a Survey Meter" on the website of the Prime Minister's Office
Characteristics of External Exposure Doses

1) **Distance**: Dose rates are inversely proportional to the distance squared.

\[ I = \frac{k}{r^2} \]

- **I**: Radiation intensity (dose rate)
- **r**: Distance
- **k**: Constant

2) **Time**: Doses are proportional to the time of exposure provided the dose rates are the same.

(Total) dose (microsieverts) = Dose rate (microsieverts/h) \( \times \) Time
External Exposure (Measurement)

Dose Measurement and Calculation

Measure with a personal dosimeter

Radioactive source

Dose rates are high near radioactive materials

Low at a distance

Survey meter measurement: Ambient dose rate (microsieverts/h) multiplied by the time spent in the relevant location roughly shows an external exposure dose.
Ambient dose rate shows measured amount of γ-rays in the air. Indicated in microsieverts per hour (μSv/h).

Fallout density is the amount of radioactive materials that have deposited (or descended) per unit area in a certain period of time. e.g., becquerels per squared meter (Bq/m²)
Shielding and Reduction Coefficient

<table>
<thead>
<tr>
<th>Location</th>
<th>Reduction coefficient*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wooden house (one or two stories)</td>
<td>0.4</td>
</tr>
<tr>
<td>Block or brick house (one or two stories)</td>
<td>0.2</td>
</tr>
<tr>
<td>The first and second floors of a building (three or four stories) with</td>
<td>0.05</td>
</tr>
<tr>
<td>each floor 450-900m² wide</td>
<td></td>
</tr>
<tr>
<td>Upper floors of a building with each floor 900m² or wider</td>
<td>0.01</td>
</tr>
</tbody>
</table>

* The ratio of doses in a building when assuming that a dose outdoors at a sufficient distance from the building is 1

Source: "Disaster Prevention Countermeasures for Nuclear Facilities, etc." (June 1980 (partly revised in August 2010)), Nuclear Safety Commission
Additional Exposure Doses after an Accident (Example of Calculation)

It is important to subtract values in normal times.

Dose rate (increase due to an accident: μSv/h)

0.23 – 0.04 (temporary) = 0.19

Normal times (temporary)

Reduction coefficient: 0.4

When the time staying outdoors/indoors is 8 hours/16 hours

Actual measurement (example)

0.19 × 8 hours (outdoors)
+ 0.19 × 0.4 × 16 hours (indoors)

(μSv/day)

× 365 days ÷ 1,000μSv/year
= 1.0 mSv/year
Calculation of Internal Exposure Doses

Differences in effects by the type of radiation

- α-particles: 20 times
- β-particles: one time
- γ-rays: one time
- Neutrons: 2.5 to 21 times

Differences in sensitivity among organs

- Dose to each organ (equivalent dose)
- Dose to the whole body

Dynaics within the body

Half-life

Intake

Becquerel (Bq)

Multiply

Committed effective dose coefficient

Determine the coefficient for each radioactive material through mathematical modeling calculation

Age-related differences are taken into account in calculating committed effective dose coefficients.
Committed Effective Doses

Exposure dose estimating how much radiation a person will be exposed to in lifetime from a single intake of radioactive materials.

**Calculation of internal exposure**

**Integrating future doses**
- Public (adult): 50 years after intake
- Children: up to age 70 after intake

**Effective dose** (Sv: sievert)

Assuming that the relevant person was exposed to the total amount in that year.
## Conversion Factors to Effective Doses

### Committed effective dose coefficients (μSv/Bq) (ingestion)

<table>
<thead>
<tr>
<th></th>
<th>Strontium-90</th>
<th>Iodine-131</th>
<th>Cesium-134</th>
<th>Cesium-137</th>
<th>Plutonium-239</th>
<th>Tritium*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three months old</td>
<td>0.23</td>
<td>0.18</td>
<td>0.026</td>
<td>0.021</td>
<td>4.2</td>
<td>0.000064</td>
</tr>
<tr>
<td>One year old</td>
<td>0.073</td>
<td>0.18</td>
<td>0.016</td>
<td>0.012</td>
<td>0.42</td>
<td>0.000048</td>
</tr>
<tr>
<td>Five years old</td>
<td>0.047</td>
<td>0.10</td>
<td>0.013</td>
<td>0.0096</td>
<td>0.33</td>
<td>0.000031</td>
</tr>
<tr>
<td>Ten years old</td>
<td>0.06</td>
<td>0.052</td>
<td>0.014</td>
<td>0.01</td>
<td>0.27</td>
<td>0.000023</td>
</tr>
<tr>
<td>Fifteen years old</td>
<td>0.08</td>
<td>0.034</td>
<td>0.019</td>
<td>0.013</td>
<td>0.24</td>
<td>0.000018</td>
</tr>
<tr>
<td>Adult</td>
<td>0.028</td>
<td>0.022</td>
<td>0.019</td>
<td>0.013</td>
<td>0.25</td>
<td>0.000018</td>
</tr>
</tbody>
</table>

μSv/Bq: microsieverts/becquerel

*Tissue free water tritium

(e.g.) An adult consumed 0.5 kg of foods containing 100 Bq/kg of Cesium-137

\[
100 \times 0.5 \times 0.013 = 0.65 \mu Sv \\
= 0.00065 mSv
\]

### Committed effective dose coefficients (μSv/Bq)

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Bq: becquerels; μSv: microsieverts; mSv: millisieverts

Methods of Measuring Radioactivity for Estimation of Intake

Direct counting

- Thyroid monitor
- Whole-body counter

Measure radiation from radioactive materials in the body

Bioassay

- Measure radioactive materials contained in body waste

Bioassay
## Comparison of Methods of Assessing Internal Radioactivity

<table>
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<th>Direct counting</th>
<th>Bioassay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly measure the human body</td>
<td>Indirect measurement</td>
</tr>
<tr>
<td>Need to spare time to receive direct measurements</td>
<td>Submit samples (urine, feces, etc.)</td>
</tr>
<tr>
<td>Mainly target materials that emit γ-rays</td>
<td>Able to measure all radioactive materials</td>
</tr>
<tr>
<td>Short measuring time using the apparatus</td>
<td>Chemical analysis takes time.</td>
</tr>
<tr>
<td>Accurate dose assessment</td>
<td>Large margin of error in results of dose assessment</td>
</tr>
</tbody>
</table>

![Diagram of shielding and radiation detector](image1.png)

![Diagram of bioassay with samples](image2.png)
Instruments for Measuring Internal Exposure

- Stand-up whole-body counter
- Chair whole-body counter
- Scanning bed whole-body counter
- Thyroid monitor

Detector
Data on Internal Exposure Measured by Direct Counting

Measure radiation emitted from within the body \( \Rightarrow \) Measure internal radioactivity for each radioactive material

The amount of potassium in the body is around 2 g per 1 kg of body weight, and approx. 0.01% of that amount is radioactive potassium (Potassium-40)

keV: kilo electron volts
The younger a person is, the smaller the amount of radioactive materials remaining in the body. ↓

In estimating additional exposure through ingestion,
- finite values are unlikely to be obtained for children.
- it is more reasonable to examine adults in order to detect trace intake.

Source: Modified from a material released for the Japan Society of Radiation Safety Management Symposium in Miyazaki (June 29, 2012)