Radiation Safety Course
(School of Science, the University of Tokyo)

Biological Effects of Radiation to Human Body

FY2023
Japan begins releasing treated water from Fukushima Daiichi plant

Tokyo Electric Power Company said it has started discharging treated and diluted water from the Fukushima Daiichi nuclear power plant. The first round of the release will happen over 17 days. The full process could take at least 30 years to complete.

Cited from NHK WORLD-JAPAN News (https://www3.nhk.or.jp/nhkworld/en/news/)
Contaminated water with radioactive materials is being generated after the accident at TEPCO’s Fukushima Daiichi NPS. "ALPS treated water" refers to the water that has been treated by the Advanced Liquid Processing System (ALPS) and other equipment and has been purified to a level where contained radioactive materials, except for tritium, satisfy the regulatory standards for discharge into the environment.

Freshwater obtained through desalination is used as coolant.

Purification treatment of 62 types of radioactive materials other than tritium

Pre-treatment facilities (co precipitation treatment)

Adsorption tower

Purification treatment of cesium and strontium

SARRY

Kurion

Separate fresh water

Desalinator

Water that satisfies the regulatory standards for environmental discharge with regard to radioactive materials, except for tritium, contained therein

Secondary treatment using ALPS or reverse osmosis membrane equipment

ALPS treated water


Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Contaminated water generated at TEPCO's Fukushima Daiichi NPS not only contains tritium but also contains Cesium 137, Strontium 90 and other radioactive materials which are seldom detected in water discharged from ordinary nuclear power stations.

Out of those radioactive materials, 62 types of nuclides that are likely to be contained in the contaminated water at certain levels in consideration of regulatory standards respectively set for those types of nuclides are purified by the use of the Advanced Liquid Processing System (ALPS) and other equipment to the extent that their concentrations become below those regulatory standards.

- Cesium 137
- Cesium 134
- Strontium 90
- Cobalt 60
- Antimony 125
- Ruthenium 106
- Iodine 129
- Technetium 99

Nuclides to be purified using ALPS (62 types)

Major seven types

55 types

- Carbon 14
- Other nuclides


Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Comparison of Tritium Concentrations

- **日本の安全基準** (Japan’s safety standards)
- **WHOの飲料水基準** (WHO’s drinking water standard)
- **ALPS処理水を海水放出する際の濃度** (The concentration of ALPS-treated water when it is released into the sea)

- **60,000 Bq/L**
- **10,000 Bq/L**
- **1,500 Bq/L**

Tritium is a radioisotope of hydrogen, called "hydrogen-3."

**Physical half-life:** 12.3 year

**E_{\text{mean}}:** 5.7 keV

**E_{\text{max}}:** 18.6 keV

**HTO**

**Structure of water molecules**

- Water molecule solely consisting of ordinary hydrogen: **H_{2}O**
- Water molecule consisting of ordinary hydrogen and tritium: **HTO**

Source: Prepared based on the "Important Stories on Decommissioning 2018" by the Agency for Natural Resources and Energy, METI, the "Tritiated Water Task Force Report" by the Tritiated Water Task Force (2016), and the "Scientific Characteristics of Tritium (draft)" by the Subcommittee on Handling of the ALPS Treated Water

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Amount of Tritium Existing in Nature

- **Amount of tritium produced annually by cosmic rays**: \(7 \times 10^{16}\) Bq
- **Produced from nitrogen or oxygen**:
  - \(^{14}\text{N} + \text{neutron} \rightarrow ^{3}\text{H} + ^{12}\text{C}\)
  - \(^{16}\text{O} + \text{neutron} \rightarrow ^{3}\text{H} + ^{14}\text{N}\) (\(^{3}\text{H}\): tritium)
- **Produced in the earth’s crust**:
  - \(^{6}\text{Li} + \text{neutron} \rightarrow ^{3}\text{H} + ^{4}\text{He}\)
  - \(^{238}\text{U} + \text{neutron} \rightarrow ^{3}\text{H} + \text{others}\)

**Released from nuclear testing**
\((1.8 - 2.4) \times 10^{20}\) Bq

**Total amount existing in nature**
\((1 - 1.3) \times 10^{18}\) Bq

- **Produced by cosmic rays, etc.**
  - About \(7 \times 10^{16}\) Bq/year

- **Total amount existing in nature**
  - \((1 - 1.3) \times 10^{18}\) Bq

- **Annual amount of tritium released from nuclear facilities, etc.**
  - \(2 \times 10^{16}\) Bq (worldwide)

- **Amount of tritium in the precipitation all over Japan**
  - About \(223 \times 10^{12}\) Bq/year

- **Total amount discharged from nuclear power stations all over Japan**
  - (Average annual amount discharged into the ocean during five years before the accident)
  - About \(380 \times 10^{12}\) Bq/year

- **La Hague (France) Reprocessing Facility (2015)**
  - About \(1.4 \times 10^{16}\) Bq/year

- **Originating from nuclear testing (1945-63)**
  - \((1.8 - 2.4) \times 10^{20}\) Bq

**Amount of tritium currently stored in tanks within the premises of Tokyo Electric Power Company’s Fukushima Daiichi NPS**
- About \(860 \times 10^{12}\) Bq (as of October 31, 2019)

*The amount at the time of release from nuclear testing. The amount of tritium has currently been reduced according to the half-life.*

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Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Changes in Tritium in Radioactive Fallout over Time

Nuclear weapon tests (1950-1963)

Tritium (Fallout)

Source: UNSCEAR 2016 Report, Annex C-Biological effects of selected internal emitters-Tritium

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Types of Ionizing Radiation

 Ionizing radiation

 Particle beams

 Protons
 Neutrons
 Electrons

 Radiation that causes ionization

 α-particles (helium nuclei ejected from a nucleus)
 β-particles (electrons ejected from a nucleus)
 Neutron beams (produced in nuclear reactors, accelerators, etc.)
 Proton beams (produced in accelerators, etc.)
 X-rays (generated outside a nucleus)
 γ-rays (emitted from a nucleus)

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Penetrating Power of Radiation

- **α-particles**
- **β-particles**
- **β-particles** emitted from tritium
- **γ-rays**
- **Neutrons**

However, when you want to block β-particles, you should use a plastic sheet or an aluminum plate. You should not use a lead plate as the first shielding material against β-particles.

Cited from METI ANRE website (https://www.enecho.meti.go.jp)
Internal and External Exposure

**External exposure**
- From outer space and the sun
- Suspended matters
- From a radiation generator
- Buildings
- Ground

**Body surface contamination**
- Receive radiation from outside of the body

**Internal exposure**
- Inhalation
- Food and drink consumption
- Radio-pharmaceuticals
- Lungs
- Wound

**Receive radiation from within of the body**

The body is equally exposed to radiation in both cases.

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
External Exposure and Skin

Skin structure

Part highly sensitive to radiation

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Internal Exposure

(i) **Ingestion**
From the mouth (swallowing)
Absorption through the digestive tract

(ii) **Inhalation**
Incorporation from the respiratory airways
Absorption from the lungs and the surface of the airways

(iii) **Percutaneous absorption**
Absorption from the skin

(iv) **Wound contamination**
Contamination from a wound

(v) **Intake of radiopharmaceuticals**
Injection, oral administration \(\rightarrow (i)\)
Inhalation of gas \(\rightarrow (ii)\)

Radioactive materials within the body decay as they emit radiation within the body.

They may accumulate in some specific organs.

They are gradually excreted in the urine and feces.

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
The characteristics of radioactive materials that especially cause problems in internal exposure

(i) $\alpha$-emitters $> \beta$-emitters or $\gamma$-emitters

(ii) Materials that enter easily but are difficult to excrete

(iii) Materials that are likely to accumulate in specific organs

$$\frac{1}{T_e} = \frac{1}{T_p} + \frac{1}{T_b}$$

$T_e$: Effective half-life
$T_p$: Physical half-life
$T_b$: Biological half-life

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Metabolism of Tritiated Water in the Human Body

Tritiated Water (HTO) is assimilated via Inhalation, Absorption, and Ingestion. It then enters the Circulatory Pathway of Body Fluid. Approximately 94% to 95% of the ingested tritiated water is eliminated in the urine, with a biological half-life of 10 days. The remaining 5% to 6% of the tritiated water is converted into Organic Compounds, which have a biological half-life of 40 days (Short-Term Components) and 1 year (Long-Term Components). The biological half-life of Organically Bound Tritium (OBT) is also depicted. H. Matsumoto et al., J Radiat Res., 2021
DNA → Cells → Human Body

Damage (chemical change)

Repair enzyme
DNA

Incomplete repair
Mutation
Possibility of causing cancer and hereditary effects

Repair failed
Cell death or cell degeneration
Possibility of causing acute effects and fetal effects

Repair succeeded
No hazard

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Comparison of Exposure Doses per Year

Natural radiation

Global avg.

Japanese avg.

CT scan
CT検査
2.4~12.9mSv

From foods
食物からの自然放射線（日本平均年間）
0.99mSv程度

Tokyo to New York

Dental X-ray scan

Exposure dose when the ALPS-treated water is released into the sea

<table>
<thead>
<tr>
<th>Type of exposure</th>
<th>Breakdown of radiation sources</th>
<th>Effective dose (mSv/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External exposure</td>
<td>Cosmic rays</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Ground radiation</td>
<td>0.33</td>
</tr>
<tr>
<td>Internal exposure (inhalation)</td>
<td>Radon-222 (indoors and outdoors)</td>
<td>0.37</td>
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<tr>
<td></td>
<td>Radon-220 (thoron) (indoors and outdoors)</td>
<td>0.09</td>
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<tr>
<td></td>
<td>Smoking (Lead-210, Polonium-210, etc.)</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Others (uranium, etc.)</td>
<td>0.006</td>
</tr>
<tr>
<td>Internal exposure (ingestion)</td>
<td>Mainly Lead-210 and Polonium-210</td>
<td>0.80</td>
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<tr>
<td></td>
<td>Tritium</td>
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<td></td>
<td>Carbon-14</td>
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<tr>
<td></td>
<td>Potassium-40</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>2.1</strong></td>
</tr>
</tbody>
</table>


Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation.
Tritium Exposure Accidents

2 watch factories in Europe in the 1960s

• A factory worker ingested tritium over 7.4 years. Exposure dose was estimated at 3-6 Sv. → Developed isochromic anemia, and subsequently died of pancytopenia.

• A factory worker ingested tritium over 3 years. Exposure dose was estimated at 10-20 Sv. → Died of pancytopenia after following a similar disease as the same as above.

Images are cited from KENTEX website (https://www.kentex-jp.com)
Sources:
- The 2007 ICRP (International Commission on Radiological Protection) Report
- The exposure guideline of the Japan Association of Radiological Technologists
- "Life Environmental Radiation (Calculation of the National Dose)," new edition

Prepared by the National Institute of Radiological Sciences based on the sources above (May 2018)

mSv: millisieverts

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation