LET'S TALK ABOUT RADIATION
Due to the Great East Japan Earthquake that occurred on March 11, 2011, a nuclear accident occurred at the Fukushima Daiichi Nuclear Power Station, operated by Tokyo Electric Power Company. Consequently, there has been widespread skepticism and anxiety about radiation, not only in Japan, but also in other countries that operate nuclear power plants. However, a major factor contributing to this spread of skepticism and anxiety is probably the lack of information available for people to understand the situation for themselves. Therefore, this document is provided to help people better understand radiation and its effects.

Most of the authors are health care professionals involved in radiation therapy, mainly in the Kyoto area. We continue to use radiation levels determined based on contributing to the health of patients. We will try to explain what we have learned about radiation in terms that can be easily understood by those learning about radiation for the first time. Feel free to skip to topics of particular interest. Terms marked with an asterisk are defined at the bottom of respective pages.

A note to risk communicators:

If communicating to mothers, it may be more effective to start with Chapters 04, 05, and 06.
Presumably, the universe was created a long time ago by a big bang. That filled the universe with small particles that coalesced or split apart, releasing large amounts of radiation. Ever since then, countless radiation waves have continued to fly around the universe.

In fact, the Earth was formed from a collection of space dust and small planets. That resulted in not only collecting various elements such as copper and iron, but also simultaneously collecting elements that emit radiation, such as uranium and thorium.

Life on Earth was born in an environment where such radiation was present. Even now we live in an environment where we are constantly exposed to radiation from space and the Earth. All foods obtained from the land and sea contain radioactive elements. That means all animals and people that eat those foods also contain radioactive substances. Furthermore, cement and stone materials used in construction also contain uranium and thorium. Uranium converts to radon, a radioactive gaseous substance. Therefore, the air inside buildings is mixed with radon gas emitted from building materials, such as concrete and stone, which we inhale with every breath.

These photographs show the radiation emitted from radioactive substances that have always been contained in food and stone materials. They were obtained by leaving them for several weeks in a component used to detect X-rays in X-ray systems used for radiological examinations.

Notes 1 to 4: The following are all radioactive substances that exist naturally on the Earth.

1. Uranium: Used as a fuel for nuclear power.
2. Thorium: Being researched for use as a fuel for nuclear power.
3. Radon: There are hot springs referred to as radon hot springs.
4. Radon gas: Radioactive gas substance that exists naturally on the Earth. It is the same as radon.
A variety of elements contained in food are used to sustain life. One of the elements commonly found in food is potassium (K). A certain proportion of potassium emits radiation. This type of potassium is called potassium-40. The cells in our body contain a certain proportion of potassium. Therefore, the heavier our body weight, the more potassium-40 we contain. We also ingest radioactive elements such as polonium, uranium, thorium, and radium in what we eat and drink. The quantity of radiation-emitting substances in our body is equivalent to about 7000 becquerel for a 60 kilogram adult. That means we are exposed to radiation from within our own bodies. On average, Japanese are exposed to about 1 millisievert of radiation per year. This quantity is equivalent to the radiation exposure from space and Earth, resulting in a total exposure of 2 millisieverts per year. Note that the number of becquerels indicates how much radiation is emitted from something, whereas sieverts indicate how much effect the radiation has.

### Naturally Radioactive Substances in Our Bodies and Food


<table>
<thead>
<tr>
<th>Naturally Radioactive Potassium-40 in Food</th>
<th>(given 1 kg in Japan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>30</td>
</tr>
<tr>
<td>White sandwich bread</td>
<td>30</td>
</tr>
<tr>
<td>Fish</td>
<td>100</td>
</tr>
<tr>
<td>Beef</td>
<td>100</td>
</tr>
<tr>
<td>Milk</td>
<td>50</td>
</tr>
<tr>
<td>Dried milk</td>
<td>200</td>
</tr>
<tr>
<td>Spinach</td>
<td>200</td>
</tr>
<tr>
<td>Fish</td>
<td>700</td>
</tr>
<tr>
<td>Dried kelp</td>
<td>2000</td>
</tr>
<tr>
<td>Fresh seaweed (wakame)</td>
<td>200</td>
</tr>
<tr>
<td>Green tea leaves</td>
<td>600</td>
</tr>
<tr>
<td>Potato chips</td>
<td>400</td>
</tr>
<tr>
<td>Refined sake</td>
<td>1</td>
</tr>
<tr>
<td>Beer</td>
<td>10</td>
</tr>
<tr>
<td>Wine</td>
<td>30</td>
</tr>
</tbody>
</table>

(Units: becquerels/kg)

### Quantities of Radioactive Potassium-40 in Food

<table>
<thead>
<tr>
<th>Potassium-40 in Food</th>
<th>(given a typical 60 kg Japanese)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium-40</td>
<td>4000 becquerels</td>
</tr>
<tr>
<td>Carbon-14</td>
<td>2500 becquerels</td>
</tr>
<tr>
<td>Rubidium-87</td>
<td>500 becquerels</td>
</tr>
<tr>
<td>Lead-210 and polonium-210</td>
<td>20 becquerels</td>
</tr>
</tbody>
</table>

Notes:
- 5 Polonium: Even contained in cigarettes.
- 6 Uranium: Used as a fuel for nuclear power.
- 7 Thorium: Being researched for use as a fuel for nuclear power.
- 8 Radium: Discovered and named by Marie and Pierre Curie.
- 9 Becquerel: Unit used to express the quantity of radioactive substances. The becquerel was named for Dr. Becquerel, who discovered radioactive substances.
- 10 1 millisievert = 1/1000 of a sievert. Sieverts are used to express the radiation exposure level to humans.
Devices for Measuring Radiation

Radiation levels are measured using a variety of instruments. The main purpose of measuring radiation is to determine the amount of radiation flying around within a given space, the amount of radiation emitted from an object or person, or the amount of radiation exposure received by a person. This section describes some representative types of instruments used for measuring radiation. These all must be used correctly based on measuring objectives and, just like scales for measuring body weight, their performance must be checked periodically. Some people may have purchased such instruments for personal use, but they may be measuring values incorrectly. Consequently, some manufacturers and vendors have even been offering training sessions and so on.

Purpose of Measurement

- Determine the amount of radiation flying around within a given space.
- The amount of radiation emitted from an object or person.
- The amount of radiation exposure received by a person.

Representative Types of Measuring Instruments

- **Personal Dosimeter**
  These devices are worn on clothes. Normally, they are used by people working in areas where radiation is used.

- **Geiger-Müller Counter**
  This is used to determine whether or not radioactive substances are present on a surface.

- **Whole Body Counter**
  This is used to investigate radioactive substances inside the body.
Let’s start with knowing >>>

**Effects on Humans**

Studies to determine the effects of radiation or environmental substances on humans involve investigating large numbers of people. If too few are investigated, personal characteristics such as age, sex, smoking or alcohol habits, or personal tastes can have a major effect that can prevent drawing accurate conclusions.

The largest radiation exposure events to humans were the atomic bombing of Hiroshima and Nagasaki during World War II. Japanese researchers went to these sites immediately after the events. Then later, together with American researchers, they began investigating the amount of radiation experienced by people. This research continues to this day. Though the dropping of the atom bombs is something we must never allow to occur again, investigating the events over the last 60 years has provided valuable information about the effects of radiation. The graph shown was prepared by the United Nations Scientific Committee on the Effects of Atomic Radiation. It shows that single large exposures to radiation increase the risk of cancer. Similarly, the lower the radiation exposure, the lower the risk of cancers caused by radiation, though we cannot say that even a low level of radiation has no effect. That is why many researchers say that, based on those results, the effects of low radiation levels cannot be determined.
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05

Effects on Children

How are radiation effects different for children than adults? Cases of major radiation exposure to children include the bombing of Hiroshima and Nagasaki and the nuclear accident at Chernobyl, Russia. The effects on the children involved in these tragedies have been studied in detail.

The cancer risk of people exposed to radiation from the atomic bombings was researched based on exposure dose and age. This research determined that the risk from a single one-sievert exposure is over twice as high for children as for adults. However, for lower radiation exposure levels, there was no difference in risk due to age.

The Chernobyl nuclear accident was an unfortunate accident that occurred when researchers conducting an experiment that involved recreating conditions of a nuclear accident lost control of the nuclear reactor. Furthermore, remedial measures for local residents by the former Soviet government were particularly inadequate during the first two weeks after the accident. Consequently, large numbers of children drank milk contaminated with radioactive iodine, which resulted in many cases of thyroid cancer in children. However, the thyroid cancer rate in adults changed very little.

This fact was revealed by Japanese researchers that were researching radiation victims in Nagasaki and Hiroshima.

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**Data**

Radiation Dose to the Thyroid Recognized as Having an Effect

<table>
<thead>
<tr>
<th>Age at Time of Exposure</th>
<th>Exposure Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 5</td>
<td>50mGy</td>
</tr>
<tr>
<td>10 to 19</td>
<td>100mGy</td>
</tr>
<tr>
<td>20 to 39</td>
<td>1000mGy</td>
</tr>
<tr>
<td>40 or more</td>
<td>No effect</td>
</tr>
</tbody>
</table>

Source: Nuclear Safety Research Association (Training material of the Radiation Emergency Medicine Information Network)

☆ A milligray (mGy) is one thousandth of a Gray.

☆11 Chernobyl nuclear accident: Nuclear disaster that occurred in 1986 at a nuclear power plant in Ukraine. It was the largest release of radioactive matter into the environment in human history.

☆12 Radioactive iodine: One of the radioactive isotopes released into the environment during the nuclear accident. When it enters the body, it accumulates in the thyroid, causing radiation exposure (internal exposure) to the thyroid.
Let's start with knowing >>>

06 Effects on Pregnant Women and Unborn Children

Several locations in the world have been discovered where natural radiation levels from the Earth are 5 to 6 times higher than normal. These areas have been populated with many people for a long time, but the cancer rate is not higher. An investigation of the genes in their cells showed that adults have an increased rate of genetic changes presumably due to radiation. However, no such abnormalities were discovered in the genes of newly born infants. Similar results were also confirmed in children born from victims of the Hiroshima and Nagasaki bombings. These results suggest that humans do not pass on negative effects from radiation to their offspring.

The amount of radiation required to affect unborn babies in pregnant women exposed to radiation has been determined in detail. This table is used to explain that amount to patients that need to have a radiological examination during pregnancy.

It compares the radiation exposure dose to the mother with the effects on the child during radiological examinations. It shows that normal radiological examinations do not result in any detrimental effects to unborn babies.

<table>
<thead>
<tr>
<th>Effects on Pregnant Women and Unborn Children</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="data.png" alt="Comparison of Dose to Fetus and Dose Required to Affect Fetus" /></td>
</tr>
</tbody>
</table>

[ICRP publication 84, some additions or modifications were made by the author]
Let’s start with knowing >>>

**Effects on Cells**

Differentiating Between the Terms “DNA” and “Genes”

Now let’s take a closer look at the effects of radiation at the cell level. If damage to DNA is minimal, then the DNA is repaired to produce identical cells. Higher damage levels can cause repairs to fail, resulting in cells that are different than the original cells, which is called a mutation. However, mutations also can occur due to failures in routine cell division processes that are not due to radiation damage. Mutant cells are not the same thing as cancer cells. These cells are eliminated by the body’s system for eliminating defective cells or by the immune system. If mutant cells make past these systems repeatedly, they can result in cancer. Note that cells with more extensive radiation damage die immediately.

* DNA is genetic information located at the nucleus of cells.
Data

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08

Types of Radiation

Basically, there are two main forms of radiation. One is an electromag-
netic wave similar to light that travels like a wave, whereas the other is a
particle beam consisting of small particles flying at high speeds.

The electromagnetic wave spectrum includes a variety of wave types,
not just radiation. Each type is classified by wavelength. Electromag-
netic waves with a wavelength of about 100 meters are called radio
waves, which are used for radio broadcasting and so on. Electromag-
netic waves used in microwave ovens are called microwaves and have
short wavelengths of about one meter. Electromagnetic waves with
shorter wavelengths than that include infrared rays, visible light, and
ultraviolet rays. Even shorter wavelengths, with higher energy levels,
are referred to as X-rays and gamma rays. X-rays and gamma rays have
the characteristic of passing through objects. X-rays have a wavelength
that is about 1/100,000,000 of a centimeter long and gamma rays about
1/1,000,000,000 of a centimeter long.

Particle beam types include alpha, beta, and proton beams.

Recent cancer treatment methods have used these particle beam
characteristics to successfully treat tumors located deep within the
body.
Substances that emit radiation are called radioactive substances. The capacity for a substance to emit radiation is called radioactivity. The level of radioactivity is expressed in terms of becquerel units, which compares the amount of radioactive substances in respective substances. Once a radioactive substance emits radiation up to a few times, it loses its ability to emit radiation, which means it is no longer a radioactive substance. In other words, the radioactivity due to radioactive substances naturally decreases as time passes. How quickly a substance loses its radioactivity is fixed for different substances. This rate of decrease is normally expressed in terms of the time it takes for the substance to lose half of its radiation. In the case of cesium, for example, which many of you became aware of during the nuclear power plant accident, there are actually two kinds of cesium that are emitted into the air, cesium 134 and cesium 137. The time it takes for cesium 134 to lose half its radioactivity is about 2 years, whereas for cesium 137 it is about 30 years.

When a radioactive substance enters the body, it is metabolized and excreted together with urine or feces. The speed with which a radioactive substance passes through the body is also referred to in terms of how long it takes for the amount in the body reduces to half the amount that originally entered the body. In this case as well, the time is determined separately based on the type of substance. When a substance actually enters the body, the age of the person is a major factor as well. It might take about 3 months to metabolize cesium to half the original level in an adult, but only 1 or 2 months for children, who have a faster metabolism, or about 2 weeks for infants.
Let’s start with knowing...  

10

Estimating the Internal Exposure Level

In the case of the Fukushima nuclear power station accident, it was reported that worker exposure level was a given number of millisieverts externally and a given number of millisieverts internally. Internal exposure refers to radiation exposure from radioactive substances that entered the body. The effects of radiation from outside the body can be estimated from the intensity and duration of radiation exposure. However, estimating the effects of internal exposure requires considering how the substance was absorbed or eliminated from the body. How fast the substance is eliminated is being researched for each type of the various radioactive substances, such as based on results from surveying people that participated in an atomic test. Therefore, a technique was established for converting the number of becquerels that entered the body into the number of millisieverts of effect on the body. Publicly reported values were calculated in this way.

The time it takes for substances to mix with urine and feces and be eliminated from the body varies significantly depending on the substance, but in general, internal radiation effects are assumed to last 50 years. During that time, the radioactive substances are eliminated each day, a little at a time. Since the exposure level decreases each day, the exposure level differs depending on the day. Then the cumulative radiation exposure from each day over the 50-year period is estimated (assuming, of course, that any amounts that decrease to zero before the 50-year period remain at zero thereafter). Consequently, the internal exposure level is estimated in this way.

In other words, when it is reported that internal exposure was a given number of millisieverts, it means that is the effect based on the total exposure until the radioactive substance is completely eliminated from the body.

Data

Concept of Internal Exposure Level (Committed Dose)

As radiation naturally decreases, it is eliminated from the body mixed in urine or feces.

For working professionals (or up to about 70 for the general population), exposure estimates assume that an exposure equivalent to the cumulative exposure that occurs little by little within the body over a long period occurs at the initial time of exposure (gray portion of bar graph).
Data

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11

Effects on Residents Due to the Fukushima Daiichi Nuclear Power Station Accident

“Radiation exposure following the nuclear accident at Fukushima-Daiichi did not cause any immediate health effects. It is unlikely to be able to attribute any health effects in the future among the general public and the vast majority of workers.” (Source: October 2013 Report of the United Nations Scientific Committee on the Effects of Atomic Radiation) Nevertheless, Fukushima prefectural authorities have started a health survey of prefecture residents to confirm their radiation exposure level and establish appropriate remedial measures. Significant amounts of the survey results have already become apparent.

The biggest problem caused by a nuclear accident is the accumulation of ingested radioactive iodine in the thyroid, which has caused an increase in thyroid cancer in children. Therefore, worried experts also surveyed the children that were evacuated from the surrounding area immediately after the accident. This survey found that none of the evacuated children had ingested sufficient amounts of radioactive iodine to increase their risk of developing thyroid cancer in the future. Thyroid glands were also examined, but the results were roughly the same as for children in other prefectures.

100,000 people have already been examined using a whole body counter, a device that measures the radiation emitted from the body. In over 99% of those surveyed, measurements were 1 millisievert or less.

The food from Fukushima was also investigated. As a result, shipments of certain fish, such as rock trout and flounder, are still not permitted due to radioactive cesium settling on the ocean floor, but amount of radioactive substances detected in products being sold at shops are extremely low, which was also shown in the results of the national government survey conducted during the winter of 2011 after the accident.

Except for immediately after the accident, no radioactive substances from the accident have been found in the public drinking water either. Food products and water continue to be inspected to ensure public safety. These results are kept posted by the government. Those who have concerns can check the results via the Internet, for example, or in the case of the Kyoto prefecture, they can contact the Food Safety and Security Division. We will never know the extent of emotional damage suffered by Fukushima residents. Therefore, the prefectural public health survey is also focusing on assessing emotional health as well.

Data

<table>
<thead>
<tr>
<th>Annual Exposure from Foods</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Units: millisieverts)</td>
</tr>
<tr>
<td>Prefecture</td>
</tr>
<tr>
<td>Tokyo</td>
</tr>
<tr>
<td>Miyagi</td>
</tr>
<tr>
<td>Fukushima</td>
</tr>
</tbody>
</table>

Data was determined based on the premise of eating only food produced within the prefecture and purchased at food stores.

(20111222 Food Safety Commission of Japan)

*14 Radioactive iodine: One of the radioactive isotopes released into the environment during the nuclear accident. When it enters the body, it accumulates in the thyroid, causing radiation exposure (internal exposure) to the thyroid.

*15 Whole body counter: Instrument used to measure the quantity of radioactive cesium and other substances in the entire body.

*16 1 millisievert = 1/1000 of a sievert. Sieverts are used to express the radiation exposure level to humans.

*17 Radioactive cesium: A radioactive substance that is representative of the radioactive substances released into the environment due to the nuclear accident and that persists in the environment for a long time.
In anticipation of the potential for radioactive substances entering the food supply during emergency conditions resulting from a nuclear accident or war, the Nuclear Safety Commission (currently the Nuclear Regulation Authority) of the Cabinet Office had established regulation standards for foods in the event of a nuclear accident. These regulation standards are the values that were applied immediately after the Fukushima accident. However, now the nuclear power station that caused the accident has been stabilized. Unfortunately, the regulation does not specify acceptable concentration levels for radioactive substances in food for the current rebuilding period. Standards for harmful substances contained in food products are normally set at very strict levels by the Food Safety Commission of Japan to ensure the safety of the country’s citizens. Consequently, the Food Safety Commission has now issued new standards for radioactive substances contained in food products. The criteria values for those standards were determined based on the premise of providing a higher sense of reassurance to consumers. Therefore, they were based on the food consumption of high school boys, who consume more food than any other demographic. Considering all effects of radioactive substances from the accident that have a half-life of one year or more, they assumed that 50% of what the boys ate would be from domestic sources and that all of that food would be contaminated with cesium and other radioactive substances. Even given those assumptions, the allowable level of radioactive substances in food was decided based on the amount of additional radiation exposure from eating the amount of food that a high school boy eats in one year being 1 millisievert or less.

Furthermore, a wide safety margin was also included in the quantity of allowable radioactive substances. Consequently, this means that about 750 kilograms of food containing the upper limit value of radioactive substances would have to be consumed at one time to actually achieve internal exposure levels equivalent to 1 millisievert.

It is supposed to be the responsibility of the national government to dispose of any disaster debris containing high concentrations of radioactive substances. To facilitate cleaning up the debris as soon as possible, waste processing facilities throughout Japan have been used to process debris that contain radioactive substances, but at lower concentration levels, as regular garbage, or in other words, as regular disaster debris. However, to ensure exposure levels to those living near the facilities processing the debris is below 1 millisievert, limits are specified for the amount of radioactive substances contained in the disaster debris that can be processed by respective prefectures. The 1 millisievert value is the same as the limit value specified for factories or hospital facilities that handle radioactive substances.
Using Radiation in Health Care

One of the most familiar uses of radiation in our daily lives is in the health care field. Most people have had an X-ray before and know what CT scans, contrast radiography of the gastrointestinal tract, and catheterization examinations are. These types of examinations all use X-ray radiation. A key property of radiation is its ability to penetrate objects (transmission), which is used in radiological examinations to see inside the body based on differences in X-ray transmission due to the atomic number and density of substances in the body. (It is based on the same principle as the baggage scanners used at airports.) In addition, radioactive substances are used for some types of examinations. This involves using a special camera outside the body to view radiation emitted from radioactive substances in administered drugs. It is used for diagnosing the health status or illness of a patient. Radiation also contributes to other medical fields, such as PET examinations of cancer. Radiation can be detrimental to the body if inappropriately large amounts are used. Therefore, in medical practice, specialists use only the amount of radiation necessary for that patient.

Because large amounts of radiation can damage cells (see 07: Effects on Cells), radiation is also used to treat malignant tumors. Radiotherapy is used throughout the world as a patient-friendly treatment that allows the patient to be treated without cutting. Radiotherapy that administers radioactive substances is also available. Radioactive iodine, discussed in 05 and 11, is the substance that was frequently in the news after the nuclear power station accident. However, by using its tendency to accumulate in the thyroid, it can be used to help treat hyperthyroidism or administered to patients with multiple pulmonary metastases of thyroid cancer. This treatment can be helpful even in cases that cannot be treated with surgery. Thus, radiation can be helpful to patients in diagnosing or treating such illness inside the body.
Radiation Levels in Japan

Even within the borders of Japan alone, the radiation level varies significantly depending on the location. Areas with large amounts of radium hot springs, radon hot springs, or exposed granite containing high levels of radioactive substances such as uranium or thorium have naturally high levels of radiation. These types of areas are particularly common in the Kinki, Chugoku, and Shikoku regions of Japan. In contrast, radiation levels are low in the Kanto Plain, which is covered in volcanic ash from past eruptions of Mount Fuji.

Afterword

The booklet was prepared to provide basic information about radiation. When you first hear the words radiation or radioactive substance, you may not immediately understand them clearly. However, to understand things that you previously didn’t know about, you need to read the same explanations several times or keep listening to related explanations. As you do that, you will begin to understand the words and gain the ability to draw conclusions for yourself. This booklet that we created only contains a fraction of all the relevant information, but we urge you to review the information from time to time. We hope that this booklet will inspire you to confront the issue of radiation. Rather than feeling overwhelmed or defeated by the nuclear power station accident, we hope this will help get you feeling back on your feet. We offer it with heartfelt sincerity.
This booklet was prepared by the Research Group for the Promotion of Measures to Ease Anxiety over Health Concerns Regarding Radiation from Risk Communicators Based on Regional Characteristics (head researcher: Kazuko Ohno) as part of the 2013 Japanese Ministry of the Environment efforts to investigate the effects of a nuclear power disaster.

There continues to be many problems that are not addressed in this booklet. For more information, refer to our website.

HP (URL/https://riscomi.kyoto-msc.jp)