Basic Information on Radiation Exposure from Radioactive Contamination

1. Radiation, radioactivity, and radioactive contamination

Radiation exposure can cause disease. Radiation damages organs and tissue in humans, sometimes resulting in disease. If radiation is emitted by particular substances (**radioactive substances**), they are referred to as being **radioactive**, and the situation in which radioactive substances are not managed securely with potential human exposure is called **radioactive contamination**.

2. Radiation exposure pathways from radioactive contamination

a. External exposure and internal exposure

There are two main pathways for human radiation exposure: **external exposure** and **internal exposure**. External exposure happens when radiation is emitted by radioactive substances (referred to as **radiation sources**) outside the body, and internal exposure occurs when radiation is emitted from radiation sources taken into the body.

b. Radiation exposure pathways from nuclear power plant accidents

There are two or more pathways for radiation exposure in the case of radioactive contamination caused by nuclear power plant accidents, as follows:

(i) External exposure to radiation emitted by radioactive substances from nuclear power plants

The level of this type of radiation exposure decreases as the distance between a person and the radiation source increases (gamma-ray doses, for example, decrease inversely with square of distance) and as the sojourn time decreases (doses decrease proportionally with sojourn time). Exposure level is further reduced if shielding is present between the person and the radioactive substance.

(ii) External exposure to radiation emitted by radioactive substances that are released from nuclear power plants, carried by wind and rain, and affixed to skin, clothes, and soil

The level of radiation exposure from radioactive substances carried far from nuclear power plants is determined by the distance between a person and the radioactive substance, the time the person spends close to the radioactive substance, and shielding between the person and the radioactive substance (how the person is shielded from the substance).

(iii) Internal exposure to radiation emitted by radioactive substances that are released from nuclear power plants and taken into the body through breathing, food and drink, and wounds

This type of exposure continues for the duration of time such radioactive substances remain in the body.

3. Radioisotope and radiation

An atom, the basic unit of matter, consists of an atomic nucleus and electrons. The atomic weight is determined almost exclusively by the numbers of protons and neutrons, and the total number of protons and neutrons combined is known as the atomic mass. The atomic nucleus contains protons and neutrons. The same atoms (or elements) have the same number of protons (e.g., hydrogen has one, and helium two). However, there are numerous elements in nature with different weights (or masses) that still are the same element. For example, the most common atomic mass of a carbon atom is 12, which is expressed as carbon-12 with the mass number indicated after the element name, but the isotope used for archeological dating estimates is a carbon isotope with the atomic mass of 14 (carbon-14). The difference between the two isotopes is the number of neutrons in the atomic nucleus (the number of protons is six for both isotopes). Carbon-12 has six protons and six neutrons in its nucleus and does not emit radiation, while carbon-14 has two extra neutrons and does. Strangely enough, having too few or too many neutrons in a nucleus destabilizes the atom. Variants of atoms of a particular element with differing mass numbers are called “isotopes” and radioactive isotopes are called “radioisotopes.”

a. Nuclear decay

Radioisotopes have unstable nuclei, and with a certain probability, emit excess energy as radiation, thus transforming to different elements. This process is called nuclear decay (disintegration). Three types of radiation are emitted from this process of nuclear decay -- alpha, beta, and gamma rays -- and the type of radioisotope (**radionuclide**) determines what type of radiation is emitted.

b. Half life of radionuclide

The time for half of a radionuclide’s atoms to decay is called the **half-life (physical half-life)** of a radioactive substance, and this timeframe differs among radionuclides. Another type of half-life called **biological half-life** is the time required for a radionuclide taken into the body to lose half of its radiologic activity through such biological processes as metabolism and excretion. The time it takes for a radioactive substance taken into the body to halve its radioactivity as a result of the combined action of nuclear decay and biological elimination is known as **effective half-lif**e.

c. Radionuclides released in nuclear power plant accidents

Whether from nuclear power generation or an atomic bomb, energy is generated from atomic fission caused by the collision of neutrons in uranium or plutonium. Atomic fission (or nuclear fission) is, just as the term indicates, a phenomenon marked by an atomic nucleus splitting into two or more parts. When uranium-235 undergoes nuclear fission in a nuclear reactor, it produces such radioactive substances as iodine-131, cesium-137, strontium-90, and cobalt-60. Release of such radioactive substances into the environment in large quantities due to a nuclear power plant accident could cause serious health effects from radiation exposure to these substances.

Iodine-131: Physical half-life of 8.02 days, meaning that it takes about eight days for 100 radioactive iodine-131 nuclei to be reduced to half that number (50 nuclei), and another eight days to be further reduced to 25 nuclei. Iodine tends to bind to the thyroid. The relationship between childhood exposure to radioactive iodine and increased risk of thyroid cancer has been confirmed as a result of the Chernobyl nuclear power plant accident.

Cesium-137: Half-life of 30.07 years. It is readily absorbed into muscle tissue.

Strontium-90: Half-life of 28.78 years. It is readily absorbed into bone tissue.

Cobalt-60: Half-life of 5.27 years.

4. Measurement of radiation

Radiation is measured by many methods and expressed in different units, depending on the purpose, as follows:

a. Measurement of contamination: unit = counts per minute (cpm)

The number of ionizing events per minute (cpm) resulting from radiation emission is measured at the sensor screen of radiation measurement devices (e.g., Geiger-Mueller [GMsurvey] meters). This method, usually employed to evaluate contamination levels, is the type of radiation measurement (contamination test) being conducted for residents living near the Fukushima Daiichi nuclear power plants after the accident. Cpm readings by GM survey meters mainly reflect beta rays, which do not penetrate deeply inside the body (traces of gamma rays are also measured). Therefore, cpm readings themselves cannot be converted to exposure doses. In measuring levels of radiation contamination in foodstuffs, instruments much more complex than survey meters are used to count nuclear decay per kg (unit: decay per minute, dpm, or decay per second, dps). Dps is equivalent to the unit becquerel (Bq). With information on types of radionuclides, energy of radiation emitted can be determined, making it possible to convert readings to exposure doses.

b. Measurement of radiation energy absorbed by substances: unit = **gray (Gy)**

The energy absorbed is called "**absorbed dose**" and 1 Gy means absorption of 1 joule of energy by a substance with a mass of 1 kg. Joule is a unit of energy, and 4.2 joules is equivalent to 1 calorie, the amount of energy needed to increase the temperature of 1 gram of water by 1 °C. This means that absorption of (exposure to) a dose of 1 Gy is a minuscule amount of thermal energy barely enough to heat 1 kg of water by 0.0002 °C. However, radiation energy has the unique characteristic of damaging DNA and other substances at a molecular level imperceptible to humans.

c. Risks from radiation exposure (risk of developing cancer in the future): unit = **sievert (Sv)**

There are two types of doses: **equivalent dose** and **effective dose**. Each dose is multiplied by a specific factor(s) for estimation of such risks.

(i) Equivalent dose = absorbed dose × **radiation weighting factor**

Radiation weighting factors are used, in expressing exposure doses, to take into account different radiation effects and risks for the same energy absorption, depending on radiation type, such as alpha, beta, and gamma rays. The factors for gamma ray, neutron, and alpha ray are 1, 10, and 20, respectively. This means that absorption of energy equivalent to 1 joule is expressed differently for gamma rays and neutrons: 1 Sv and 10 Sv, respectively.

(ii) Effective dose = absorbed dose × radiation weighting factor × **tissue weighting factor**

Tissue weighting factors are used in expressing exposure doses to reflect different radiation effects depending on the organ and tissue.

5. Radiation risks and radiation protection standards

a. Radiation risks as scientific findings

Radiation risks are scientific estimates based on epidemiological studies and related basic research of radiation-exposed populations. Results of epidemiological studies and basic research throughout the world are collected, assessed, and assembled as radiation risks by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). This organization’s 2000 report concluded that “The results of that research (i.e., the studies of the Japanese survivors) provide the primary basis for estimating the risk of radiation-induced cancer” (para. 76), and that “Statistically significant risks for cancer in the Life Span Study are seen at organ doses above about 100 mSv” (para. 78). The report also refers to studies of the victims of the Chernobyl nuclear power plant accident in terms of studies of internal exposure and states that “an elevated risk of thyroid cancer ... as a result of the Chernobyl accident shows a link with radioactive iodine exposure during childhood” (para. 81).

b. Radiation protection standards based on radiation risks

The International Commission on Radiological Protection (ICRP) recommends specific regulatory standards for radiation protection, such as maximum permissible dose, based on radiation risks scientifically assessed with UNSCEAR’s and ICRP’s standards, which take into consideration societal demands, ethics, and past experience in application of standards. ICRP’s recommendations are incorporated in the international Basic Safety Standards (BSS) of the International Atomic Energy Agency (IAEA) and in national regulations of various countries.