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Position Statement (View, Suggestion, Explanation, Others)

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Atomic Energy Society of Japan

Health Physics & Environmental Science Division

Effects of low-level radiation exposure on human health

Introduction

Owing to the Fukushima Dai-ichi nuclear power plant disaster, many people are concerned about the effects of radiation on human health. In this paper, the effects of low-level radiation exposure on human health are explained in an easy-to-understand manner on the basis of recommendations of the International Commission on Radiological Protection (ICRP) that have been adopted in domestic radiation safety regulations in many countries including Japan.

Radiation effects

The effects of low-level radiation exposure can be divided into two main categories, "deterministic effects" and "stochastic effects".

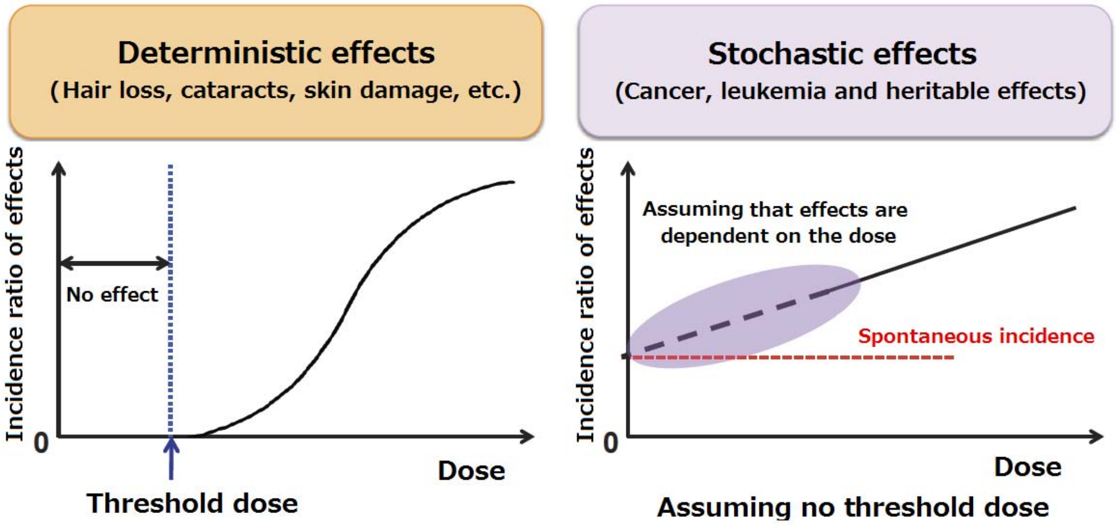

Fig. 1 Deterministic and stochastic effects

Reference: Booklet to provide basic information regarding to health effects of radiation ver.2015001 (http://www.env.go.jp/chemi/rhm/h27kisoshiryo/attach/201606mat2-03-4.pdf)

Deterministic effects of radiation

A deterministic effect occurs when people are exposed to radiation (hereinafter, radiation exposure) exceeding a certain level, as shown in the left graph of Fig. 1. This level is called the "threshold dose" because it is a threshold value (target) determining whether or not effects on human health occur. Once people are exposed to a high dose exceeding, the threshold level, a significant deterministic effect will occur (at a rate of 1% or more[1]). In addition, the higher the dose, the more serious the effect becomes, with an increase in the likelihood of occurrence. Deterministic effects include sterility, a decrease in haematopoiesis (lymphocyte), skin damage, hair loss, cataracts and damage to the gastrointestinal tract, lungs, kidneys and nervous system. It has been revealed that the threshold dose of each symptom depends on the type of effect[1]. In its latest main recommendation in 2007[1], the ICRP, which is the leading international body for formulating protective measures against the effects of radiation exposure on human health, recommended that the minimum threshold dose among these symptoms is about 100 mGy (equal to about 100 mSv in the case of exposure to gamma rays) (*1) when the dose is received at a single time. This value is considered to be the same when the total dose is received throughout a year such as that received by radiation workers[1]. In addition, it was also recommended that the exposure of embryos and fetuses to doses of less than 100 mGy incurs no risk of malformation[1]. Regarding mental retardation (the delay of mental development), according to data for atomic bomb survivors on the induction of severe mental retardation after exposure during the most sensitive prenatal period (8–15 weeks post-conception), it is considered that the threshold dose for mental retardation is 300 mGy, below which there is no risk of mental retardation[1]. In summary, it can be concluded that deterministic effects do not occur at doses less than 100 mGy. Fortunately, in the Fukushima Dai-ichi nuclear power plant accident, the exposure of the public to high doses of 100 mGy or more was not observed[2]. For the above reason, there is no need for the public who were exposed to radiation as a result of the accident to be concerned about deterministic effects.

Stochastic effects of radiation

Stochastic effects include cancer (including leukemia) and heritable effects that occur in offspring after the exposure of the parent. As shown in the right graph of Fig. 1, stochastic effects have a characteristic that their incidence rate increases with the irradiated dose in the case of exposure to a high dose. Since stochastic effects do not occur in everyone exposed to radiation, it is necessary to estimate the incidence rate by collecting data on a large number of people exposed to radiation. The investigation of the incidence rate of stochastic effects has used a large amount of epidemiological data (on the effects on human health such as cancer) obtained from follow-up surveys of groups of about 120,000 atomic bomb survivors from Hiroshima and Nagasaki, inhabitants exposed to radiation after the Chernobyl nuclear power plant accident, patients exposed to medical radiation to cure cancer and so forth[3-4]. So far, cancer incidence data have mainly been analyzed in detail. On the basis of these data, various standards for radiation control to ensure the safety of human health have been prepared. Regarding heritable effects, there is no significant statistical difference between naturally occurring effects and effects observed in atomic bomb survivors and radiation therapy patients[1)].

Effects of low-level radiation exposure on human health

When we consider the effects of low-level radiation exposure on human health, cancer is the only issue because deterministic effects do not occur at doses of less than 100 mSv (*2) and a significant incidence of stochastic heritable effects has not been observed even in atomic bomb survivors who were exposed to higher doses. The cancer incidence rate due to low-level radiation exposure has mainly been estimated using the investigation results for a group of atomic bomb survivors from Hiroshima and Nagasaki. Regarding the relationship between radiation dose and cancer incidence, the cancer incidence rate increases linearly with the dose above a dose of approximately 100 mSv. However, at doses below 100 mSv, it is unclear whether the cancer incidence rate linearly increases because the rate of cancer incidence due to radiation exposure is too low. Moreover, it has been clarified by experiments on animals that the effect of radiation exposure on health tends to be reduced when the total dose is received little by little over a long time, such as in the case of radiation workers, that is, exposure with a low dose rate (low dose per unit time), compared with the case when the total dose is received in a short time, such as for atomic bomb survivors, that is, exposure with a high dose rate[1)]. The dose and dose rate effectiveness factor (DDREF) is used as an index to indicate the degree of reduction of the effects of low-level dose or/and low-dose-rate radiation exposure on human health. The ICRP recommends the use of a value of two for the DDREF when estimating the incidence rate of stochastic effects on human health because the incidence rates for a low dose (200 mSv or less) and a low dose rate (100 mSv per hour or less) are half of those for a high dose or a high dose rate[1)].

The ICRP adopts a model assuming that cancer occurs with a probability proportional to the total dose even if the received dose is very small (LNT model) on the basis of experimental studies and epidemiological data[1)], assuming that stochastic health effects such as cancer incidence increase linearly with the total dose. There has been considerable discussion on the appropriateness of the LNT model even though the ICRP recommendations and Japanese radiation safety regulations based on the ICRP are premised on the LNT model. The French Academy of Sciences and French National Academy of Medicine argued for the existence of a lower limit of the radiation dose that increases cancer incidence in a joint report[5)]. In their report, it is explained that the

LNT model overestimates stochastic effects at low doses of 100 mSv or less because there is a mechanism for the body to remove damaged cells following radiation exposure according to radiobiology research results and because the incidence rate of leukemia was not found to be proportional to radiation exposure in epidemiological studies. In contrast, the BEIR-VII (Health risks from exposure to low levels of ionizing radiation) report[6] published by National Academy of Sciences reached the opposite conclusion, that is, the relationship between stochastic effects and radiation exposure can be explained by the fact that damage to DNA can occur even if the radiation dose is relatively low, as a result, cancer and mutation are probabilistically related. On the basis of these discussions, the ICRP recommends the adoption of the LNT model for the practical purposes of radiological protection and radiation control[1].

In the ICRP 2007 main recommendations[1], on the basis of a study on a group of atomic bomb survivors from Hiroshima and Nagasaki, the ICRP recommends that the risk coefficients (risk factors estimated on the basis of the cancer incidence per unit radiation exposure, loss of life span and the reduction in the quality of life due to cancer), which are estimated using a value of 2 for the DDREF and the LNT model, are 5.5% per Sv whole population and 4.1% for adult workers, thus making it appropriate to use a risk coefficient of about 5% per Sv for the purpose of radiation control. The higher risk coefficient for the whole population, which includes adults and children, is because the risk for children is higher than that for adults. The ICRP recommends that it is prudent to assume that the cancer risk for a fetus in the uterus following exposure is almost the same as that following irradiation in early childhood, that is, up to about 2-3 times that of the population as a whole[1]. Taking into consideration these recommendations, the decontamination of living environments used by small children, for example, school yards, were carried out with high priority after the Fukushima Dai-ichi nuclear power plant accident.

To realize a risk of 5% per Sv, it is important to understand the cancer risk incurred by Japanese people in daily life due to smoking, alcohol consumption, chemicals agents and so forth, that is, lifetime cancer mortality (hereinafter, lifetime cancer risk). As shown in Fig. 2, the national average lifetime cancer risk in Japan as of 2010 is 25.4%[7]. This indicates that one in four in Japanese people die from cancer. If each Japanese person is exposed to 100 mSv radiation, the lifetime cancer risk will increase by 0.5% according to the LNT model, taking into consideration the risk coefficient of 5% per 1,000 mSv, which means that the national average lifetime cancer risk will increase from 25.4% to 25.9%. On the other hand, the lifetime cancer risk in daily life without additional exposure varies between 23.7% and 28.3% among the prefectures of Japan due to differences in lifestyle such as diet[7]. This increase in risk of 0.5% following exposure to 100 mSv radiation is sufficiently small to be buried in the deviation. In epidemiological studies, it cannot be clarified whether the increase in risk is proportional to the radiation exposure when the radiation dose is approximately 100 mSv or less because the increase in risk is too small. However, assuming that there is a risk based on the LNT model, radiation exposure of 20 mSv and 1 mSv will lead to increases in risk of 0.1% and 0.005%, respectively.

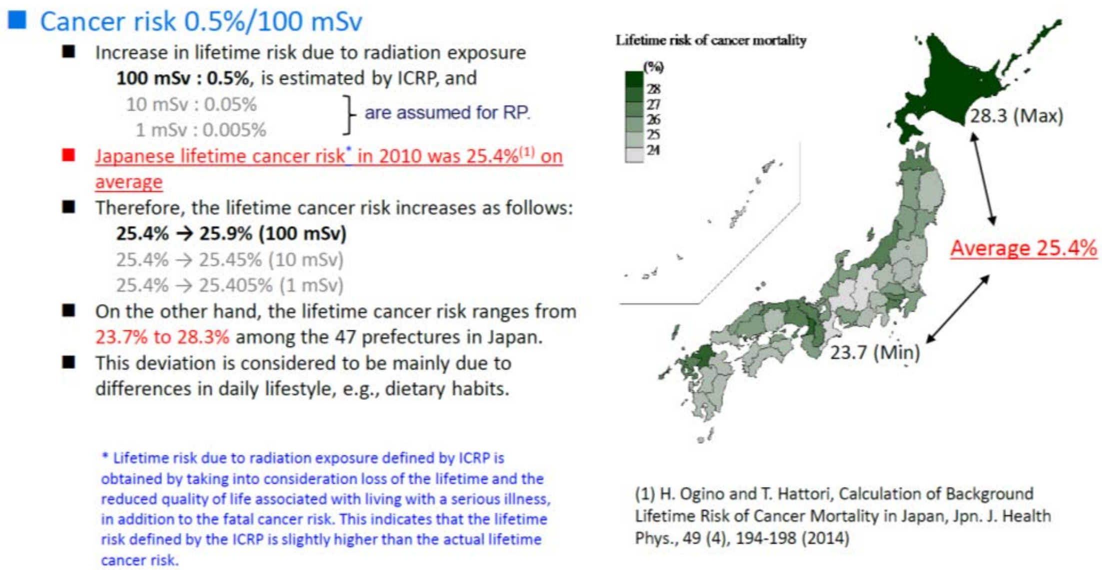

Fig. 2 Deviation of lifetime cancer risk[7)]

As explained above, the stochastic effects following radiation exposure are cancer and heritable effects. However, from recent epidemiological studies on atomic bomb survivors and research on health effects in groups of radiation therapy patients and recovery workers at the Chernobyl nuclear power plant, it has been reported that mortality due to heart disease, strokes, digestive diseases and diseases of the respiratory system may increase in proportion to radiation exposure similarly to cancer[8)] as if they are stochastic effects. In the ICRP 2007 recommendations, it was judged that these non-cancer effects should not be included in the risk of low-level radiation exposure because their incidence mechanisms have not been clarified sufficiently and because there is no inconsistency among the studies even if there is a threshold dose at approximately 500 mSv[1)]. In a statement released after the recommendations, the ICRP clarified that circulatory diseases such as heart disease and strokes should be classified as deterministic effects[8)].

Closing remarks

The Health Physics & Environmental Science Division of the Atomic Energy Society of Japan supports the concepts in the ICRP 2007 main recommendations[1)], which was published on the basis of scientific knowledge gathered before the early 2000s and transparent discussion. The previous main recommendations of the ICRP in 1990[9] provide the fundamental principles of the current radiological safety regulations in Japan and various other countries. Since the Basic Committee of the Radiation Council has already published a second interim report[10] that summarizes the results of debating the adoption of the ICRP 2007 recommendations, in the near future, the contents of the ICRP 2007 main recommendations[1] will be incorporated in Japanese national regulations. The concepts of radiological protection and radiation control are continuously evolving with the adoption of new scientific knowledge. For the sake of considering whether the ICRP should select a different value of the DDREF, adopt a new model other than the LNT, and include non-cancer effects in the radiation risk, it is necessary to accumulate further knowledge on epidemiological studies related to radiation effects and biological studies to clarify the mechanism associated with radiation effects.

References

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Note #1

The unit mGy is the unit of dose used to show the amount of energy received by a materials or human from radiation (hereinafter, absorbed dose). In the case that the energy received is 1 J per kg, the absorbed dose is 1 Gy, and one-thousandth of this dose is 1 mGy.

Regarding the deterministic effects in the text, the dose corresponding to the rate of radiation exposure effects (hereinafter, equivalent dose) should have been expressed using the unit Sv. However, to distinguish the equivalent dose from effective dose (for which the same unit Sv is used) discussed in Note #2 below, the absorbed dose is given in Gy for the deterministic effects in this statement. In the case of X-rays or gamma rays, the absorbed dose in Gy and the equivalent dose in Sv have the same value.

Note #2

The unit mSv is a unit of the effective dose. The effective dose is used as the radiation dose for the purpose of radiological protection and radiation control. For a given absorbed dose, the incidence rates of deterministic and stochastic effects are different depending on whether the whole body or specific organs are exposed (regional exposure). The effective dose is the radiation dose corresponding to the total cancer rate for the whole body, which is obtained by adjusting the weighting of the radiation dose received by each tissue and organ with the tendency of the incidence of cancer due to radiation (including the hereditary effect). If the whole body is exposed to gamma or X-rays of 1 mGy, the effective dose will be about 1 mSv. The unit mSv is frequently used as 1/1,000 Sv. In UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) reports[3, 11)], the average effective dose received by the public worldwide from natural radiation is given as 2.4 mSv per year.