Priority Subjects — **Establishment of Optimal Risk Management**

Quantitative Evaluation of Low-Dose Radiation Risk and its Reflection on Radiation Protection

Background and Objective

The radiation exposure to the public from environmental contamination caused by nuclear accidents and to workers in nuclear facilities is characterized as prolonged low-dose-rate exposure. Epidemiological research studies of residents in high background radiation areas suggest the existence of a dose-rate effect with no increase in radiation risks at a low-dose-rate. Understanding biological mechanisms of the dose-rate effect are needed to relieve public concern towards radiation exposure, and to establish scientific and reasonable protection systems. It is also useful to review the system of radiation protection that targets radiation use in general.

This project aims to reflect the dose-rate effect in radiation protection systems by elucidating its biological mechanisms through experimental studies, and to clarify the issues in risk assessment and radiation protection, which were revealed by the Fukushima Daiichi nuclear power plant accident, to support the resolution.

Main results

1 Construction and verification of a mechanistic model of dose-rate effects

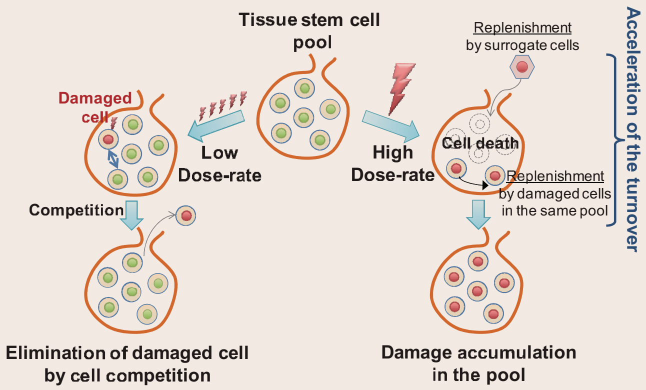
It is known that cancers are caused by accumulation of genetic lesions in a group of tissue stem cells*1 (stem cell pool). In the case of high dose-rate radiation exposure, all cells in the stem cell pool are damaged simultaneously by radiation and most of them are lost by cell death. To keep tissue mass constant, the stem cell pool has to be replenished by damaged surrogate cells. This would result in accumulation of damaged stem cells (Fig. 1, right). In contrast, at a low-dose-rate, a limited number of stem cells in the pool are damaged at a time. Therefore, we hypothesized a dose-rate dependent mechanism that damaged cells may be eliminated by the turnover of stem cells or in competition with undamaged stem cells at a low-dose-rate (Fig. 1, left).

In order to verify this hypothesis, we evaluated whether stem cell pool affected by stem cell replenishment after the same cumulative dose by different dose-rate using genetic transgenic mice, in which loss of the stem cell pool can be detected by color. After 1 Gy irradiation, stem cell replenishment could be observed, however, it could not be detected by a low-dose-rate (Fig. 2). This result indicated that the stem cell pool could be affected by independent mechanisms under different dose rate conditions.

2 Identification of important solutions by surveying the reports related to the Fukushima Daiichi Nuclear Power Plant accident

Regarding radiation exposure of the members of the public and radiation workers due to the release of radioactive substances from the Fukushima Daiichi Nuclear Power Plant accident, several issues on dose/risk estimation, and on radiation protection were enumerated by domestic and international professional bodies. In order to apply those lessons learned and experiences for the development of protective actions and for the improvement of the system of radiation protection in the future, identification of main solutions is necessary. For this, by surveying dose and risk estimation reports*2 published by the professional bodies, uncertainty factors have been categorized and assessed from the viewpoint of their characteristics such as the possibility of a substitute plan, etc., to identify the major requirements and corresponding solutions. Then, the relationship between those solutions and radiation protection issues were clarified. Consequently, it was found that the important solutions, which means common and noteworthy challenges for both dose/risk estimation and radiation protection issues, were implementation of personal monitoring at the emergency exposure situation*3 for reduction of the uncertainty of dose estimation, and quantified assessment of low-dose radiation risks, which is the basis of adequacy judgement of risk evaluation and radiation protection standards (Fig. 3).

*1 Cells of origin which maintain the tissues with small number and can produce functional cells throughout life.
*2 Reports published by the World Health Organization (WHO), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological protection (ICRP), and the Japan Health Physics Society were selected.
*3 A situation requiring urgent action to avoid or reduce the risk of radiation exposure.



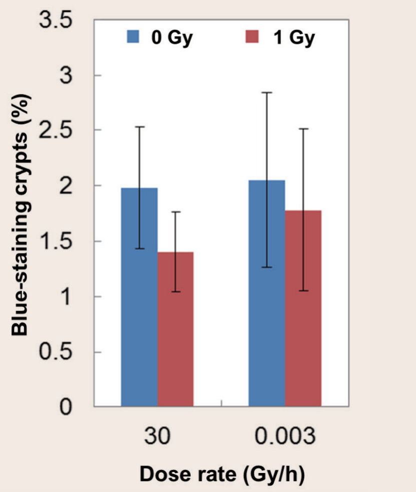


Fig. 1: A mechanistic model of dose-rate effect and stem cell replenishment

The stem cell pool was maintained by replenishment of surrogate cells at a high dose-rate, then damage accumulated in the pool (right). In contrast, stem cells were maintained by turnover or cell competition, which can eliminate damaged cells (left). However, an experimental turning point of the dose-rate effect is still unknown. Using transgenic mice, stem cell replenishment can be detected as the loss of blue-stained tissue components, named crypts.

Fig. 2: Dose-rate effect of stem cell replenishment

Percentage of blue-staining crypts after 1 Gy (red bars) irradiation by high dose-rate (30 Gy/h, left) or low dose-rate (3 mGy/h, right), compared to unirradiated background levels (blue bars). Statistically significant replenishment was observed only at high dose-rate radiation exposure (p=0.04).

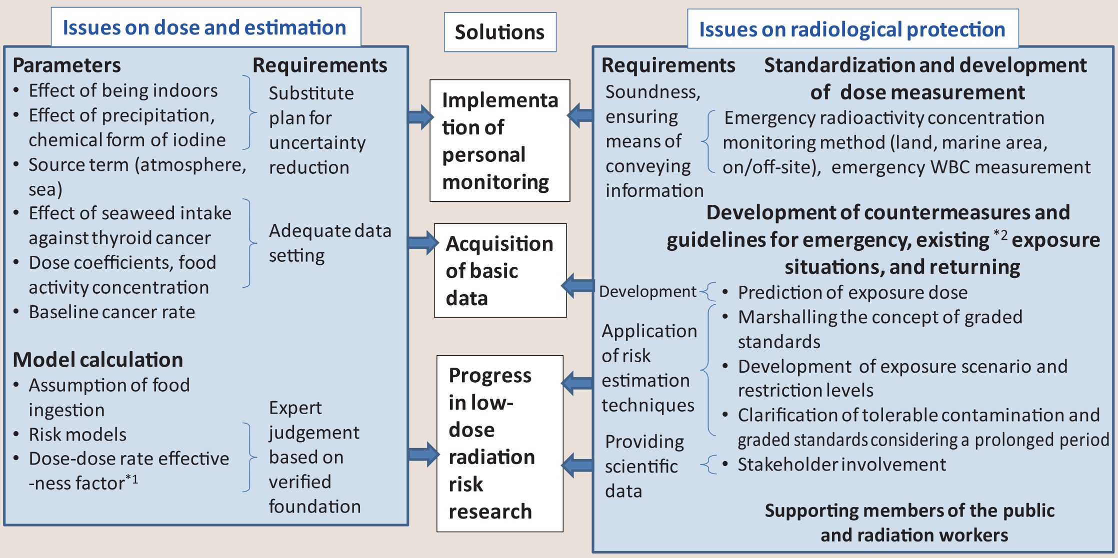


Fig. 3: Important issues and solutions on dose/risk estimation and on radiation protection

Uncertainties in the dose and risk estimation relate to the parameter values and the models performed in the calculation. It was found that those two issues were important since the former includes external doses during and after the nuclear power plant accident, which is difficult to improve the accuracy of afterwards; the latter includes dose-dose rate effectiveness factor, which requires the adequacy of expert judgment (Fig. 3, left). Furthermore issues on radiation protection, which were identified and enumerated by the professional bodies from their own viewpoints, were comprehensively reviewed (Fig. 3, right). In order to solve the issues on uncertainty related to dose and risk estimation, and on radiation protection, it was clarified that implementation of personal monitoring and progress in low dose risk estimation researches are especially important (Fig. 3, center).

*1: A reduction factor to estimate radiation risk at a low-dose and a low-dose-rate exposure.
*2: A situation in which there is an existing radioactive source prevalent, such as exposure over a prolonged period following a nuclear accident.