Chapter 2
Outline of the Radiation Dose Estimation of Residents After the Fukushima Daiichi Nuclear Power Plant Accident

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Abstract The outline of research with relationship to the dose estimation of the residents, which was carried out by a variety of organizations and individuals, is summarized here. This research may be categorized into that for external dose and for internal dose estimation. In addition to the large-scale investigations carried out by governmental organizations, several important studies were carried out by small sectors and individuals.

Keywords Dose estimation • Dose reconstruction • External exposure • Health effects • Internal exposure • Radiation dose

2.1 Introduction

Many residents in the Fukushima Prefecture and neighboring areas were exposed to significant doses of radiation as a result of the radioactive nuclides that were accidentally released from TEPCO'S Fukushima Daiichi nuclear power plant. In the days immediately following the accident, radiation exposure was caused by isotopes of iodine and short-lived radionuclides. As time progressed, radiocesium, that is, cesium-134 and cesium-137, became the major source of radiation. The exposure pathways were external irradiation by radiocesium deposited in the environment and internal irradiation through consumption of foods contaminated with radiocesium.

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Although an accurate estimation of the radiation dose was essential for predicting the health risks to residents and for adopting suitable and effective measures against the radiation risks, it was not easy to achieve an accurate dose assessment for residents because of the complexity of the exposure routes.

Soon after the accident, environmental monitoring of air dose rates and measurements of the concentrations of radioactive nuclides in various environmental materials, including soil, tap water, and food, were widely implemented by the Japanese and local governments, institutes, universities, small groups, and individuals. Some of the results of such monitoring were reported by news media as well as on Internet websites, used for dose estimation for residents, and published in scientific papers. In contrast with this environmental monitoring and these surveys, direct monitoring or measurement of individual radiation doses was not widely carried out in the early stages after the accident. Compared with environmental monitoring, there have not been many attempts to estimate actual radiation doses in the residents, except for large-scale surveys by governmental organizations.

The personal radiation dose is the most important parameter for planning and implementing suitable protective measures. Nevertheless, the attention of the public, governments, and even scientists has mainly been focused on environmental radiation dose and radioactivity, and not particularly on actual radiation dose in individuals, especially in the early stages after the accident. A detailed and easily understandable explanation of the concept of radiation dose assessment is provided in the excellent commentary article by Dr. Inaba in this book (see Chap. 4). In this chapter, we outline the activities performed in an attempt to monitor, measure, or estimate the personal radiation doses of the residents, based mainly on the information presented at the International Symposium on Environmental Monitoring and Dose Estimation of Residents after the Accident of TEPCO's Fukushima Daiichi Nuclear Power Stations, organized by Kyoto University Research Reactor Institute on December 2012 (hereafter referred to as "The Symposium").

2.2 External Dose Estimation

There are two main pathways in external exposure: exposure from a radioactive plume released from nuclear facilities into the atmosphere in the early stages after an accident, and exposure from radionuclides deposited in the surrounding environment, such as land and buildings, after the plume has passed through. A few approaches are generally used to estimate the external radiation doses. A direct and reliable method is personal monitoring with a dosimeter. Personal dosimeters, such as a glass badge and an electric dosimeter, can be used for this purpose. Such direct monitoring is most common for radiation workers in a radiation-controlled area. However, if such direct personal monitoring is not possible, the dose should be estimated using models with some assumptions and environmental monitoring data such as air radiation dose rates.

In the early stages when the radioactive plume was a major source, it was almost impossible to monitor the personal doses of residents directly, and there was no such report in the case of the Fukushima accident. It was speculated that some radiation workers with a personal dosimeter worked with the refugees and were exposed to the radioactive plume. However, personal doses for those radiation workers have not been reported anywhere. In the future, personal dosimeters should be provided to certain public facilities, such as schools and city halls, in specific areas near nuclear facilities such as the emergency planning zone (EPZ), and used for monitoring actual personal radiation doses.

If direct monitoring or measurement of a personal dose is difficult, it may be possible to estimate it using monitoring data (e.g., air radiation dose rates) and analyses of personal behavior, with relatively better accuracy than the estimation of internal doses. The Fukushima Prefecture carried out an estimation of personal doses on a large scale, with the support of the National Institute of Radiological Sciences: this was done as part of the Fukushima Health Management Survey, and 400,000 personal doses were assessed over 4 months, from March to July 2011. This assessment is retrospective; therefore, it is sometimes referred as "dose reconstruction." Detailed data of this assessment are provided at the prefecture's Internet site [1] and are also commented on by Inaba (see Chap. 4).

In the later stages when the deposited radiocesium became the dominant radiation source, some trials began to include the direct monitoring of personal radiation doses, which was handled by local government, groups, and individuals using dosimeters. For example, Fukushima City provided glass badges to 16,223 citizens for 3 months and reported that the cumulative dose of the period was less than 0.2 mSv [2]. In contrast with this large-scale governmental monitoring, some small groups also tried to clarify the actual personal radiation doses locally. Yoshida et al. monitored the personal dose equivalent in local towns in Miyagi Prefecture by using optically stimulated luminescent dosimeters (see Chap. 19). This study provides not only information about the actual radiation doses of the residents, but also scientific explanations of the discrepancy between the personal doses derived from the air dose rates and those measured directly with a personal dosimeter. In Chap. 17, Kinashi et al. report the personal radiation doses of the staff of Kyoto University, who were dispatched to Fukushima to screen the radio-contamination of refugees in the evacuation shelters. This report shows a typical personal radiation dose of a person who stayed in a specific shelter.

Some researchers also estimated personal doses from the environmental monitoring data (e.g., air dose rates), retrospectively and prospectively. Some of these have been reported in this book as well as in the Symposium. Takahara et al. provides an excellent research work on the probabilistic dose assessment of the residents living in contaminated areas (see Chap. 18). Yamamoto et al. measured the air dose rate and estimated the annual dose after the accident in Tochigi Prefecture [3]. Similar assessments had been carried out by Endo et al. for Miyagi Prefecture and by Amano et al. for Chiba Prefecture [4, 5].

2.3 Internal Dose Estimation

Major routes of intake of radionuclides into the human body are by inhalation and oral ingestion. The uptake by inhalation may be categorized into two patterns: inhaled as radioactive gas or particles in the plume, and as particles resuspending from initially deposited sites. The ingestion of foodstuffs and water contaminated with radionuclides is a common route of oral intake, and additionally licking contaminated hands and daily items such as toys becomes a possible intake route, especially for infants and children.

In the early stages after the accident, no attention was paid to internal radiation doses. It seemed that the government intentionally ignored internal exposure. The estimation of internal radiation doses resulting from inhalation of radionuclides is generally complex and difficult, compared with the estimation of external doses. At present, few data and little information are available for estimating the accurate internal doses of each resident resulting from the inhalation of radioactive gases and short-lived radionuclides such as radioiodine in the plume. The National Institute of Radiological Sciences is now making extensive endeavors to reconstruct a system for estimating the internal radiation doses soon after an accident (i.e., a dose reconstruction system). Their interesting and important activities are summarized in Chap. 16 by Kurihara et al.

Radiation exposure of the thyroid is an important issue for human health, especially for children, in the early period after a nuclear accident. Induction of thyroid cancer by the intake of radioiodine in the plume through inhalation had been a major concern because of the Fukushima accident. The Japanese government carried out a screening survey for 1,062 children living near the nuclear plant and reported that no child had an equivalent thyroid dose of more than 50 mSv. Tokonami et al. also measured radioiodine activity in thyroid in situ [6]. Radioiodine activity determined by a whole-body counter in the volunteer workers at the shelter facilities is presented by Kinashi et al. in Chap. 17.

In the later stages after the accident, Fukushima Prefecture started monitoring radiocesium activity in residents by using a whole-body counter. According to their data, 132,011 people were surveyed from 27 July 2011 to 31 March 2013 and only 26 people were estimated to have a committed dose of more than 1 mSv [4, 7].

2.4 Conclusion

The direct monitoring or measurement of personal radiation doses was not carried out sufficiently, especially for internal dose estimation at the early period after the accident, compared with monitoring of radiation dose rates and radioactivity in the environment. The huge numbers of becquerels (Bq) in the environment (kilo, mega, giga) caused severe concern initially, although if these numbers were converted to effective doses, the actual personal radiation doses are not so significant. I wish to conclude this chapter by stressing that it is important in the future to clarify the personal radiation dose soon after an accident so that suitable and effective protective measures can be undertaken for residents against radiation risks to ensure their safety.

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