

Chapter 12

Safety Evaluation of Radiation Dose Rates in Fukushima Nakadori District

Masayoshi Kawai, Michikuni Shimo, and Muneo Morokuzu

Abstract After the TEPCO Fukushima DAIICHI NPP accident, IAEA and ICRP advised accelerating the decontamination work to clean up the living environment of the areas where additional annual radiation exposure doses are beyond 1 mSv per year (i.e., 1 mSv/y) and to diminish radiation worries. However, the advice was not recognized well because it did not contain clearly understandable numerical data. In the present work, the ambient radiation dose rates in the Nakadori district have been investigated to clarify that the doses are lower than 1 mSv/y in the major part where the decontamination was completed. A part of the district and three municipalities in the special decontamination area have doses of 1.0–2.0 mSv/y. The country-averaged annual doses of natural radiation in the world have been evaluated using the basic data taken from the UNSCEAR 2000 report. The result shows that total annual exposure doses containing cesium and natural radiation contributions in Fukushima are 2–4 mSv/y, which are close to the natural radiation doses in Europe. The risk coefficient of the public exposure limits, 1 mSv/y, has also been evaluated to be 4.5×10^{-7} per year. It is lower than that of traffic accidents by two orders of magnitude. These results will be useful to judge how the safety of the Fukushima prefecture is secured.

Keywords Cesium contamination • Decontamination • Annual exposure dose • 1 mSv/y • Risk coefficient • Natural radiation • Nakadori district • Fukushima

M. Kawai (✉)

High Energy Accelerator Research Organization (KEK), Oho, Tsukuba, Ibaraki 305-0801, Japan
e-mail: masayoshi.kawai@kek.jp

M. Shimo

Fujita Health University, Dengakugakubo, Kutsukake-cho, Toyoake, Aichi 470-1192, Japan

M. Morokuzu

(NPO) Public Outreach, 1-1-11 Nezu, Bunkyo-ku, Tokyo 113-0031, Japan

12.1 Introduction

More than 4 years have passed since the TEPCO Fukushima Daiichi nuclear power plant accident. The accident brought severe contamination by radioactive cesium isotopes in very wide areas of the Fukushima prefecture as well as neighboring prefectures in the Tohoku and Northern Kanto regions. Decontamination work is being done in order to reduce the ambient radiation level in the living space of the areas where the additional annual radiation exposure doses for individuals are beyond 1 mSv per year (i.e., 1 mSv/y). In the area where the work is assigned to the Fukushima prefecture, about 70 % of the decontamination work plan up to FY 2014 (i.e., up to March 2015) has been completed for housing sites [1]. In the special decontamination area where the work is being done by the Japanese government against the regions having a dose below 50 mSv/y, full-scale decontamination has been completed in four municipalities such as Tamura-shi, Kawauchi-mura, Narahamachi, and Okuma-machi within FY 2014 [2].

As a result, the ambient radiation dose rates were reduced to values less than 0.23 μ Sv/h in most parts of the decontaminated areas of the Nakadori district and the average radiation dose rate in the former three municipalities was about 0.4 μ Sv/h in addition to the effect of natural decay of radioactive nuclides and weathering effects by rain and wind within FY. 2014. The local governments of Tamura-shi and Naraha-machi have declared their intent to remove the evacuation order. However, there are in total about 116,000 people who will be forced to evacuate inside the Fukushima prefecture (69,000) and outside (47,000) in March of 2017 [3]. A recent survey about their will to return reports [4] that 37.3 % of the residents moved within the prefecture and 19.8 % outside it and wanted to return to their home town under certain conditions, whereas half of them did not know what they wanted to do or gave no answer. The residents who moved in Fukushima raised the following conditions for returning: completing the decontamination (48.8 %), lifting the evacuation order in addition to decontamination completion (42.7 %), and disappearance of worries regarding radiation exposure (42.4 %). The people who moved outside Fukushima answered as follows: disappearance of worry about radiation exposure (52.2 %), completing the decontamination (45.7 %), as well as insurance of nuclear plant safety in the future (38.9 %). Anyhow, it should be noted that there is a high proportion of strong or vague worry about radiation influence.

Since 2011 international support activities have been energetically performed to accelerate recovery of the eastern region of Japan, especially the Fukushima prefecture by IAEA and ICRP. IAEA has made many technical advisories on the decontamination of the contaminated area, recovery of the town infrastructure, evacuation and return of the residents, as well as safety reinforcement and its examination of nuclear plants, and so on. In the autumn of 2013, the IAEA's international expert Mission Team for Fukushima Remediation Issues issued important advice in order to accelerate the decontamination and people's return that the government should strengthen its efforts to explain to the public that the additional individual dose of 1 mSv/y is a long-term goal [5]. On the other hand, ICRP has

given psychological support through the dialogue meeting with the residents of the Fukushima prefecture mainly to discuss radiation problems concerning its influence on health and radiation protection in their daily life. The representative meeting was held on November 3, 2012 in Fukushima-shi. At the meeting, after the residents' presentation on worry about radiation a few members of ICRP answered that the radiation level in Fukushima was close to the natural radiation in their home town [6]. An explanation of "natural radiation" seems to be very instructive and effective for people to become aware of leading a healthy life even under radiation: people are always exposed to radiation from radioactive isotope intake through food, for example, of K40 accumulations to about 4000 Bq in an adult, as well as cosmic rays and gamma rays from soil and radon. However, their suggestions without understandable scientific numerical data have not worked to change the situation of Fukushima as much as IAEA and ICRP expected.

In the present work, the authors have prepared materials to explain the security situation at Fukushima. First they investigated the radiation distributions in the Nakadori district and its neighboring municipalities, and clarified the annual excess exposure doses. They also evaluated the risk of public standard limits of radiation exposure, 1 mSv/y, and country-averaged annual doses of natural radiation in the world. These data should be very useful for residents to recognize that the present status of the Fukushima prefecture is safe and judge how they will live there.

12.2 Radiation Level of Fukushima Nakadori District

The Fukushima Nakadori district is a region comprising the middle third of the Fukushima prefecture. It is sandwiched between the Aizu district to the west and Hamadori to the east. The Nakadori district contains the large cities of Koriyama-shi, local capital Fukushima-shi, and many middle-sized cities such as Date-shi, Nihonmatsu-shi, and Shirakawa-shi, among others. It occupies a major part in the government and economy including industrial activities and agriculture of the Fukushima prefecture. After the accident, many residents moved here from the Hamadori district having the TEPCO Fukushima NPPs. In Fukushima, contamination by radioactive cesium generally becomes lower with moving to the west therefore the problem of radiation in the Nakadori district is lower than in Hamadori.

Decontamination in the "Intensive Contamination Survey Area" where an additional annual exposure dose between 1 mSv and 20 mSv is promoted for living space by the municipalities, initiating from the higher radiation level zone. The present status of the decontamination work (to March 31, 2015) is shown in Table 12.1 [1]. About 70 % of housing and 97 % of farmland of the implementation plan up to FY 2014 has been decontaminated. In the "Special Decontamination Area" containing a total of 11 municipalities, which consists of the "restricted areas" located within a 20 km radius from TEPCO's Fukushima Daiichi NPP, and "Deliberate Evacuation Areas" where the dose was anticipated to exceed 20 mSv/y, the national government performs the decontamination work except where the radiation level area is higher

Table 12.1 Progress of decontamination work in designated municipalities to March 31, 2015

Item	Housing (Household)	Public facilities (Number of facilities)	Roads (km)	Farmland (ha)
Planned to FY 2014	318,392	8,298	8,572	29,720
Implementations	215,126	6,782	3,767	22,412
Progress rate	67.6 %	81.7 %	43.9 %	75.4 %

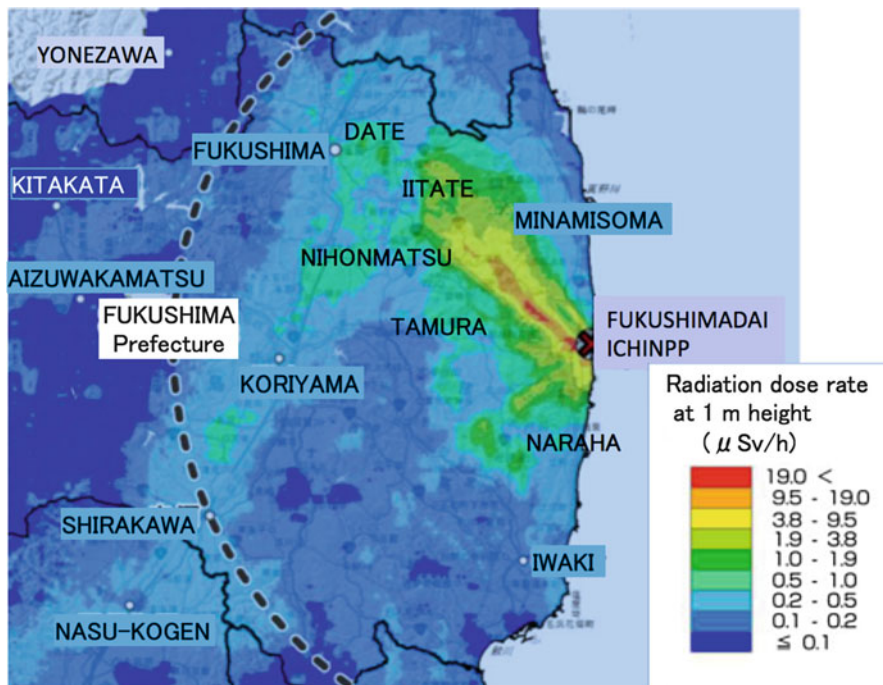
than 50 mSv/y, where residents will face difficulties in returning for a long time (i.e., “Difficult-to-Return Zone”) and has finished the full-scale decontamination for housing, public facilities, roads, and farmland in Tamura-shi, Naraha-machi, Kawauchi-mura, and Okuma-machi within FY 2014 [2]. Lifting the evacuation order for the former two has been declared by the local government, taking account of a radiation level reduction below 0.4 $\mu\text{Sv/h}$ on average, as well as that for the special places of Date-shi, Kawauchi-mura, and Minamisoma-shi where the evacuation orders were spotty and issued from the special decontamination area. Housing decontamination has been completed in Katsurao-mura, Kawamata-machi, and Iitate-mura within FY 2014. Full-scale decontamination is continuing, aiming at completion in FY 2017 or FY 2018 for the remaining seven municipalities.

Owing to decontamination as well as the natural decay of radioactive cesium isotopes and weathering effects, present ambient radiation levels have become fairly lower. Figure 12.1 shows the monitoring information of the environmental radiation dose rate estimated at the 1 m height from the surface of the ground which was measured from an airplane [7]. It is found from the figure that the major part of the Nakadori district is colored by radiation dose rates lower than 0.5 $\mu\text{Sv/h}$, whereas a part of Date-shi and Nihonmatsu-shi has a higher radiation level between 0.5 and 1 $\mu\text{Sv/h}$ which seems to be assigned to mountainous zones where decontamination has not been done because they lie outside living spaces.

Table 12.2 compares the radiation dose rates recently measured using a survey meter or a portable type radiation detector located at the representative monitoring posts in the important municipalities in the Fukushima prefecture with those on April 29 of 2011 [8]. The recent data become smaller by a factor of 3 through 12 from those of 2011. A small reducing factor means nondecontamination work. All values except for the Fire Center at Yamakiya in Kawamata-machi are lower than 0.23 $\mu\text{Sv/h}$, which is the long-term target for decontamination.

From the figure and table, it can be said that radiation levels in the living space of the Nakadori district are generally below 0.23 $\mu\text{Sv/h}$ so that the additional annual dose will be expected to be below 1 mSv/y. Even at a higher radiation level where the ambient dose rate is 0.5 $\mu\text{Sv/h}$, the additional dose would be 2.5 mSv/y.

Soma-shi, Iwaki-shi, and Hirono-machi in the Hamadori district are in the same situation as Fukushima-shi, Koriyama-shi, and Shirakawa-shi. In the special decontamination area, the average radiation dose rates measured in the housing sites of Tamura-shi, Naraha-machi, and Kawauchi-mura after the decontamination were reported [9] to be 0.35 $\mu\text{Sv/h}$ (June 2014), 0.38 $\mu\text{Sv/h}$ (June 2014), and



44 months after NPP Accident(2014.11.7)

Fig. 12.1 Monitoring information of environmental radiation dose rates in the Nakadori and Hamadori districts measured from an airplane.

0.41 $\mu\text{Sv/h}$ (August 2014), respectively. At the places higher than 1 $\mu\text{Sv/h}$ before decontamination, the individual average values were reduced from 1.19 to 0.54 $\mu\text{Sv/h}$ (7 %), 1.38 to 0.63 $\mu\text{Sv/h}$ (19 %), and 2.02 to 1.03 $\mu\text{Sv/h}$ (30 %) arranged in the same order. The value in parentheses expresses a fraction of the number of housing sites over 1 $\mu\text{Sv/h}$.

12.3 International Support Activities

12.3.1 IAEA's International Expert Mission Team for Fukushima Remediation Issues [5]

In the autumn of 2013, the IAEA's international expert Mission Team for Fukushima Remediation Issues came to Japan in response to the request made by the government of Japan, to follow up with the main purpose of evaluating the progress of the on-going remediation work achieved since the previous mission in October 2011. The Team reported [5] that Japan is allocating enormous resources

Table 12.2 Ambient radiation dose rate at the monitoring posts in Fukushima prefecture (unit: $\mu\text{Sv/h}$)

Place		April 29, 2011	Nov. 7, 2014	April 19, 2015
Date-shi	Government office	1.25, 1.23	0.23, 0.21	0.22, 0.19
Fukushima-shi	Kenpoku health office	1.58	0.24	0.22
Kawamata-machi	Government office	0.73, 0.75	0.16, 0.16	(0.14, 0.14) ^a
Kawamata-machi	Yamakiya fire center	3.0 (approx.)	0.68, 0.68	(0.67, 0.67) ^a
Nihonmatsu-shi	Government office	1.39, 1.44	0.25, 0.26	(0.23, 0.23) ^a
Tamura-shi	Local office at Tokiwa	0.26	0.10, 0.09	(0.10, 0.09) ^a
Koriyama-shi	Common building	1.53	0.13	0.13
Shirakawa-shi	Common building	0.64	0.09	0.09
Aizuwakamatsu-shi	Common building	0.18	0.06	0.04
Minamisoma-shi	Common building	0.54	0.11	0.11
Hirono-machi	Shimokitasako meeting place	0.8 (approx.)	0.11, 0.11	(0.08) ^a
Iwaki-shi	Common building	0.27	0.07	0.07

N.B. ^aValue on March 31, 2015

to developing strategies and plans and implementing remediation activities, with the aim of enhancing the living conditions of the people affected by the nuclear accident, including enabling evacuated people to return and that, as result of these efforts, Japan has achieved good progress in the remediation activities and, in general, has well considered the advice provided by the previous mission in 2011.

It also noted that based on the basic principles of the Act of Special Measures, a system has been established to give priority to remediation activities in areas for which decontamination is most urgently required with respect to protection of human health and to implement such measures taking into account the existing levels of radiation. The Ministry of the Environment, as one of the implementing authorities, is coordinating and implementing remediation works giving due consideration to this policy on prioritization. However, the announcement made by the authorities shortly after the accident that “additional radiation dose levels should be reduced to annual exposure doses below 1 mSv in the long run” is often misinterpreted and misunderstood among people, both inside and outside the Fukushima prefecture. People generally expect that current additional radiation exposure doses should be reduced below 1 mSv per year immediately, as they believe that they are only safe when the additional dose they receive is below this value.

Finally, the team gave the following advice: Japanese institutions are encouraged to increase efforts to communicate that in remediation situations, any level of individual radiation exposure dose in the range of 1–20 mSv per year is acceptable and in line with international standards and with the recommendations from the relevant international organizations, such as ICRP, IAEA, UNSCEAR, and WHO. The government should strengthen its efforts to explain to the public that an additional individual exposure dose of 1 mSv per year is a long-term goal, and that it cannot be achieved in a short time, for example, solely by decontamination work.

There remains, however, worry about radiation exposure even after the IAEA advice. The authors think that the nonobjective explanation without understandable data clearly showing a safety of the dose “1 mSv/y” isn’t effective in this case. Accordingly, it is worthwhile to publicize a communication to the people to clarify quantitatively the radiological safety of Nakadori district by evaluating the risk of “1 mSv/y” as well as natural radiation.

12.3.2 Community Dialog Forum for Residents of Fukushima Prefecture at Fukushima-shi [6]

This community dialogue forum was held on November 3, 2012 at Fukushima-shi for residents of the Fukushima prefecture to discuss matters such as returning their lives to normal in areas affected with long-term radiation from the TEPCO Fukushima Daiichi NPP accident, concentrating on the effects on health from exposure to radiation, with overseas experts mainly consisting of ICRP members who have expertise and knowledge in this field. After the key note lecture by the forum chair person of ICRP, several speakers from local media, the medical fraternity, and the residents belonging to various fields presented their actions just after the accident and problems they encountered. Almost all the speakers commonly talked about confusion due to lack of knowledge of radiation as well as poor information on the progress of the accident just after its occurrence. They felt strong anxiety regarding radiation. In the discussion, a few ICRP members mentioned that the radiation level of Fukushima was considerably lower in comparison with that of Chernobyl and they recommended comparing it with the natural radiation level. At that time, almost all Japanese had only limited information on natural radiation exposure doses such as the world average and higher values of India and China as well as the values in Japan. The higher values seemed to be not persuasive, because the Japanese knew neither such local high radiation areas in India and China nor the natural radiation levels in the European countries of the ICRP members. The material of Europe Atlas on natural radiation [10] which was informed after the community dialogue forum seemed to be doubtful to the authors, because the values given in the material were several times higher than the well-known world average value of 2.4 mSv/y. Accordingly, it is important to evaluate the country-averaged annual exposure dose by natural radiation for countries familiar to the Japanese. The country-averaged annual exposure dose is described in Sect. 12.5.

12.4 Risk Evaluation of 1 mSv/y for Public Radiation Exposure Limits

The latest recommendation for occupational and public radiation exposure limits have been made by ICRP in 2007 [11], taking account of the result of the long-term cohort study [12] on health effects in Japanese atomic bomb survivors in Hiroshima and Nagasaki, with a focus on not only “stochastic effects,” primarily cancer, but also hereditary disorders. The data are given in three categories of exposure situations, namely, planned exposure situations that involve the deliberate introduction and operation of sources; emergency exposure situations that require urgent action in order to avoid or reduce undesirable consequences; and existing exposure situations that include prolonged exposure situations after emergencies. The most important quantities are the recommended dose limits in the planned exposure situations: occupational and public limits given in Table 12.3. The public exposure limit of “1 mSv/y” is taken as the lowest criterion to select the areas to be decontaminated and its risk is one of the most interesting matters to show safety.

The public limits were determined in order to secure excellent safety compared with those of other factors of mortality, on the basis of the concept proposed in 1977 [13]: (1) humans have always been exposed to radiation from the natural environment, the basic sources of natural radiation exposure. Man-made modifications of the environment and human activities can increase the “normal” exposure to natural radiation (2). Radiation risks are a very minor fraction of the total number of environmental hazards to which members of the public are exposed and the acceptable level of risk for stochastic phenomena for members of the general public may be inferred from consideration of risks that an individual can modify to only a small degree and which, like radiation safety, may be regulated by national ordinance. An example of such risks is that of using public transport. On this basis, a risk in the range of 10^{-6} to 10^{-5} per year would be likely to be acceptable to any individual member of the public.

In this chapter, the authors would certify the amount of radiation risk of public limits, “1 mSv/y” by using statistical data on Japanese mortality in 2008. The risk coefficient of the radiation dose of 100 mSv inducing cancer was estimated by using the death increase in a lifetime of 0.5 %, which was given by ICRP, the number of dead, 900,000, and the Japanese population, about 100 million. The results are compared with those of malignant tumors (cancer) and traffic accidents

Table 12.3 Recommended dose limits in planned exposure situations

Type of limit	Occupational, mSv in a year	Public, mSv in a year
Effective dose	20, averaged over 5 years, with no more than 50 mSv in any one year	1 (exceptionally, a higher value of effective dose could be allowed in a year provided that the average over 5 years does not exceed 1 mSv in a year)

Table 12.4 Risk coefficients of natural cancer, traffic accident and radiation exposure

Item	Mortality		Lifetime mortality (%)
	Number of deaths per 100,000 people	A fraction (Risk coefficient)	
Malignant tumors (Cancer)	270.1	2.7×10^{-3}	30.1
Traffic accident	5.9	5.9×10^{-5}	0.66
Radiation exposure of 100 mSv	4.5	4.5×10^{-5}	0.5

in Table 12.4. Because the limits of the occupational and public radiation exposure are one fifth and one hundredth of 100 mSv from the view point of total exposure dose, the risk coefficients were estimated as follows:

Occupational exposure limit 20 mSv/y: risk coefficient = 9.0×10^{-6} ,

Public exposure limit 1 mSv/y: risk coefficient = 4.5×10^{-7} .

Consequently, it is noted that the risk coefficient of “1.0 mSv/y” is satisfactorily lower than 10^{-6} to 10^{-5} per year to be expected by ICRP.

12.5 Country-Averaged Annual Exposure Doses of Natural Radiation in the World

The ICRP members frequently said in the dialogue meetings with the residents of the Fukushima prefecture that the annual exposure doses in Fukushima were as low as those of natural radiation in their countries in Europe. The natural radiation doses in Europe are given in Reference [10] but they seem to be too large compared with the world -average value of 2.4 mSv/y reported in UNSCEAR 2000 [14]. Accordingly, the authors have evaluated the country-averaged annual exposure doses by the natural radiation in the world, on the basis of the fundamental data on indoor radon concentration, external exposure both outdoor and indoor, cosmic rays, and intake of food which were taken from Reference [14].

In the calculation, the authors assumed that a man stayed for 19.2 h (80 %) a day indoors and 4.8 h (20 %) outdoors, and that the concentration of outdoor radon was one third of that of indoor radon, as the conditions had been taken in the estimation of the world -averaged value. The conversion factor from the radon concentration to exposure dose was taken as $Q = 9.0 \times 10^{-6}$ (mSv/Bq m⁻³) and a decay fraction of radon isotopes to the daughter nuclides contributing to actual radiation exposure as $k = 0.4$ that were ordinarily used in the estimation of the effect of natural radiation. Likewise, the conversion factor of a gamma-ray adsorbed dose to an effective equivalent dose was $C = 0.748$ (mSv/mGy). Annual exposure dose by cosmic rays was assumed to be 0.39 mSv/y for countries near the North Pole and

Table 12.5 Comparison of annual exposure dose due to natural radiation (unit: mSv/y)

Object		Radon	Cosmic rays	Indoor gamma	Outdoor gamma	Intake foods	Total
Japan	Published	0.48	0.30	—	0.33	0.98	2.09
	Present	0.53	0.30	0.07	0.28	0.98	2.16
World average	Published	1.26	0.39	—	0.48	0.29	2.42
	Present	1.17	0.38	0.08	0.44	0.29	2.35

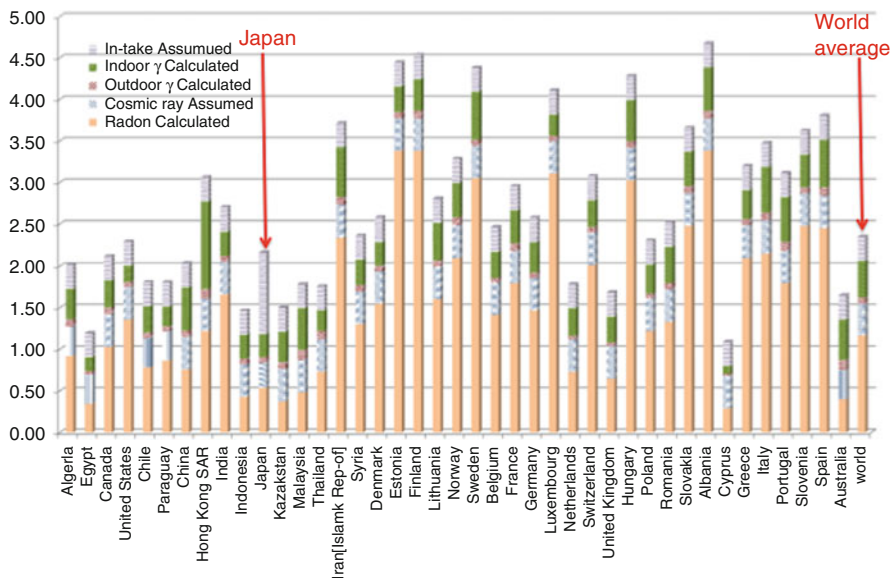


Fig. 12.2 Country averaged annual exposure dose rate due to natural radiation in the world

0.35 mSv/y, otherwise, except for 0.30 mSv/y for Japan. The annual dose due to food intake was also assumed to be the world -averaged value 0.29 mSv/y, except for 0.98 mSv/y for Japan: the Japanese eat many sea products, which contain radioactive isotopes such as polonium-210 and lead-210 and have high dose conversion factors in the human body.

In Table 12.5, the present results for Japan and the world average are compared with the widely published values. Good agreement is observed so that the authors might be convinced that the present method is verified. Figure 12.2 compares the calculated country-averaged annual exposure doses in the world. It is found that the values of northern and eastern European countries such as Finland, Estonia, Sweden, Luxemburg, Hungary, and Albania are quite high, exceeding 4 mSv/h because of high radon concentrations, whereas the values are lower than those of about 7 mSv/y given in Reference [10].

12.6 Discussion

The decontamination of a major part of living spaces of the “Intensive Contamination Survey Area” in the Fukushima prefecture has been done and ambient radiation dose rates have been measured to be below $0.23 \mu\text{Sv/h}$ on average, whereas a higher radiation level is observed in a small part but does not exceed $0.5 \mu\text{Sv/h}$ at the highest. In the special decontamination area of three municipalities such as Tamura-shi, Naraha-machi, and Kawauchi-mura, the average radiation dose rate was $0.38\text{--}0.41 \mu\text{Sv/h}$ within FY 2014. At 15–30 % places, slightly high radiation has remained in the amount of $0.54\text{--}1.03 \mu\text{Sv/h}$ measured immediately after the decontamination. The additional annual exposure dose for an individual due to radioactive cesium can be roughly estimated by multiplying 5000 h to the ambient radiation dose rate. The additional annual dose thus obtained can be expected to be below 1 mSv/y in most parts of the Nakadori district and 2 mSv/y on average even in the three municipalities.

The total annual dose that the resident will actually receive should be calculated by adding the contributions of natural radiation of about 2 mSv/y to the additional exposure dose due to radioactive cesium isotopes. It can be roughly said that the people in the Nakadori district will be exposed by 3 mSv per year maximum, and 4 mSv on average in the “Special Decontamination Area” of Tamura-shi, Kawauchi-mura, and Naraha-machi. A similar dose will be normally received in Europe, where radon concentration is high, as the ICRP members said.

The present work also clarified that the risk coefficient of 1 mSv/y is quite low, 4.5×10^{-7} , compared with that of traffic accidents of 5.9×10^{-5} . Even in the case of 7 mSv/y where the environmental radiation dose rate is about $1 \mu\text{Sv/h}$ observed in Kawauchi-mura, its risk coefficient is 3.2×10^{-6} and seems to be low enough. Of course, the occupational exposure dose limits are also at a safe level: their risk coefficient 9.0×10^{-6} is one order lower than that of traffic accidents.

Accordingly, the authors hope the present results help people accept the reasonable decontamination work and not aim for instantaneously realizing 1 mSv/y and determine their return back to their hometowns in an environment of a few mSv/y.

Nevertheless, it is considered that the people who moved would be afraid of the influence of low-level radiation on cancer in their children and hesitate to return to their hometown. Low-level radiation brings a stochastic influence on health, essentially increasing death due to cancer with the probability of 0.5 % per 100 mSv in accordance with the linear model with the nonthreshold hypothesis proposed by ICRP [11]. On the other hand, the lifetime mortality of malignant tumors (cancer) is quite high because many stresses in daily life produce much reactive oxygen in a human body. The reactive oxygen damages the DNA of a cell in the human body; a double-strand break is especially a problem likely to produce a cancerous mother cell. Inasmuch as almost all DNA damage is repaired and imperfectly repaired DNA causes cell death (loss of cells) through apoptosis, a person will seldom get the cancer, additively owing to his immunity to guard his body against impermissible different kinds of cells. He may get the cancer by losing immun ability as he ages. Laughter

is helpful in strengthening immunity power by increasing killer cells in the human body. Accordingly, spending a daily life without so much stress is important for a person to protect against cancer by reducing reactive oxygen production and keeping immunity power. There is research that shows the stress of daily life produces a double-strand break of the DNA by about 300 times as much as 1 mSv/day radiation exposure does [15]. It might be evidence of the high lifetime mortality of malignant tumors, shown in Table 12.4. Anyhow, it can be said that the influence of low-level radiation below 100 mSv is not so large.

It is a difficult problem how we consider the influence of the total exposure dose of low-level radiation accumulated during a human lifetime. For example, the total dose by natural radiation of 2.1 mSv/y is estimated to be 150 mSv by taking into account age-wise sensitivities to radiation. Its risk coefficient can be estimated to be 6.75×10^{-5} according to the LNT hypothesis which was proposed for radiation management in the radiation facilities by the ICRP, and the radiation effect is considered to increase proportionally to the radiation exposure dose. However, there is an idea that the influence of low-level radiation is not transmitted for a long time because its effects are eliminated for a short time by the human body guard system such as the functions of repairing the damaged DNA, immunity against the inimical cells, and so on. Recently, Banto al. [16] discussed human body recovery due to repairing damaged DNA and showed that the radiation effect becomes saturated to certain values. This idea implies that the present risk estimation for the public limits, 1 mSv/y, is always applicable to long-time exposure without integrating the risk per year.

12.7 Conclusion

In the present work, the additional radiation exposure dose in Fukushima is clarified. Newly evaluated country-averaged annual exposure dose by natural radiation and risk coefficient of 1 mSv/y also showed that the Fukushima Nakadori district is safe.

The decontamination work is being carried out throughout the living space of the Fukushima prefecture aiming at a goal in FY 2018. Recent measurements of the environmental radiation dose rates showed that the additional annual exposure dose was generally below 1 mSv/y in the major part of the Nakadori district and about 2.0 mSv/y in the special decontamination area of Tamura-shi, Naraka-machi, and Kawauchi-mura. The total exposure dose taking account of both cesium and natural radiation, 3–4 mSv/y are the same as the dose from natural radiation in Europe. There are no data to show any correlations between such country-averaged exposure doses by natural radiation and the cancer death data which can be taken from Reference [17]. It means that the low-level exposure of natural radiation does not cause any cancers.

The risk of the 1 mSv/y exposure has been certified to be quite low, 4.5×10^{-7} per year, as the ICRP 1977 recommendation expected as a condition of the public exposure limit.

This information should give a light to the residents to live in the Fukushima prefecture in the future. The authors would expect the people outside Fukushima, especially residents of the Tokyo metropolitan area, to correctly understand the risk coefficient of the 1 mSv/y and to recognize that the radiation level of Fukushima becomes lower to the harmless level, and finally to abandon their negative consciousness about Fukushima.

The major cause of cancer is stress in daily life such as an irregular life, unbalanced meals, friction with other people, smoking, and so on rather than radiation. A tranquil life with laughter is very important to protect from cancer rather than worrying about the influence of low-level radiation. Finally, the authors hope that the government and the media will accept the present result and publicize it widely in order to make both Fukushima and the whole of Japan brighter, through acceleration of the decontamination work and the rehabilitation together with the excellent ideas and passionate efforts to recreate a town in the damaged areas.

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