Effective doses among residents living 37 km northwest of the Fukushima Daiichi Nuclear Power Plant

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Abstract

We estimated external and internal effective doses for 15 residents who lived approximately 37 km northwest of the Fukushima Dai-ichi Nuclear Power Plant. The average cumulative effective dose was 8.4 mSv for adults and 5.1 mSv for children. The average committed effective dose from ^{134}Cs and ^{137}Cs was 0.055 mSv for adults and 0.029 mSv for children. The committed effective doses for thyroid gland was 27-66 mSv at maximum.

Introduction

A catastrophic nuclear accident occurred on March 11, 2011, at the Fukushima Daiichi Nuclear Power Plant in Japan, which was run by the Tokyo Electric Power Company. Monitoring of air and sampling of soils have been performed and are still in progress. Radioactive plumes were not distributed uniformly, but in various directions from the power plant mainly due to wind. Iitate Village and Kawamata Town lie about 37 km northwest of the power plant and is known to be one of the highly contaminated areas. The purpose of this study was to estimate cumulative effective doses and committed effective doses of residents in the Iitate Village and Kawamata Town.area. The maximum dose for thyroid gland was also estimated through urinary bioassay method.

Materials and Methods

Samples

Iitate Village and Kawamata Town are located about 37 km northwest of the Fukushima Daiichi Nuclear Power Plant. Surveyed persons were 10 residents in Iitate Village (G6-G15) and 5 residents (G1-G5) in Kawamata Town (10 males and 5 females; age range of 4–77 years). We interviewed the residents about where they stayed, what kind of food they ate and what kind of structures (Japanese-style wooden houses or concrete buildings) they lived in from March 11 to May 5. To measure internal dose, urine samples were collected twice; on May 5 (first sample, 54 d after deposition) and from May 29 to June 6 (second sample, 78–85 d after deposition).

Air dose rate

To estimate the external exposure of residents, air dose rates over time are needed. Such data are available from monitoring post data at the Iitate Village and Kawamata Town offices through the home page of Fukushima prefecture. Moreover, the air dose rates outside the homes of each resident were measured 1 m above the ground with a scintillation survey meter (TCS-161 Aloka Co. Ltd., Tokyo, Japan) on May 5. Shielding coefficients were measured to correct the external dose rate for where each resident had been staying. Coefficients were 1, 0.8, 0.4 and 0.1 for outside, inside a car, inside a Japanese wooden house or inside a concrete building, respectively.

Bioassay of urine samples

Urine samples were poured directly into a 100 ml Teflon vial (4.5 cm diameter × 6.5 cm long; inner volume, 110 ml), and a screw cap was tightly closed. Gamma-ray measurement was performed with a low-background Ge detector. Fission products ^{131}I, ^{134}Cs and ^{137}Cs were detected. The radioactivity of each fission product was obtained in Bq/l, and the radioactivity at the time of sampling was determined by correcting the elapsed time from sampling to measurement.

Results and Discussion

Estimation of cumulative effective doses

The cumulative effective dose at the location of monitoring post can be obtained by integrating the air dose rate. Individual effective dose can be calculated from the air dose scaled by a factor of the air dose rate measured outside the individual home of each resident 1 m height above the ground divided by the monitoring post data and duration time and shielding factor (outdoor, inside Japanese wooden house or concrete building, and inside a car). A conversion factor of 0.8 from dose equivalent of 1 cm depth to effective dose was adopted. The estimated cumulative effective doses for 15 residents are shown in Fig. 1. Effective doses for adults were 6.6–11.2 mSv, with an average of 8.4 mSv, and those for children were 3.9–5.6 mSv, with an average of 5.1 mSv.

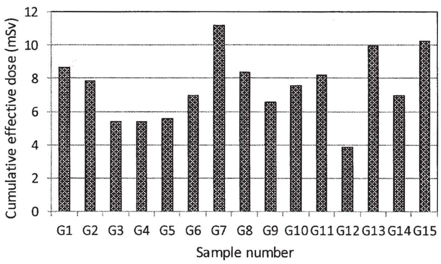

Fig. 1 Cumulative effective doses for 15 residents up to 54 d from the deposition. G3–G5 and G12 are children, and the others are adults.

In this study, we used the air dose rates 1 m above the ground to calculate the effective doses for children. However, air dose rates 50 cm above the ground would have been more suitable for children because who are generally shorter than adults and air doses at this height were 30 % higher than at 1 m. Thus, the actual effective dose for children might be 30 % higher than reported (3.9-5.4 mSv). In addition, children are known to be about three times more sensitive than adults to radiation (Preston 2003). Taking these factors into consideration and neglecting dose rate effect if any, children's doses could be 15-21 mSv. The government of Japan announced 20 mSv/y as the maximum permissive level of radiation exposure in the case of an emergency. Since residents about 37 km from the power plant were already reaching this level at 54 d after the deposition, they should have been evacuated at that time.

Estimation of committed effective doses from radiocesium

The radioactivity concentration of ^{131}I, ^{134}Cs and ^{137}Cs in urine samples were determined and ^{131}I was observed in the first sampling but not in the second sampling. Because the short-lived ^{131}I was observed in only five residents, internal radioactive contamination was considered to occur through ingestion of contaminated foods.

Total excretion of radioactivity per day is expressed by radionuclide concentration in urine A_u (Bq/l), total urinary volume per day M_u (l) and ratio of radionuclide in urine to total excretion F as $X_i=A_uM_u/F$. The total amount of urine volume per day was reported as 1–2 l for adults. In the present study, total urine volume was assumed to be 3% of bodyweight. The ratio F was taken to be 0.8 from ICRP Pub 54 (1989), which was replaced with ICRP Pub 78 (1998).

The retaining radioactivity in the whole body at *t* days after intake is expressed with initial intake I_0 (Bq) and retention function R(t) as follows, $I(t)=I_0R(t)$. The total excretion of radioactivity from the whole body at *t* days after intake is expressed as the time differential of I(t) as $X(t)=dI/dt=I_0Y(t)$, where Y(t) is the excretion rate for individual radionuclides. Thus, the initial intake radioactivity, I_0(Bq) is expressed as follows, $I_0=A_uM_u/(FY(t))$. The retention function of Cs is described with two components in Pacific Northwest National Laboratory (PNNL) report (PNNL-15614, 2009) and also ICRP Pub 78(1997) : one is 10 % with a clearance half-time of two days and second one is 90 % with a half-time of 110 days.

As a result, the committed effective dose is evaluated as $E(70)=I_0e(70)$, where, e(70) (mSv/Bq) is an effective dose conversion coefficient for the general public until 70 y old. The age-dependent effective dose coefficients for ingestion of ^{137}Cs and ^{134}Cs are given in ICRP Pub 72 (1996). Committed equivalent doses of ^{134}Cs, ^{137}Cs and total radiocesium for individuals and the ratio of external to total radiocesium doses are given in Fig. 2. Committed equivalent doses from radiocesium were 0.022–0.110 mSv for adults and 0.007–0.036 mSv for children.

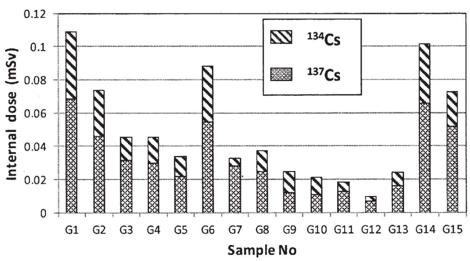

Fig. 2. Committed effective doses from ^{137}Cs and ^{134}Cs. G3–G5 and G12 are children, and the others are adults.

Estimation of effective dose from ^{131}I

Generally, 30 % of iodine is concentrated in the thyroid gland and 70% is excreted in urine at 1 d after intake. The retention function and urine excretion rate of ^{131}I ingestion are given in Fig. 7 based on PNNL-15614 (2009) and ICRP Pub 78 (1997). The urine excretion rate at 46 d was graphically obtained as 1.9×10^{-5}. The age-dependent effective dose coefficient e(70) for ^{131}I is given in ICRP Pub 72 (1996). Estimated effective doses are given in Table 2. The thyroid effective doses are 27-66 mSv for adults and 44 mSv for one of children.

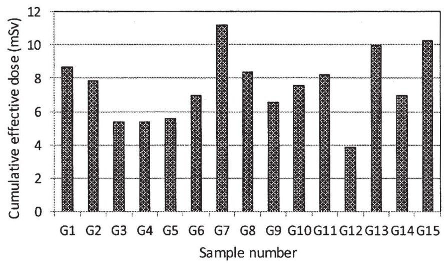

Fig.3 Thyroid effective doses for 15 residents. G3–G5 and G12 are children, and the others are adults.

Conclusion

The average cumulative effective dose of 15 residents about 37 km northwest of the Fukushima Daiichi Nuclear Power Plant was about 8.4 mSv for adults and about 5.1 mSv for children up to 54 d after deposition. The committed effective dose from radiocesium was less than 0.11 mSv for all residents surveyed, which was considerably lower than external effective dose. Committed effective dose for thyroid gland was estimated 27-66 mSv at maximum.

Acknowledgement

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