

External effective radiation dose to workers in the restricted area of the Fukushima Daiichi Nuclear Power Plant during the third year after the Great East Japan Earthquake

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ABSTRACT

Since the Great East Japan Earthquake on 11 March 2011, Iitate Village has continued to be classified as a deliberate evacuation area, in which residents are estimated to receive an annual additional effective radiation dose of >20 mSv. Some companies still operate in Iitate Village, with a special permit from the Cabinet Office Team in Charge of Assisting the Lives of Disaster Victims. In this study, we measured the annual effective radiation dose to workers in Iitate Village from 15 January to 13 December 2013. The workers stayed in Iitate for 10 h and left the village for the remaining 14 h each working day. They worked for 5 days each week in Iitate Village, but stayed outside of the village for the remaining 2 days each week. We found that the effective radiation dose of 70% of the workers was <2 mSv, including natural radiation; the maximum dose was 3.6 mSv. We estimated the potential annual additional effective radiation dose if people returned full-time to Iitate. Our analysis supports the plan for people to return to their home village at the end of 2017.

KEYWORDS: effective radiation dose, Fukushima, ambient dose rate, decontamination

INTRODUCTION

On 11 March 2011, the Great East Japan Earthquake caused the Fukushima Daiichi Nuclear Power Plant disaster, which resulted in the release of radioactive material into the surrounding environment. Terada *et al.* pointed out that a certain amount of the ¹³⁷Cesium was carried by a south-east wind as a radioactive plume and precipitated over land [1]. The government designated the 20-km radius around Fukushima Daiichi Nuclear Power Plant as a restricted area and the 30-km radius as a deliberate evacuation area. Although Iitate Village is located 30 km northwest of the Fukushima Daiichi Nuclear Power Plant, the density of deposition from the radioactive material there as measured more than 1000 kBq/m² adjusted to 14 June 2011 [2], and

a village-wide evacuation was officially announced. Maps around Fukushima showing the measured dose distribution are summarized in Fig. 1.

However, the Japanese Ministry of the Environment has permitted the continued operation of some companies and firms in Iitate, under the condition that workers are subjected to a maximum additional effective radiation dose of <20 mSv/year, excluding the natural dose [3]. Consequently, a certain number of workers have been allowed to stay in Iitate for limited hours each day, provided they commute from a place of refuge located outside of Iitate. To meet the guideline conditions for returning to the village, people in Iitate have carried out decontamination.

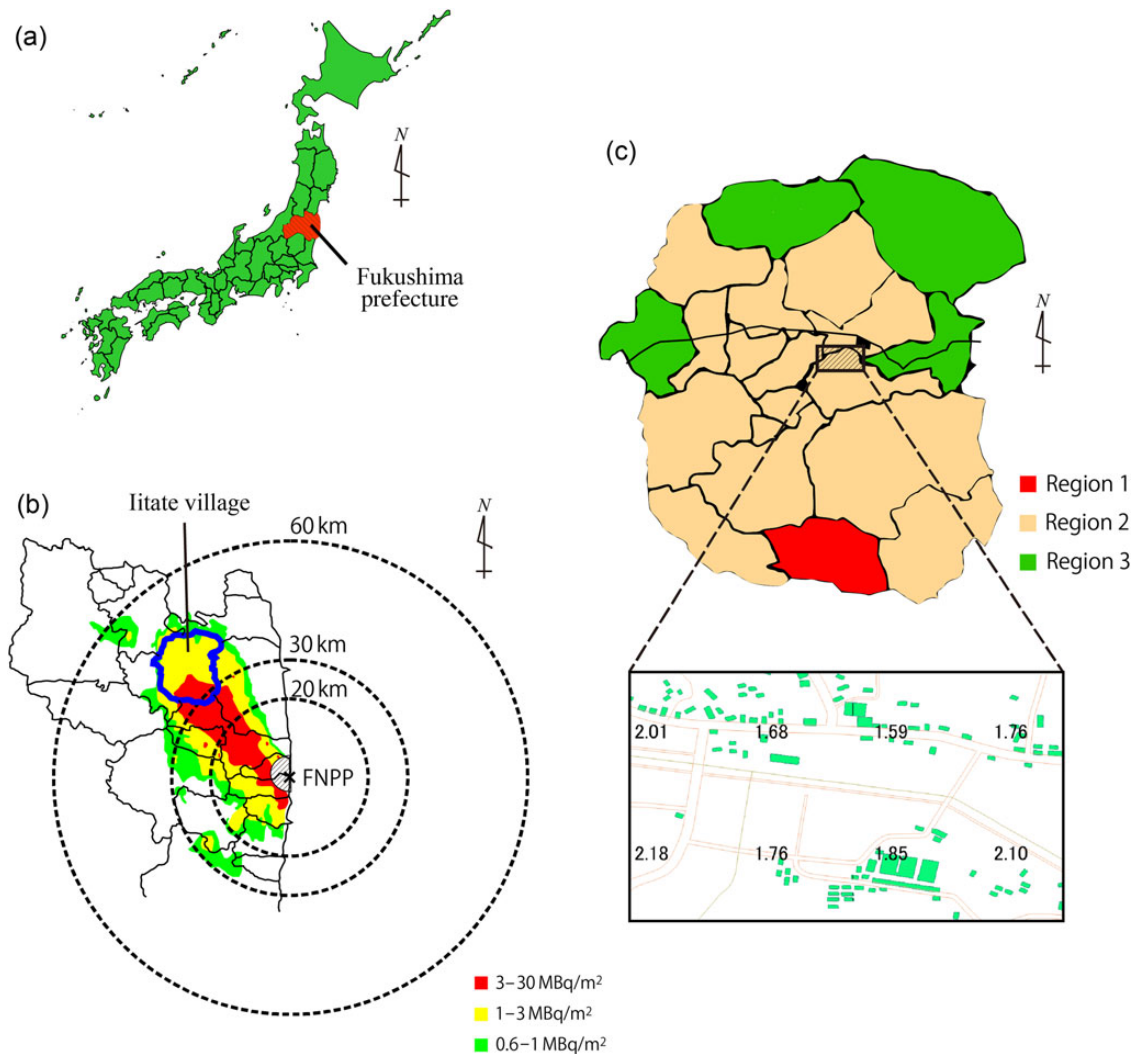


Fig. 1. Maps around Fukushima with dose distribution. (a) Location of Fukushima prefecture in Japan. (b) Cumulative dose distribution of cesium-134 and cesium-137 at ground around east side of Fukushima prefecture, which was measured by the airplane monitoring of MEXT and U.S. Department of Energy. The location of Fukushima-Daiichi nuclear power plant is shown by the point FNPP. Dose measurement is not performed for the shaded area in the vicinity of FNPP. The area surrounded by a thick line corresponds to Iitate village. (c) Areas to which evacuation orders have been issued in Iitate village, reported by Ministry of Economy, Trade and Industry [17]. Region 1 corresponds to areas where it is expected that the residents have difficulties in returning for a long time. Region 2 corresponds to areas in which the residents are not permitted to live. Region 3 corresponds to areas to which evacuation orders are ready to be lifted. The workers whose external effective radiation dose measured in this study stayed within the enlarged square area of this map for 10 h in each day. The numbers in the square area correspond to ambient dose rates [$\mu\text{Sv}/\text{hour}$] measured by airborne monitor on September 2013 reported by Ref. [16].

However, direct measurement of the external exposure at Fukushima was abbreviated [4–6], and much of the data were estimated from the ambient dose rates determined by airborne monitoring [2, 7–10]. In general, the summation of the ambient dose rate is much higher than that determined by direct measurements with a semiconducting detector [4–6].

We performed direct measurements with a glass dosimeter (as is popularly used for radiation protection in laboratories and hospitals) on workers in the deliberate evacuation area. By analyzing the data,

we determined the potential annual effective radiation dose for people returning to their daily lives in Iitate.

MATERIALS AND METHODS

In order to measure the effective radiation dose of workers, we used a glass dosimeter (Glass Badge: GD-450, Chiyoda Technology Corp.). This type of dosimeter is normally used to monitor the radiation exposure of a person. We asked the workers to carry the dosimeters continuously during the year (including for their commute and while

staying in their houses). We replaced the dosimeter every 2 months because the lowest detectable dose per 2 months by the glass dosimeters was 0.05 mSv, which corresponds to 0.3 mSv per year. The control glass dosimeter mostly measured the dose of natural radiation from the ground and space, which was then subtracted from the raw data. The measurement period for the estimation of the annual effective radiation dose was from 15 January to 13 December 2013 (i.e. 333 days). We recruited workers to carry the dosimeters throughout the year. We explained how to carry the dosimeter and the significance of the estimated effective radiation dose.

We recruited 64 workers (age: 19–62 years old, median: 38 years old, sex: 39 men, 25 women) in Iitate. Twenty control ambient dose monitors (in air) were employed (at 12 points indoors and eight points outdoors) at a certain facility in Iitate. Each point indoors was located by the window within the room. The ambient dose rate was measured with a NaI scintillator (TCS-172, Hitachi-Aroka Inc.).

The Ethics Board approved the protocol for this study.

RESULTS AND DISCUSSIONS

In this study, we measured two parameters using glass dosimeters: the ambient dose rate around the decontaminated facility and the total effective radiation dose per person.

Figure 2 shows a histogram of the annual effective radiation dose of the workers in 2013. For 70% of the workers, the annual effective radiation dose was <2 mSv. All of the workers with an effective radiation dose >3 mSv behaved similarly; they worked outdoors for almost 10 h in each working day. The maximum effective radiation dose reached 3.6 mSv; this worker worked outdoors close to a road located in the center of Iitate. The mean and median doses were 1.73 and 1.53 mSv, respectively. Figure 3 compares the human effective and ambient doses. There was a large difference between the effective human dose and the ambient dose both indoors and outdoors.

We roughly estimated the maximum annual additional effective radiation dose people will encounter when they fully return back to Iitate and their daily lives. To calculate such a maximum index, we use the maximum value for the annual effective radiation dose of 3.6 mSv/year in Fig. 2, which may correspond to the long tail of the histogram in [10]. This worker, and the others who belong to the high-dose group in Fig. 2, stayed at Iitate for almost 10 h and resided at a place of refuge outside Iitate for 14 hours in each working day; they worked for 5 days and stayed outside of the village for the residual 2 days in each week. Therefore, the annual additional effective radiation dose per year for a person staying full-time in Iitate (D_i) or staying outside of Iitate full-time (denoted by D_0) can be expressed by:

$$(3.6 - 0.54) = D_i \times \delta + D_0 \times (1 - \delta),$$

$$\delta = \frac{10[\text{h}] \times 5[\text{days}]}{24[\text{h}] \times 7[\text{days}]} \approx 0.298.$$

where 0.54 mSv/year is the natural dose in Fukushima Prefecture measured by Chiyoda Technology Corp. [6]. δ corresponds to the fraction of dwell time in Iitate relative to one week. Then, $D_i = 9.34$ mSv/year if D_0 is set to the mean value of 0.4 mSv/year reported by Fukushima City. At its maximum, $D_i = 10.28$ mSv/year if D_0 is set to 0 mSv/year. Thus, D_i is clearly less than the Ministry condition of 20 mSv/year. Furthermore, much decontamination has been performed, and several

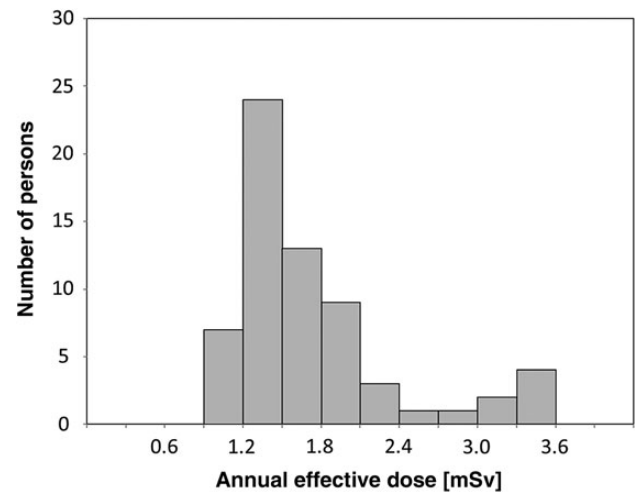


Fig. 2. Histogram of the annual effective radiation dose of 64 workers in Iitate Village for 2013. The workers stayed for 10 h of each day within the enlarged square area of Fig. 1c. We observed bipolarization of the low-dose group (showing a semi-logarithmic distribution) and the high-dose group (>3 mSv), reflecting the bipolarization of work forms; some worked mainly indoors, whereas the others worked outdoors.

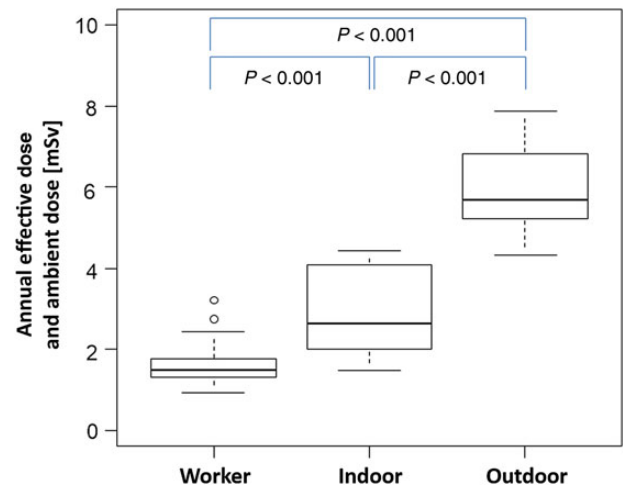


Fig. 3. Comparison of the effective human dose to workers (denoted by the column 'worker') and the ambient dose in Iitate (denoted by 'indoor' and 'outdoor'). Twenty control ambient dose monitors (in air) were used (12 points indoors and eight points outdoors). Each indoor point was located by the window within a room, so the mean value indoors tended to be larger than that of workers, according to the present measurements. P values were calculated using the Student's t test.

half-lives of $^{134}\text{Cesium}$ (i.e. 2.06 years) have passed since 2011. Therefore, the actual potential effective radiation dose should be less. This result positively supports the planned return of people to their home village at the end of 2017. The actual decision to return should be left

to the people, but our results may help support their decisions and sense of well-being.

The radioactivity levels of all foods grown in Fukushima were found to be below the strict safety levels established by the Food Safety Commission of Japan, which performed strict inspections of rice and meat. The amount of internal exposure of people consuming these foods in Fukushima was less than the lower detection limit of a whole body counter (WBC) [11–14]. Therefore, most of the effective radiation dose is due to external exposure, which has not been systematically measured before. Fukushima City reported the annual exposure of people who evacuated and who were staying outside Iitate. In contrast, we measured the annual exposure of people who returned to Iitate at fixed intervals. Our data can be applied for estimation of the expected radiation dose that would be received by people who fully return to their homes and daily lives. It is unprecedented that residents return and stay in the exposure area for a certain period; this was not allowed immediately after the Chernobyl nuclear power plant accident. Therefore, our direct measurements can provide valuable data on the annual exposure likely to be experienced in the event of a nuclear disaster.

One limitation of this study is that negative feelings endemic to the afflicted people prevented us from conducting the proper behavioral survey. Now, we are following up the afflicted people with a behavioral survey in preparation for our continued research into the situation. Furthermore, Iitate does not necessarily represent the overall situation for Fukushima. By following up on the recent WHO project [16], we are planning to get comprehensive data concerning the effective radiation dose by 'D-Shuttle', together with each person's daily behavior record, which will make it possible for us to promote risk communication in Fukushima. Our recent project on time-resolved measurement and the resultant systematic risk communication will be summarized in our next report.

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