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Abstract

We selected and re-categorized the monitoring data opened by the goverment of Fukushima prefecture focusing on the radiocesium concentrations in four agricultural products , from the data on 90,000 samples analyzed during 3 years. Radioactivity was found to be high during 3 months after the accident because of direct fallout. The internal exposure in the area with the highest contamination area of rice during the first 3 months was calculated and estimated to be 0.75 mSv year^{-1}. The radioactivity in foods products rapidly decreased after 3 months later, but in the case of some forestry products and fish, there are still some products in which radioactivity was above the regulated value, 100 Bq kg^{-1}.

Keywords

Monitoring inspection, Fukushima Daiichi nuclear power plant, Radiocesium, internal exposure

Introduction

The Tohoku Region Pacific Coast Earthquake, which occurred on March 11, 2011, caused an accident at the Fukushima Daiichi power station operated by the Tokyo Electric Power Company. Radioactive materials released by the accident spread to farmlands in Fukushima and neighboring prefectures and contaminated the soil and agricultural products [1,2]. To guarantee the safety of agricultural, livestock, forestry, and marine products, "Environmental Radiation level Emergency Monitoring for Agricultural, Forestry, and Fishery Products" (hereafter referred to as monitoring inspections) was established as an emergency response measured by the Japanese government's Nuclear Emergency Response Headquarters under the Act on Special Measures Concerning Nuclear Emergency Preparedness. To fulfill the requirements of the Food Sanitation Act in Japan (Law No. 233 issued in 1947), on March 17, 2011, the Ministry of Health, Labor and Welfare (MHLW) established a provisional regulation level for radiocesium as 500 Bq kg^{-1} in cereals, vegetables, meat, and fishery products, immediately after the disaster. On April 1, 2012, a further decreased value of 100 Bq kg^{-1} was established as the new regulation level of radiocesium in general food, except for infant food, milk, water, and beverages [3,4]. Therefore, monitoring inspections were performed before the shipment. If the radiation detected in the food exceeded the regulation level, the government would order the municipalities to suspend the shipments or limit consumption. By the end of March 2015, approximately 500 types of the foods were selected and 90,000 samples were measured in total. These results have been summarized for rice [5] and fish [6]; however, there is only limited information on other products [7-10]. Therefore, the authors selsected the data to analyze the trend in the decrease in radioactivity in several categories of agricultural productions. Further selection of the data was performed to calculate the internal exposure for residents during the first three months after the accident.

Experimental

Monitoring data was opened by the government of Fukushima Prefecture [11] and the Ministry of Health, Labour, and Welfare [12] , obtained by cutting the samples into small pieces, placing them in a vessel, and measured using the germanium semiconductor detector at Fukushima Agricultural Technology Centre [13]. Of the data for 90,000 samples monitored during 3 years after the nuclear accident, we selected and re-categorized the data on radiocesium concentration in four types of agricultural products; category A:cereal, vegetables and fruits, category B: meats, milk and eggs, category C:mushrooms and wild vegetables and category D:fish in sea water and fresh water, out of 90,000 monitoring data during 3 years after the nuclear accident. The ratios of the monitoring samples are 38 % for category A (cereal, vegetables, fruits et al.), 25 % for category B (meat, egg, milk et al.), 6 % for category C (mushrooms, wild plants et al.), and 31 % for category D (saltwater fish and freshwater fish et al.). Further selection of the individual data from Fukushima Prefecture was performed for rice, vegetables, fruits, meats, milk, forest products and fish especially produced in Sousou district (Fig. 1) where the highest contamination of rice was confirmed in 2011. The radioactivity data for each food product were classified into 4 groups, less than 25Bq/kg, from 25 to100Bq/kg, from 100 to 500Bq/kg and more than 500Bq/kg. Based on these values, an average value of each group, average uptake amount of each food based on the self-sufficiency [14], and the internal exposure were calculated. The ratio of ^{134}Cs to ^{137}Cs was set as the same [15] and the deposition effective dose coefficient for oral absorption was set as 1.9×10^{-8} Sv Bq^{-1} and 1.3×10^{-8} Sv Bq^{-1} for ^{134}C and ^{137}Cs, respectively.

Results and discussion

Fig. 2 shows the plotted data selected and categorized from 90000 measurements collected by the government of Fukushima Prefecture. As is shown in Fig.2 (a), the radiocesium concentrations in categoryA showed the highest value immediately after the accident, and then rapidly decreased within the first three months. The ratio in which radiocesium concentration exceeded the 100 Bq kg^{-1} from March to June 2011 was 18 %. The maximum concentration of radiocesium in this category was 84000Bq kg^{-1}. The contamination process could be divided into two; one is the direct contamination, in which radiocesium was deposited directly onto the agricultural products, and the other one is the indirect contamination, where the plants in fields absorbed the radiocesium from the soil via their roots. Direct contamination apparently resulted in higher radioactivity than indirect contamination. Therefore, the high concentration value observed during the first 3 months, from March to June 2011, could be attributed mainly to direct deposition of the fallout on plants that had already grown at the time of the accident. Since the agricultural products in category A were grown after July 2011, except for the fruits, most of the contamination observed after 3 months was indirect. The ratio of cesium 134 and 137 was 1:1, according to the publicly disclosed data[15]. The half-lives of cesium ^{134}Cs and ^{137}Cs are approximately 2 years and 30 years, respectively, and therefore, the physical decrease in concentration in a year is expected to be approximately 15 %. In addition to the decrease in the radioactive nuclides based on the physical half-lives, tillage also contributed to the decrease in radioactive concentrations of the plants grown in the field because the radioactive cesium is firmly fixed to the clay minerals and by mixing, the concentration of the cesium is decreased. Providing potassium, homogogous element to cesium, to the field is another effective tool to minimize cesium uptake in the plants. In the case of category B, meets, milk and eggs, most of the radioactivity concentration was decreased below the regulated value and the lower value is expected in 2015. But in the case of the forest products and fish, the radiocesium concentartion was higher than those of the plants grown in field or livestock products. This survey identified the trend in reamining high radiocesium concentration for forestry products compared to the other items, the same results as previously reported [16,17]. Radiocesium concentrations of forest product remained high even after July 2011, suggesting that forestry products were not only contaminated directly with radiocesium released from the nuclear accident, but also with the radiocesium absorbed from the soil, which were accumulated above ground part of the mushroom or plants, different from the other types of agricultural products. Although the radiocesium concentrations for fishery product is gradually decreasing, samples exceeding 100Bq kg^{-1} are still remained. But all the kinds of the fish did not show high value, the radioactivity was different among the fish kinds [6]. Therefore, some kind of fish, keeping low radiocesium concentration, have been targeted and tentative fishing of these kinds has started by Fukushima prefecture. In our previous report measuring the rice plants [5], the radiocesium concentration in the rice harvested from Sousou area (Fig. 1) was the highest in Fukushima prefecture. If people eat vegetables, fruits, forestry products, meat, milk, and fishery products grown in Sousou area during March to June in 2011, the calculated internal exposure would be 0.75 mSv $year^{-1}$ (Table 1). This is noticeably higher than 0.022-0.110 mSv $year^{-1}$ that reported as effective dose[18]. so the monitoring inspection was effective in order to ensure people's safety.

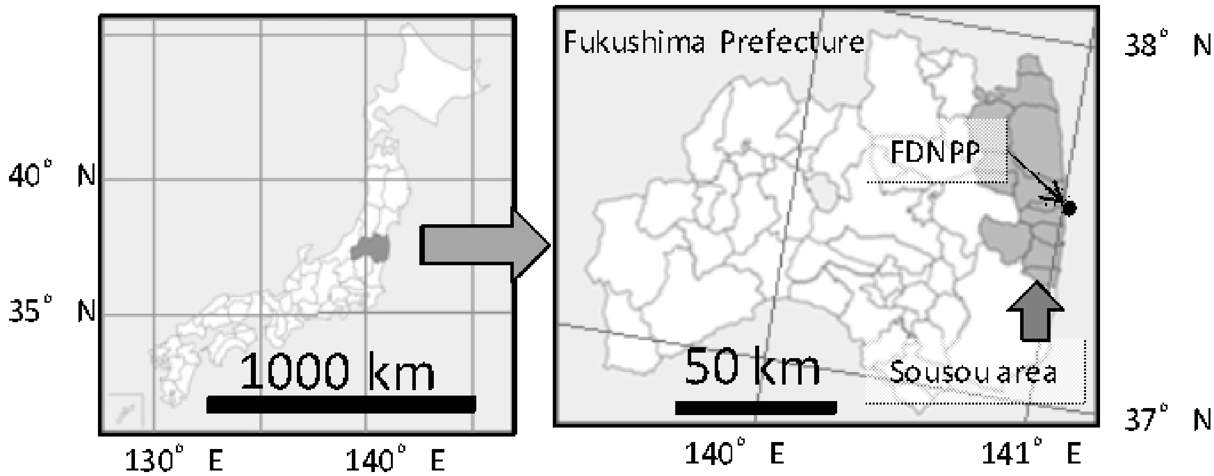
Conclusions

Radioactivity was high during the first 3 months after the accident. The internal exposure in the area with highest contamination during the first 3 months was estimated to be 0.75 mSv $year^{-1}$. The contamination was considerably reduced immediately, but the radioactivity in some food products was above the regulated value. Since the half-life of cesium, ^{137}Cs, is 30 years, and the leaching of cesium from soil is a difficult process, monitoring of agricultural products should be continued for a long time, not only to understand the dynamics of radioactive nuclides but also to devise an effective de-contamination strategy.

Table1 Ratio of radiocesium concentration and the calculated internal exposure in Sousou area from March to June 2011.

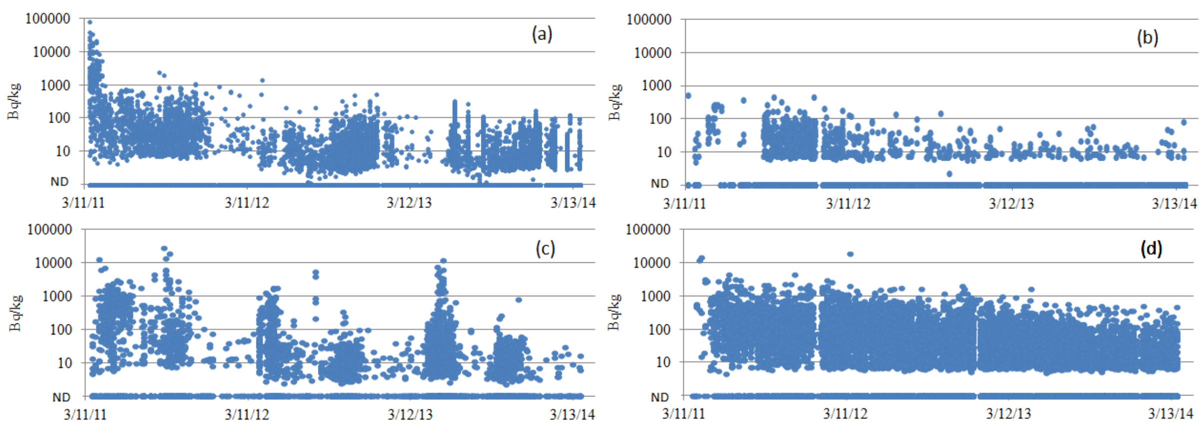
item	Ratio of radiocesium concentration				Amount of consumption*	Degree of self-sufficiency	Calculated internal exposure
	-25 Bq Kg^{-1}	25 – 100 Bq Kg^{-1}	100 – 500 Bq Kg^{-1}	500 Bq Kg^{-1} -			
	%	%	%	%	Kg y^{-1}	%	mSv y^{-1}
Rice	40	55	4	0	91.1	100	0.05
Vegetables	71	18	7	3	93.5	79	0.29
Fruits	0	10	40	50	38.3	39	0.11
Meat	17	30	52	0	30.0	55	0.04
Milk	82	14	4	0	89.5	100	0.04
Forestry products	4	4	20	72	3.4	100	0.10
Fishery products	16	49	22	13	28.9	60	0.12
						total	0.75

*[14]



40° N
35° N
1000 km
130° E
140° E
Fukushima Prefecture
FDNPP
50 km
Sousou area
38° N
37° N
140° E
141° E

Fig-1



(a)
(b)
(c)
(d)
Bq/kg
100000
10000
1000
100
10
ND
3/11/11
3/11/12
3/12/13
3/13/14

Fig-2

Fig.1 Map of Sousou area in Fukushima Prefecture, Japan.

This district comprises of 12 cities, towns or villages. FDNPP (Tokyo Electric Power Company's Fukushima Daiichi nuclear power plant) is located in the south of the center of the district. The area is 1737 km^2 and the population is 179633 (2014).

Fig.2 Measurement of radiocesium concentration in food items after the Fukushima DNPP accident.

(a): category A:cereal, vegetables and fruits,, (b): category B: meats, milk and eggs, (c): category C:mushrooms and wild vegetables, (d):category D:fish in sea water and fresh water, ND: not detected, Horizontal axis indicates the days after the accident. Vertical axis indicates the radiocesium concentration (Bq per kg) on the logarithmic scale.

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