Chapter 3
Rice Inspections in Fukushima Prefecture

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Abstract We summarize the inspections of radiocesium concentration levels in rice produced in Fukushima Prefecture, Japan, for 3 years from the nuclear accident in 2011. In 2011, three types of verifications, preliminary survey, main inspection, and emergency survey, revealed that rice with radiocesium concentration levels over 500 Bq/kg (the provisional regulation level until March 2012 in Japan) was identified in the areas north and west of the Fukushima nuclear power plant. The internal exposure of an average adult eating rice grown in the area north of the nuclear plant was estimated as 0.05 mSv/year. In 2012, Fukushima Prefecture authorities decided to investigate the radiocesium concentration levels in all rice using custom-made belt conveyor testers. Notably, rice with radiocesium concentration levels over 100 Bq/kg (the new standard since April 2012 in Japan) were detected in only 71, 28 and 2 bags out of the total 10,338,000 in 2012, 11,001,000 in 2013 and 10,988,824 in 2014, respectively. We considered that there were almost no rice exceeding 100 Bq/kg produced in Fukushima Prefecture after 3 years from the nuclear accident, and the safety of Fukushima's rice were ensured because of the investigation of all rice.

Keywords Rice • Radiocesium • Monitoring inspection • Inspection of all rice • Belt conveyor tester • Fukushima prefecture

3.1 Introduction

The Great East Japan Earthquake occurred on March 11, 2011, and was immediately followed by the accident at the Fukushima Dai-ichi Nuclear Power Plant (NPP) of Tokyo Electric Power Company (hereafter referred to as the nuclear accident). Radioactive materials released during the accident reached farmlands in Fukushima and neighboring prefectures and contaminated the soil and agricultural products (Yasunari et al. 2011; Zheng et al. 2014). Rice is the main staple food of the Japanese diet, and it is the most valuable agricultural product in Fukushima

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Prefecture. Hence, the Central Government of Japan requested suspension of rice planting as a precaution in 2011, based on a special measure of the Nuclear Disaster Act, to the relevant municipal governments that were in the controlled areas within a 20-km radius of the Fukushima Dai-ichi NPP, and where radiocesium exceeding 5000 Bq/kg was detected in the soil. In 2012, as a precaution, rice planting was suspended in areas that produced rice with radiocesium levels exceeding 500 Bq/kg in 2011 and in areas where evacuation orders had been issued. Fukushima Prefecture and the Central Government of Japan have issued more detailed directives for the inspection of rice within the prefecture compared to other agricultural products (Table 3.1). The results of these inspections are publicly announced first in newspapers and then on Fukushima Prefecture webpage and Fukushima-no Megumi Anzen Taisaku Kyogikai webpage. Based on these results, this study analyzes the radioactive content in rice in the 3-year period after the nuclear accident, and it also evaluates the performance of the equipment used to inspect all rice.

3.2 Inspections in 2011

3.2.1 Inspection Method

Monitoring inspections are conducted on three samples in each municipality for each item; however, for rice, the number of samples for inspection is significantly higher. At first, a preliminary survey before harvest was conducted to understand the trends in radioactive content in rice. The sampling was performed about 1 week before harvesting, and a total of 441 samples were analysed. Next, a main inspection was conducted based on the preliminary survey. Two samples were collected for every 15 ha in municipalities where the radiocesium concentration levels exceeded 200 Bq/kg in the preliminary survey, and two samples were collected in every former municipality in other survey sectors. Unpolished rice was collected by reaping from the standing crop and then threshed, dried, and processed. In this manner, a total of 1174 samples were analysed. The inspection method involved filling 100 ml containers with rice and taking measurements for 2000 s using a germanium semiconductor detector at the Fukushima Agricultural Technology

Table 3.1 Inspections of rice from 2011 to 2013

Year	2011	2012	2013
Name of inspection	Preliminary surveys and main inspections	Comprehensive rice bag inspections	Comprehensive rice bag inspections
Measuring instrument	Germanium semiconductor detector	Belt-conveyor-type radiocesium concentration tester	Belt-conveyor-type radiocesium concentration tester
Number of inspection	1624	10,331,526	10,949,026

Centre (conducted in accordance with the "Manual for Measuring Radioactivity of Foods in Cases of Emergency" published by the Ministry of Health, Labour and Welfare, JAPAN (MHLW)). The detection limit was approximately 10 Bq/kg, and the results have been publicly announced on Fukushima Prefecture website. An emergency survey after the main inspection was undertaken by Fukushima Prefecture itself to reassure the public about food safety. The inspections were conducted on one or more samples per farm household in areas where measurements during the main inspection or preliminary survey exceeded detection limit values, 10 Bq/kg. Sampling was performed in a total of 23,247 farm households, using NaI or other types of scintillation counters. The survey methods and results have been publicly announced on the Fukushima Prefecture website.

Preliminary surveys: http://www.pref.fukushima.lg.jp/sec/36035b/23yobichousa-kekka.html

Main inspections: http://www.pref.fukushima.lg.jp/sec/36035b/23honchousa-kekka.html

Emergency surveys: http://www.pref.fukushima.lg.jp/sec/36035b/daishinsai-23komehoushaseibusshitsu-kinkyuuchosa-kekka-syukkaseigen.html

3.2.2 Results

Table 3.2 shows a ratio of radiocesium for every area. For compiling the results, areas were classified into seven administrative sectors according to their distance from the nuclear power plant (Fig. 3.1). In the preliminary survey and main inspection of 2011, 1.7 % and 4.4 % of rice samples had radiocesium concentration levels of 100 Bq/kg or more in Area 1 and Area 3 respectively, which indicates that highly contaminated rice was produced in some parts of Areas 1 and 3. These region were within 100 km northwest of the nuclear power plant, and highly contaminated by the deposited radiocesium (Hirose 2012; Kinoshita et al. 2011), because the plume released from the nuclear power plant from about 12 to 15 JST (Japanese Standard Time) on 15 March 2011 flowed northwestward and wet deposition with precipitation occurred in the nighttime of the same day (Chino et al. 2011). Therefore, the proportion of rice with 100 Bq/kg or higher was greater in these areas than for other areas in 2011. However, there were many samples with 25 Bq/kg or lower in these same areas in 2011; thus, there was a range of radiocesium concentration levels within rice in a given area. Hence, the actual spread of radiocesium was heterogeneous, and the exchangeable potassium content of the soil (Tensho et al. 1961) and the soil type (Tsumura et al. 1984), both of which affect the absorption rate of cesium by crops, were also heterogeneous. In addition, the radiocesium concentration levels in rice were lower in Area 2 (which was at the similar distance from the nuclear power plant as Area 1) and in Areas 4 and 5 (which were at the similar distance from the plant as Area 3) and received a lower radiocesium concentration in the agricultural land. The radiocesium

Table 3.2 Inspection result of rice for 3 years

(a) 2011 (Preliminary surveys and main inspections)					
Region	Total number of inspection	Ratio (%)			
		~25 Bq/kg	25 Bq/kg ~ 100 Bq/kg	100 Bq/kg ~ 500 Bq/kg	500 Bq/kg~
Area1	45	40.0	55.6	4.4	0.0
Area2	122	70.5	28.7	0.8	0.0
Area3	576	65.3	33.0	1.7	0.0
Area4	370	89.5	10.5	0.0	0.0
Area5	155	87.1	12.9	0.0	0.0
Area6	306	98.7	1.3	0.0	0.0
Area7	50	100.0	0.0	0.0	0.0
Total	1624	79.9	19.3	0.8	0.0
(b) 2012 (Comprehensive rice bag inspections)					
Region	Total number of inspection	Ratio (%)			
		~25 Bq/kg	25 Bq/kg ~ 100 Bq/kg	100 Bq/kg ~ 500 Bq/kg	500 Bq/kg~
Area1	204,315	99.6	0.4	0.0	0.0
Area2	519,593	99.7	0.3	0.0	0.0
Area3	1,299,453	99.0	1.0	0.0	0.0
Area4	3,328,643	99.9	0.1	0.0	0.0
Area5	1,520,043	99.8	0.2	0.0	0.0
Area6	3,153,887	100.0	0.0	0.0	0.0
Area7	305,592	100.0	0.0	0.0	0.0
Total	10,331,526	99.8	0.2	0.0007	0.0
(c) 2013 (Comprehensive rice bag inspections)					
Region	Total number of inspection	Ratio of radiocesium (%)			
		~25 Bq/kg	25 Bq/kg ~ 100 Bq/kg	100 Bq/kg ~ 500 Bq/kg	500 Bq/kg~
Area1	259,172	98.8	1.2	0.0	0.0
Area2	558,018	100.0	0.0	0.0	0.0
Area3	1,388,313	99.8	0.2	0.0	0.0
Area4	3,517,451	100.0	0.0	0.0	0.0
Area5	1,582,008	100.0	0.0	0.0	0.0
Area6	3,330,114	100.0	0.0	0.0	0.0
Area7	313,950	100.0	0.0	0.0	0.0
Total	10,949,026	99.9	0.1	0.0003	0.0
(d) 2014 (Comprehensive rice bag inspections)					
Region	Total number of inspection	Ratio of radiocesium (%)			
		~25 Bq/kg	25 Bq/kg ~ 100 Bq/kg	100 Bq/kg ~ 500 Bq/kg	500 Bq/kg~
Area1	301,322	99.9	0.1	0.0	0.0
Area2	565,800	100.0	0.0	0.0	0.0
Area3	1,440,598	99.9	0.1	0.0	0.0
Area4	3,575,402	100.0	0.0	0.0	0.0

(continued)

Table 3.2 (continued)

(d) 2014 (Comprehensive rice bag inspections)					
Region	Total number of inspection	Ratio of radiocesium (%)			
		~25 Bq/kg	25 Bq/kg ~ 100 Bq/kg	100 Bq/kg ~ 500 Bq/kg	500 Bq/kg~
Area5	1,548,140	100.0	0.0	0.0	0.0
Area6	3,251,179	100.0	0.0	0.0	0.0
Area7	306,383	100.0	0.0	0.0	0.0
Total	10,988,824	100.0	0.02	0.00002	0.00

concentration level in the agricultural land was also low in Areas 6 and 7, which were more than 100 km away from the nuclear power plant to the west. The proportion of rice with radiocesium content of 25 Bq/kg or lower in Areas 6 and 7 was 98.7 % and 100 %, respectively, indicating minimal impact from radiocesium.

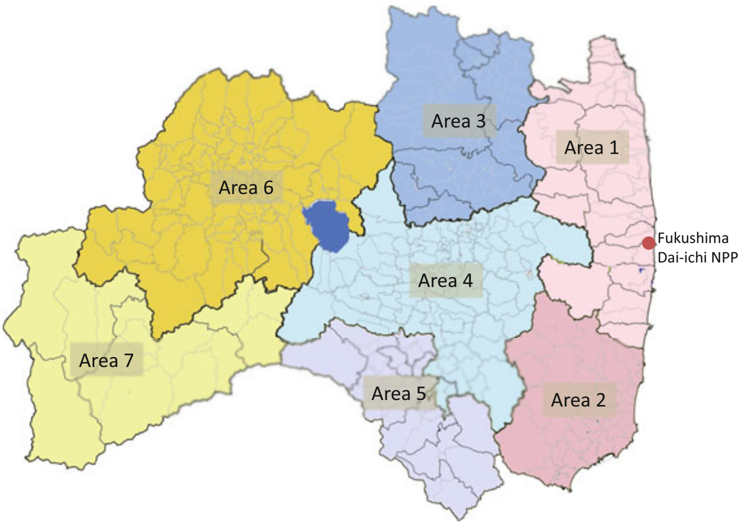

Fig. 3.1 Seven administrative sectors of Fukushima Prefecture. (**a**) Seven administrative sectors of Fukushima prefecture; Area 1 is 30–50 km to the NPP (Soso District), Area 2 is 30–50 km to the south of the NPP (Iwaki District), Area 3 is approximately 30–80 km to the northwest of the NPP (Ken-poku District), Area 4 is approximately 20–70 km west of the NPP (Ken-chu District), Area 5 is approximately 40–80 km to the southwest of the NPP (Ken-nan District), Area 6 is approximately 70–130 km to the west of the NPP (Aizu District), and Area 7 is between 100 and 150 km west of the NPP (Southern Aizu District). Area 1, 2 are called Hamadori (Coastal region); Area 3, 4, and 5 are called Nakadori (Central region); and Area 5, 6 are called Aizu. *NPP* nuclear power plant

3.3 Inspections in 2012, 2013 and 2014

3.3.1 Inspection Method

The inspections conducted by Fukushima Prefecture in 2012 targeted all the rice produced within Fukushima Prefecture (approximately 360,000 t) to reassure the public about food safety (named as inspection of all rice in all rice bags, hereafter referred to as inspection of all rice). The measurement of radiocesium concentration of all rice was considered to be the very first challenge in the world.

For this purpose, manufacturers have developed and produced equipment that can efficiently inspect all rice in Fukushima. Moreover, prefectures and municipalities have compiled information on individual farm households and built inspection frameworks.

Because there were limitations on the number of germanium semiconductor detectors available, and monitoring inspections would have taken considerable time, manufacturers were requested to develop a belt-conveyor-type radiocesium concentration tester (hereafter referred to as the belt conveyor tester) for taking measurements. The belt conveyor testers were equipped with NaI or other types of scintillation counters, and the entire measurement section was shielded by lead or iron. Rice bags weighing 30 kg passed along the belt at a rate of two or three rice bags per minute and were examined to ensure whether radiocesium concentration level exceeded 100 Bq/kg, which was stipulated by the Food Sanitation Act. This measurement method was conducted according to the "Screening Method for Radioactive Cesium in Food Products," as indicated by the MHLW, which stipulates that the value of each screening level calculated using individual equipment must be half or more of the standard value (100 Bq/kg). Fukushima Prefecture installed approximately 200 belt conveyor testers in various areas throughout the prefecture, and inspections were performed to coincide with shipments from producers. The scheme for the inspection of all rice is shown in Fig. 3.2, and can be described as follows: (1) farmers carry their rice bags to an inspection station, (2) their rice bags are sealed with a bar code label that includes the farmer's

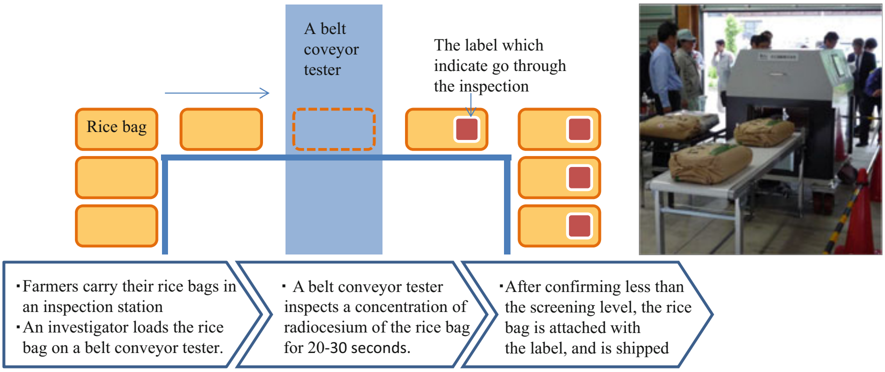

Fig. 3.2 Overview of the inspection of all rice performed from 2012

information, (3) the investigators load the rice bag on a belt conveyor tester and upload the farmer's information with a bar code reader, and (4) the belt conveyor tester measures the radiocesium concentration levels from each rice bag for 20–30 s. If the inspection result is less than the screening level, a label bearing an individual identification number is attached to the rice bag indicating the bag was inspected, and then the bag is shipped. If the screening level is exceeded, the bag is further subjected to a more detailed inspection using a germanium semiconductor detector, and it is isolated and stored until the measurement value is finalized. The result for each rice bag and the results for the rice produced from each area are posted on Fukushima-no Megumi Anzen Taisaku Kyogikai website.

Fukushima-no Megumi Anzen Taisaku Kyogikai (inspection of all rice): https://fukumegu.org/ok/kome/.

3.3.2 Results

The results of the inspection of all rice in 2012 are shown in Table 3.2. For Fukushima Prefecture as a whole (n = 10,338,291), 99.8 % of the locations had measurements of 25 Bq/kg or lower, 0.2 % had measurements higher than 25–100 Bq/kg, and only 71 bags (less than 0.001 %) exceeded 100 Bq/kg. The results of the inspection of all rice in 2013 are similar to that in 2012. Only 28 bags out of 11,001,000 exceeded 100 Bq/kg, which corresponds to 0.0003 %. 99.9 % of rice bags had measurements of 25 Bq/kg or lower.

A comparison of the results from 2011 to 2014 reveals that 0.8 % of all areas in the entire Fukushima Prefecture had contaminated rice with radiocesium concentration levels higher than 100 Bq/kg in the preliminary survey and main inspection in 2011, subsequently only 0.0007 %, 0.0003 % and 0.00002 % of bags had contaminated rice with over 100 Bq/kg of radiocesium in 2012, 2013 and 2014 (Fig. 3.3). The reason for this significant decline is assumed to be the physical reduction of radiocesium in the soil caused by factors such as decay of ^{134}Cs, fixation to the soil clay, decontamination by reversal tillage, and the effects of a thorough soil improvement effort implemented to increase the exchangeable potassium content to approximately 25 mg/100 g (dry soil) or higher, which is the guideline announced by Ministry of Agriculture, Forestry and Fisheries, Japan from 2012. Moreover, planting was restricted in 2012 (by orders from the Central Government of Japan) in areas where rice in 2011 had levels exceeding 500 Bq/kg, most of which was located in Area 3, as shown in Table 3.2.

The inspections were conducted immediately after the harvesting of rice in 2012, 2013, and 99 % of the entire amount was inspected during a 4-month period, from September to December 2012 (Fig. 3.4). In October of 2012 and 2013, about 6,500,000 samples were inspected in a month, which was the peak of the inspection number. Since the inspections were conducted using approximately 200 counters, the inspection in October was performed about 1000 samples per day by a single unit. This means that if measurements are assumed to have been taken over an 8-h

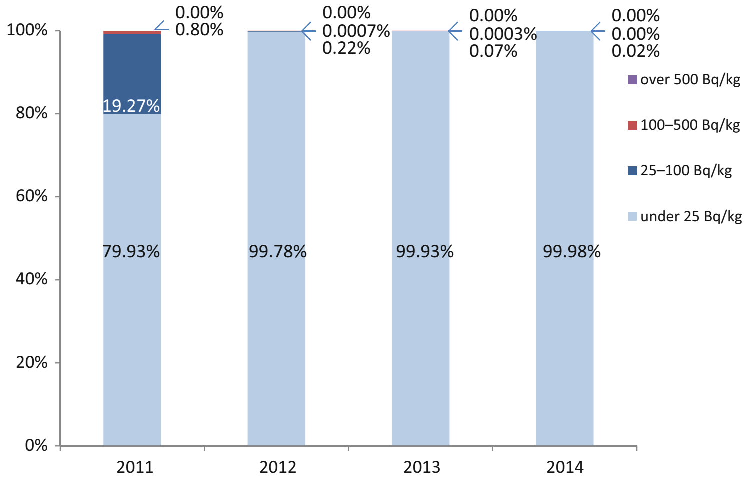

Fig. 3.3 Ratio of radiocesium concentration in rice for 4 years

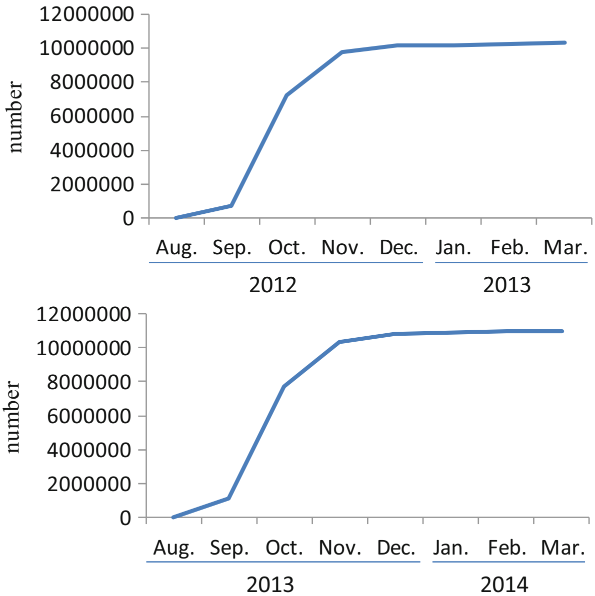

Fig. 3.4 Number of the inspection of all rice

period in a given day, two bags were inspected every minute. It is indicated that the belt conveyor tester can be considered an effective method for screening.

Rice is the main staple food of the Japanese diet, and it is the most valuable agricultural product in Fukushima Prefecture. Therefore, after the nuclear accident at Fukushima Dai-ichi NPP, inspections were performed thoroughly for rice than for other agricultural products. Note that the proportion of rice with radiocesium concentrations exceeding 100 Bq/kg was 0.8 % in 2011 and dropped to a mere 0.0007 % (71 bags out of the total 10,338,000), 0.0003 % (28 bags out of the total 11,001,000) and 0.00002 % (2 bags out of 10,988,824) in 2012, in 2013 and in 2014, respectively. In future, as agricultural operations restart in areas where planting is currently restricted, securing the safety of rice by thorough inspections and accurately communicating the inspection results will continue to be critical tools to reassure the public about food safety.

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