Surveys of Food Intake Just after the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station

Sachiko Hirakawa1,*, Nobuaki Yoshizawa1, Kana Murakami1, Mari Takizawa1, Masaki Kawai1, Osamu Sato1, Shunji Takagi1 and Gen Suzuki2

1Mitsubishi Research Institute: 2–10–3 Nagatacho, Chiyoda-ku, Tokyo 100-8141, Japan; 2International University of Health and Welfare Clinic: 2600–6 Kitakanemaru, Ohtawara, Tochigi 324–8501, Japan; *Corresponding author

As a result of the nuclear accident at the Fukushima Daiichi nuclear power station (FDNPS) after the Great East Japan Earthquake on March 11, 2011, volatile radionuclides including iodine-131 were released into the environment and contaminated open-field vegetables, raw milk, tap water, etc. It is important for the health care of residents to correctly comprehend the level of their exposure to radioactive substances released following the accident. However, an evaluation of the internal exposure doses of residents of Fukushima Prefecture as a result of the ingestion of foods, which is indicated in the report issued by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)1 is based on a number of assumptions. For instance, the estimation assumes that foods were ingested as usual, without regard to the places to which residents were evacuated after the accident, the places where food shipment restrictions were imposed, and so forth. The present report aims to improve the accuracy of estimation of the amount of food actually ingested at evacuation areas, in order to reduce as much as possible the level of uncertainty in conventional values estimated directly after the accident, which were in fact values based on conservative assumptions. More concretely, as basic source material to more accurately estimate internal exposure doses from food ingestion, various patterns of evacuation and dietary habits at the time of the accident of the residents of 13 municipalities in Fukushima Prefecture who were evacuated during the period from directly after the accident of March 11, 2011 until the end of March are clarified in this report. From survey results, most of the food that evacuees took immediately after the accident was confirmed to have been sourced from either stockpiles prepared before the accident, or relief supplies from outside of the affected areas. The restriction orders of food supplies such as contaminated vegetables and milk, and tap water intake were implemented within several days after the major release of radionuclides on March 15, 2011. In addition, collapse in supply chains, i.e., damage to distribution facilities, lack of transportation vehicles or electricity, and the closure of retail stores, contributed to a situation where food or supplies contaminated with iodine-131 were not consumed in large quantities in general, even before the food restriction order. Since people consumed tap water and water from other sources before the implementation of restriction orders in affected areas, we surveyed the status of water as a potential route of internal exposure.

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Key words: nuclear accident; iodine-131; food distribution; Fukushima Daiichi nuclear power station; evacuees; dietary habit

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Introduction

For the health care of residents, it is necessary to correctly comprehend the level of their exposure to radioactive substances released following the nuclear accident at the Fukushima Daiichi nuclear power station (FDNPS) of Tokyo Electric Power Company (hereinafter called the “accident”), which happened as the consequence of the Great East Japan Earthquake on March 11, 2011.

After the accident, attention was initially focused on the possible internal exposure to radiation from iodine...
131 (half-life period: 8 days), which might affect the thyroid gland. In addition, food contamination by radioactive cesium still persists, and efforts have been made to secure safe food distribution by regular monitoring and introduction of new reference values.

However, the evaluation of the internal exposure doses of residents of Fukushima Prefecture as a result of the ingestion of foods according to the report issued by WHO entitled "Preliminary dose estimation from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami", is based on a number of assumptions. For instance, the estimation assumes that foods were ingested as usual, without regard to the places to which residents were evacuated after the accident, the places where food shipment restrictions were imposed, and so forth.

The present report, in estimating internal exposure doses of residents, aims to improve the accuracy of estimation of the amount of food actually ingested at evacuation areas, in order to reduce as much as possible the level of uncertainty in conventional values estimated directly after the accident, which were in fact values based on conservative assumptions due to a lack of sufficient information on food ingestion at that time. More concretely, as basic source material to more accurately estimate internal exposure doses from food ingestion, various patterns of evacuation and dietary habits at the time of the accident of the residents of 13 municipalities in Fukushima Prefecture who were evacuated during the period from directly after the accident of March 11, 2011 until the end of March are clarified in this report.

In this document, we summarize the results of interviews and document surveys on the situation of residents' evacuation, their diet during refuge, and food distribution in the affected area. In addition, we estimated the amount of water that residents had ingested.

**Methods**

**Municipalities included in the survey**

We surveyed the municipalities shown in Fig. 1. Parts of these municipalities were classified as "radiation hazard area", "evacuation-prepared area in the case of emergency", and "deliberate evacuation area", and/or designated as "area of sheltering indoors" as of April 22, 2011 (Fig. S1).

**Period of survey**

In 2013, we conducted retrospective survey regarding food distribution from March 11, 2011, which was immediately after the earthquake, to March 31, 2011. This period is referred to as "survey target period" in the text.

**Survey method**

We conducted interviews with around 30 staff of municipalities who had first-hand information regarding evacuees' diet status at shelters as well as food distribution businesses in Fukushima Prefecture, such as shipment organizations, wholesalers, or retailers. We conducted document surveys on residents' diet status in the survey target period (Tables S1 and S2).

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Fig. 1. Fresh food distribution status immediately after the accident

Survey Results

Evacuation and diet status

While the purpose of this report is to provide basic source materials for evaluating the internal exposure doses that residents received when living at evacuation shelters, it is actually difficult to confirm the exact evacuation routes of individual evacuees, as well as their eating habits at that time. Therefore, this study focuses upon representative evacuation shelters operated and managed by municipalities.

The residents’ evacuation and diet status in each affected municipality based on the results of interviews and document surveys are summarized in Table S3.

Evacuation routes were confirmed by referring to materials from each municipality as listed in Table S1, and also from interviews with persons in charge at each municipality. Consequently, cases where evacuations were initiated by individuals independently are not included in this study.

At municipalities located within a range of 20 km from the accident site (including such towns as Naraha-cho, Tomioka-cho, Okuma-cho, Futaba-cho, and Namie-cho), people started evacuating on March 11 directly after the accident or in the early morning of March 12 to locations more than 20 kilometers away. Around March 15, there were also many cases of people being temporarily evacuated to other municipalities within Fukushima Prefecture (such as Iwaki-City, Kawauchi-Village, Tamura-City, and Kawakubo-Town) and staying there. It was only on or after March 19 that other locations outside Fukushima Prefecture became prepared to accept evacuees, and evacuations at a municipality level were initiated (Table S3 and Fig. S1).

According to what we heard from local municipality personnel, it seems that the food the evacuees took while in shelters was likely to have been mostly stored polished rice, pre-processed food and relief food donated from outside of the affected area (Table 1).

Diets status in the first week after the disaster

The main diet items of the refugees were distributed rice balls, soup, etc. Tap water, well water or spring water was used for cooking. In the areas without a tap water supply, water provided by water tankers was used for cooking.

Some ingredients for cooking including vegetables were provided by local people living near refuges. Because of the scarcity of open-field-cultivated vegetables in the winter season in Fukushima, it is very likely that vegetables used for cooking would have been those harvested before the disaster and stored by local families.

As for drinking water, some shelters were provided with bottles filled with tap water, well water, spring water and water from water tankers.

Diet status from one week after the disaster

At around one week after the disaster, many of the target Municipalities arranged a second transfer of refugees from the initial shelters to the western parts of Fukushima Prefecture and/or outside of the Prefecture, and subsequently the food shortage at shelters was resolved gradually. The main meals at shelters then were commercially available lunch boxes, rice balls, bread, instant noodles, etc. In addition, different kinds of food cooked by volunteers were provided. Water for cooking was mainly tap water or from water tankers.

For drinking purposes, tap water and distributed bottled water were available. In Iitate Village in particular, where tap water intake was restricted for adults, 3 L of bottled water per person per day was provided as an alternative to tap water from March 21.

Status of food distribution

We took particular note of fresh vegetables and milk as potential sources of internal exposure, because iodine-131 was detected in levels of open-field-cultivated vegetables or raw milk. We summarized the results of our survey on the distribution status of those items immediately after the disaster in the survey target area.

Shipment status of vegetable

After the detection of radioactive iodine levels exceeding the provisional regulation value of 2,000 Bq/kg in spinach grown in Ibaraki Prefecture on March 19, 2011, all municipalities of Fukushima Prefecture started voluntary suspension of shipments*. Furthermore, on March 21, the Nuclear Emergency Response Headqu-

<table>
<thead>
<tr>
<th>Table 1. Diet status of residents in target municipalities while in shelters</th>
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<tr>
<td><strong>About a week after the accident</strong></td>
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<tr>
<td>Meals</td>
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<td>Drinks</td>
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Source: Prepared by the authors based on the results of interviews, etc.

Table 2. Chronology of the accident and fresh food distribution status and countermeasures on food contamination in targeted municipalities

<table>
<thead>
<tr>
<th>Actions and Instructions of the Government</th>
<th>Fresh Food Distribution Status in Fukushima Prefecture</th>
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</thead>
</table>
| March 12 | • Hydrogen Explosion of No. 1 Unit of Fukushima Daichi Nuclear Power Station  
⇒Evacuation Order from 20-km Radius of the Plant | • Continuing Business at Wholesale Markets in Fukushima Pref. (with decreased incoming consignments)* |
| March 14− | (March 14−19)  
• A large number of retailers in the target areas closed their business |
| March 15−16 | • Major release of radioactivity from No. 2 and No. 3 Units of FDNPS that resulted in food and water contamination |
| March 17 | • Indoor Sheltering Advice for those in 20−30 km Radius was issued.  
• Establishment of Provisional Regulation Value based on the Food Sanitation Lawb |
| March 18 | • Municipalities started radiation detection analyses for food. |
| March 19 | • Radioactive iodine over the provisional regulation value from spinach grown in Ibaraki Pref. was detected.a  
(All municipalities started emergency monitoring of leaf vegetables.) |
| March 20 | Fukushima Pref. issued a request for voluntary suspension of shipment of open-field-cultivated vegetables until the release of the result of the emergency monitoring.  
The Nuclear Emergency Response Headquarters issued the shipment restriction order for spinach, kakina leaf vegetables, and raw milk produced in Fukushima Pref.  
(All municipalities started emergency monitoring of open-field-produced leaf vegetables.) |
| March 21 | The Nuclear Emergency Response Headquarters issued the shipment restriction order for spinach, kakina leaf vegetables, and raw milk produced in Fukushima Pref.  
(All municipalities started emergency monitoring of open-field-produced leaf vegetables.) |

Source: Prepared by the authors based on documents of the MHLW, and Fukushima Prefecture.  
a From interviews with people working at wholesale markets.  

As for vegetables sold through non-standard distribution routes, Prefectural authorities conducted voluntary radiation detection analyses for them, and those results have been made public.

Distribution status of vegetables

To sum up the distribution status of fresh vegetables in Fukushima Prefecture after the accident, there was a significant reduction in the shipments from farmers, even before the voluntary shipment restriction, due to fuel shortage and disrupted road conditions (Fig. 1).

Wholesale markets in the survey target area such as Iwaki-City Central Wholesale Market showed a substantial diminution of sales of vegetables produced in Fukushima in March 2011 compared to that in March 2010. The majority of the incoming consignments of vegetables and fruits to wholesale markets in Fukushima in March 2010, one year before the disaster, was from outside of Fukushima, and only 15 to 24% of the consignment volume was from within the Prefecture. The major reason is the reduced vegetable production in the winter season in Fukushima Prefecture due to climate conditions, etc. (Table S4).

In addition, most retailers in Fukushima closed their businesses even before the voluntary shipment restriction for open-field-cultivated vegetables in Fukushima (March 20, 2011). We investigated the food distribution from retailers in Fukushima Prefecture. As a result, we found that a great number of retailers in the target areas had closed their businesses from March 14 or 15 to March 19, while the major release of radionuclides occurred on March 15.

Retailers in Tamura-City and Iwaki-City in particular had to close their businesses again due to the effects of the accident, after they had recovered from the damage initially caused by the earthquake.
Immediately after the earthquake, milk plants and raw milk collection facilities in Fukushima Prefecture except Aizu District were forced to close due to damage to their cooling facilities, from March 12 to 17. As to the release of radionuclides, Minamisoma, which is located in the northern coastal area near the accident, was first affected by the radioactive plume on March 12, while other Municipalities located inland were affected after the major release of radionuclides on March 15 to 16 according to the Worldwide Version of System for Prediction of Environmental Emergency Dose Information (WSPEEDI) simulation by the Japan Atomic Energy Agency (JAEA).

In addition, monitoring of raw milk before sale was started on March 16 in Kawamata Town, and radioactive iodine levels exceeding the provisional restriction value of 300 Bq/kg were detected on March 18.

Status of milk shipment and distribution

In the survey target area before the disaster, there were 71 dairy farming households with 2,311 head of cattle. Raw milk was collected from individual dairy farmers by milk collection vehicles, and forwarded to 8 local milk cooling stations for further processing in a milk plant. Specifically, milk produced in the survey target area was collected by Fukushima Dairy Farming Cooperative Association and JA Zenno Fukushima for processing by Rakuounyugyou Co., Ltd. (milk manufacturer), and then forwarded to delivery centers for further shipment to retailers. The milk distribution status in the survey target area after the accident is summarized in Table 3.

The milk plant in Fukushima Prefecture, Rakuounyugyou, was preparing for resumption of operation, and actually started receiving raw milk from March 19. However, they received a request from Kawamata Town to voluntarily suspend the shipment and self-consumption of raw milk on that day. Furthermore, the restriction target area expanded to all over Fukushima on March 20, and the Nuclear Emergency Response Headquarters issued a shipment restriction order for milk produced in Fukushima. In these circumstances, raw milk collected by Rakuounyugyou on March 19 was reportedly discarded, and therefore raw milk produced in Fukushima after the Disaster was not distributed through the normal route.

Since there are a few examples of delivery of raw milk by dairy farmers to shelters, the possibility of limited delivery on a non-commercial basis cannot be denied. However, it might be safe to say that there was no extensive consumption of raw milk.

Status of water

Based on the above-mentioned survey results, we assumed that the major sources of internal radiation exposure could be water used for preparing rice balls and soup dishes for evacuees, and locally sourced drinking water except for bottled water. Both evacuees and non-evacuees generally ingested water from food and drinks.

We estimated the evacuees’ food intake from our interview results, while the water intake from drinks was estimated based on the questionnaire survey results published in the Contribution Ratio Sub-Committee Report of the “Integrated Research on Tap Water Quality Risk Assessment and Management”, hereinafter we refer to them as existing survey results.

As for non-evacuees, we established their water intake from drinks based on the existing survey results, on the assumption that they consumed an equivalent amount of water to that of average Japanese in a normal situation. The water intake from their staple food (rice) was added for the calculation of their total water intake.

Water intake from food and drinks

The evacuees’ basic dietary pattern in shelters and

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the tap water content in their food deduced from our survey results are shown in Table 4. The dietary pattern in Table 4 is based on the assumption that local tap water could have been used both for preparation of packed meals by caterers and for preparation of rice balls by volunteers. Under these conditions, we calculated that water intake volume from food by adults and 10-year-old children per day was 800 mL each.

We also calculated non-evacuees’ water intake volume from their staple food (rice) as 184 mL based on the assumptions that all the water intake from “rice and its processed products” in the weight of cooked rice would be from only rice, of which the water volume would be the same as the values reported in the National Health and Nutrition Survey\(^*1\) of 2010 for people over 20 years of age. In the calculation, we assumed that the total weight of rice and water before cooking was 336.8 g, based on one part of rice being cooked with 1.2 parts of water.

In terms of water intake of evacuees, we subtracted 1 L from the total volume of water intake as bottled water and water intake from drinks per day for evacuees as well as non-evacuees. We regarded water intake of 1-year-old infants, which they took milk amounting to 1 L per infant per day, prepared from powdered milk and tap water (Table 5).


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### Table 3. Overview of milk distribution status in the survey target area

<table>
<thead>
<tr>
<th>Actions and Instructions of the Government</th>
<th>Raw Milk Distribution Status in Fukushima Pref.</th>
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<tbody>
<tr>
<td>March 11</td>
<td>(March 11–16)</td>
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<tr>
<td></td>
<td>• Milk Plan Shutdown (Rakuounyugyou Co., Ltd.) except in Aizu District(^*1)</td>
</tr>
<tr>
<td>March 12</td>
<td>(March 12–17)</td>
</tr>
<tr>
<td>• Hydrogen Explosion of Unit 1 of Fukushima Nuclear Power Plant</td>
<td>• Suspension of Milk Collection due to Earthquake Damage to Milk Collection(^*1)</td>
</tr>
<tr>
<td>March 16 (March 16–18)</td>
<td>• Raw Milk Monitoring in Kawamata Town(^*1)</td>
</tr>
<tr>
<td>March 17</td>
<td>• Instruction of Indoor Sheltering in the Radius of 20–30 km.</td>
</tr>
<tr>
<td></td>
<td>• Establishment of Provisional Restriction Value based on the Food Sanitation Law</td>
</tr>
<tr>
<td>March 18</td>
<td>• Detected Radioactive Iodine Exceeding the Provisional Restriction Value from Raw Milk Produced in Kawamata Town(^*1)</td>
</tr>
<tr>
<td>March 19</td>
<td>• Requested the Voluntary Suspension of Shipment and Self Consumption of Raw Milk Produced in Kawamata(^*2)</td>
</tr>
<tr>
<td></td>
<td>• Operation Resumption of Rakuenyugyou Co. Resumption of Raw Milk Collection(^*1)</td>
</tr>
<tr>
<td>March 20</td>
<td>• Requested Voluntary Suspension of Shipment and Self Consumption of Raw Milk in the Whole Area of Fukushima Pref.(^*1)</td>
</tr>
<tr>
<td>March 21</td>
<td>• Instruction of Enforcement of Shipment Restriction of Raw Milk produced in Fukushima Pref. (NERH DG's Instruction)(^*1)</td>
</tr>
<tr>
<td>Apr. 18</td>
<td>• Resumption of Milk Collection in Nakadori and Iwaki Regions(^*1)</td>
</tr>
<tr>
<td>May 3</td>
<td>• Resumption of Milk Collection in Kawamata Town (except Yamakiya District) and Minami-Soma City (except Some Designated Areas)(^*1)</td>
</tr>
</tbody>
</table>

Source: Prepared by the authors, etc. based on documents of the MHLW and Fukushima Pref. interviews, etc.


\(^*2\) Hearing from Fukushima Dairy Farming Cooperative Association

\(^*1\) Notification of Fukushima Pref. "On Voluntary Suspension of Raw Milk Shipment". (in Japanese)


The survey results confirmed that the diet of evacuees at their shelters immediately after the accident consisted of mainly 1) rice balls and soup distributed by voluntary warm-meal activities, 2) rice balls, lunch boxes and bread produced outside of the 13 affected municipalities, and 3) stored food produced prior to the accident. These observations indicate that the possibility of internal exposure to radioactive substances through food is low.

While the iodine-131 levels detected in open-field-cultivated vegetables or raw milk exceeded the provisional regulation value, it was confirmed that they were not extensively consumed due to the shipment restrictions and disrupted distribution system including earthquake damage to facilities, closure of retail shops, etc. On the other hand, the restriction of tap water intake was not adequately implemented in some Municipalities in the early phase of the disaster and there was a possibility that internal exposure to radioactive substances might have occurred through the water supply system.

An evaluation of the levels of internal exposure doses of residents of Fukushima Prefecture in the first year after the accident, which is indicated in the report issued by WHO is based on a number of assumptions. For instance, despite consideration of restrictions on food shipping, foods were assumed to have been purchased in supermarkets and ingested as usual. As a result the internal exposure dose of adult living in Fukushima Prefecture one year after the accident was estimated to be 0.94 mSv in the report.4)

In this paper, it is considered that as the result of distribution problems such as closure of supermarkets, evacuees and residents of Fukushima Prefecture were consuming lower amounts of food than usual. Thus, we believe that proper internal dose estimation from food and especially from water is critical for future work and our survey will serve as a reference for such work. The limitations of this paper include a focus on evacuation shelters operated and managed by municipalities, so that the residents who voluntarily evacuated were outside our scope. We performed only estimation of food and water intake. Thus, estimation of internal exposure still needs to be addressed.

Acknowledgment

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References