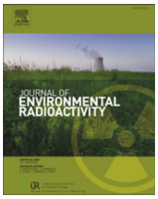
Journal of Environmental Radioactivity xxx (2011) 1–17

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad



Food safety regulations: what we learned from the Fukushima nuclear accident

Nobuyuki Hamada*, Haruyuki Ogino

Radiation Safety Research Center, Nuclear Technology Research Laboratory, Central Research Institute of Electric Power Industry (CRIEPI), 2-11-1 Iwado-kita, Komae, Tokyo 201-8511, Japan

ARTICLE INFO

Article history:
Received 13 June 2011
Received in revised form
4 August 2011
Accepted 8 August 2011
Available online xxx

Keywords:
Emergency exposure situation
Existing exposure situation
Food safety regulation
Fukushima nuclear accident
Graded triphasic reference level
Internal radiation exposure

ABSTRACT

On 11 March 2011, the magnitude-9.0 earthquake and a substantial tsunami struck off the northeast coast of Japan. The Fukushima nuclear power plants were inundated and stricken, followed by radionuclide releases outside the crippled reactors. Provisional regulation values for radioactivity in food and drink were set on 17 March and were adopted from the preset index values, except that for radioiodines in water and milk ingested by infants. For radiocesiums, uranium, plutonium and transuranic α emitters, index values were defined in all food and drink not to exceed a committed effective dose of 5 mSv/year. Index values for radioiodines were defined not to exceed a committed equivalent dose to the thyroid of 50 mSv/year, and set in water, milk and some vegetables, but not in other foodstuffs. Index values were calculated as radioactive concentrations of indicator radionuclides (^{131}I for radioiodines, ^{134}Cs and ^{137}Cs for radiocesiums) by postulating the relative radioactive concentration of coexisting radionuclides (e.g., ^{132}I, ^{133}I, ^{134}I, ^{135}I and ^{132}Te for ^{131}I). Surveys were thence conducted to monitor levels of ^{131}I, ^{134}Cs and ^{137}Cs. Provisional regulation values were exceeded in tap water, raw milk and some vegetables, and restrictions on distribution and consumption began on 21 March. Fish contaminated with radioiodines at levels of concern were then detected, so that the provisional regulation value for radioiodines in seafood adopted from that in vegetables were additionally set on 5 April. Overall, restrictions started within 25 days after the first excess in each food or drink item, and maximum levels were detected in leafy vegetables (54,100 Bq/kg for ^{131}I, and a total of 82,000 Bq/kg for ^{134}Cs and ^{137}Cs). This paper focuses on the logic behind such food safety regulations, and discusses its underlying issues. The outlines of the food monitoring results for 24,685 samples and the enforced restrictions will also be described.

1. Introduction

The Great East Japan Earthquake occurred at 14:46 (Japan standard time) on 11 March 2011. This undersea quake registered a moment magnitude of 9.0, the largest ever known to hit Japan and fourth largest in the world since 1900. The epicenter was 130 km east of the Oshika Peninsula located in the northeastern coast of the main Japanese island of Honshu, and the hypocenter was 24 km in underwater depth. The quake unleashed a substantial tsunami (reportedly ~ 40.5 m high, highest in the recorded history of Japan) that traveled up to 10 km inland. This massive disaster caused devastating damage over a wide area: as of 12 June 2011, loss of 15,421 lives has been confirmed, and 7937 people are still missing (NPA, 2011).

Two nuclear power plants that Tokyo Electric Power Company (TEPCO) owns are situated in the Futaba District of Fukushima Prefecture. The tsunami measuring over 14 m in height swept toward the sites at about 1 h after the quake, and overwhelmed the site's sea defenses designed to withstand 5.7 m high tsunamis. The plants were thus inundated and stricken. As the first ever experience in Japan, the Prime Minister declared nuclear emergency situations for the accidents at the Fukushima nuclear power plants 1 and 2 at 19:03 on 11 March 2011 and 7:45 on 12 March 2011, respectively. The Japanese government urged residents of the

---

Abbreviations: BSS, International Basic Safety Standards; BWR, Boiling water reactor; CAC, Codex Alimentarius Commission; CF, Conversion factor; DIL, Derived intervention level; FAO, Food and Agriculture Organization of the United Nations; FSC, Food Safety Commission of Japan; IAEA, International Atomic Energy Agency; ICRP, International Commission on Radiological Protection; IL, Intervention level; ILO, International Labour Organization; JRIA, Japan Radioisotope Association; MAFF, Ministry of Agriculture, Forestry and Fisheries of Japan; MDFI, Mean daily food intake; MHLW, Ministry of Health, Labour and Welfare of Japan; MHW, Ministry of Health and Welfare of Japan; NERHQ, Nuclear Emergency Response Headquarters; NISA, Nuclear and Industrial Safety Agency of Japan; NPA, National Police Agency of Japan; NSC, Nuclear Safety Commission of Japan; OIL, Operational intervention level; ORL, Operational reference level; PAHO, Pan American Health Organization; PWR, Pressurized water reactor; RCIL, Radioactive concentration giving intervention level; RL, Reference level; TEPCO, Tokyo Electric Power Company; WHO, World Health Organization.

* Corresponding author. Tel.: +81 3 3480 2111; fax: +81 3 3480 3113.
E-mail address: hamada-n@criepi.denken.or.jp (N. Hamada).

0265-931X/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvrad.2011.08.008

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

evacuation-designated zone to stay away, and those of its surrounding annular zone to stay indoors. Nuclear Emergency Response Headquarters (NERHQ) was set up in the Cabinet in accordance with Article 16 of the Act on Special Measures Concerning Nuclear Emergency Preparedness, where the Prime Minister acted as its chief.

All operating boiling water reactors (BWRs) were automatically shutdown upon the quake, but overheated due to inoperable nuclear fuel cooling systems. Partial core melt and hydrogen explosions took place, followed by radionuclide releases outside reactors. A preliminary estimate made by the Nuclear Safety Commission of Japan (NSC) indicated that 150 PBq of ^{131}I and 12 PBq of ^{137}Cs were spewed into the atmosphere from 11 March 2011 to 5 April 2011 (NSC, 2011). Likewise, the Nuclear and Industrial Safety Agency of Japan (NISA) preliminarily estimated the atmospheric release of 130 PBq of ^{131}I and 6.1 PBq of ^{137}Cs (NISA, 2011a). An updated estimate made by NISA indicated that 160 PBq of ^{131}I, 18 PBq of ^{134}Cs and 15 PBq of ^{137}Cs were discharged from reactor units 1–3 of the Fukushima nuclear power plant 1 into the atmosphere during 11–16 March 2011 (NISA, 2011b). Such radioactivity has spread across the entire northern hemisphere. Also, TEPCO preliminarily estimated the outflow of 520-ton water containing 2800 TBq of ^{131}I, 940 TBq of ^{134}Cs and 940 TBq of ^{137}Cs into the open sea from 1 April 2011 to 6 April 2011 (TEPCO, 2011a). On 12 April 2011, such Fukushima nuclear accident was provisionally rated at the top Level 7 on the International Nuclear and Radiological Event Scale (NISA, 2011a). The level is on a par with the Chernobyl nuclear accident in 1986, but its two differences from the Fukushima nuclear accident should be born in mind. On one hand, the current estimate implies that the amount of discharged radionuclides in the Fukushima accident (~770 PBq of ^{131}I and ^{137}Cs) is about one-seventh of that in the Chernobyl accident (5200 PBq) (NISA, 2011a, 2011b). On the other, the radionuclide release is continuing over a longer period of time in the Fukushima accident compared to the Chernobyl accident. On 17 April 2011, TEPCO offered a two-stage timeline hoping to achieve stable cooling by July 2011 and cold shutdowns by October 2011 to January 2012 (TEPCO, 2011b).

Internal exposure occurs, when radionuclides enter and are absorbed into the body. Ingestion of food is the most significant route of radionuclide intake for members of the public (ICRP, 1992b). Taking account of the fallout from the Fukushima nuclear power plant 1, the Department of Food Safety at the Ministry of Health, Labour and Welfare of Japan (MHLW) put regulatory limits of radioactivity in food and drink (referred hereinafter to as food) stipulated as “provisional regulation values” on 17 March 2011, and issued a notice that food exceeding provisional regulation values should be regulated under Article 6, Item 2 of the Food Sanitation Act and should not be ingested (MHLW, 2011b). Since then, the distribution (shipment and sale) and/or consumption of food contaminated above provisional regulation values have been temporarily restricted. This paper focuses on the logic behind implemented food safety regulations, and discusses its underlying issues. The outlines of available food monitoring data and the enforced restrictions shall also be described.

2. Index values as a predecessor of provisional regulation values

NSC issued the guideline for nuclear disaster countermeasures in June 1980, where “index values” were provided as evaluation criteria to launch discussion on whether NERHQ needs to restrict food consumption (NSC, 1980). So far, index values have undergone three revisions while the guideline itself was revised 14 times until August 2010. The initial index value was set in 1980 for ^{131}I not to exceed a total dose equivalent to the thyroid gland of 15 mSv when infants consumed contaminated milk, drinking water and leafy vegetables. Following the Chernobyl nuclear accident, the index value for ^{131}I was changed, and the new index values were set for radiocesium, radiostrontium, plutonium and other α-emitting transuranic elements in 1998. Following the JCO criticality accident in 1999, the additional index value was set for uranium in 2005, serving as the latest index values.

MHLW set the provisional regulation values on 17 March 2011 (MHLW, 2011b), without an assessment by the Food Safety Commission of Japan (FSC), and hence requested FSC to assess the validity of provisional regulation values on 20 March 2011. After one-week deliberations, FSC drew up a report (FSC, 2011a) on 29 March 2011, guaranteeing that the ongoing measures based on provisional regulation values are effective enough to ensure food safety for consumption, domestic distribution and exportation (FSC, 2011b). Consequently, MHLW decided to use the ongoing provisional regulation values for the time being on 4 April 2011 (MHLW, 2011g, 2011h). However, the provisional regulation value for radioiodines in seafood was additionally set on the next day (MHLW, 2011k), because fish contaminated at levels of concern began to emerge (see Section 3.2.2). Table 1 lists the provisional regulation values effective as of 12 June 2011. Provisional regulation values were adopted from the preceding index values, except the value for radioiodines in drinking water and milk consumed by infants, and that in seafood (see Section 4.2).

3. Food monitoring data and restrictions on distribution and consumption

3.1. Potable tap water

3.1.1. Policy on the enforcement of restrictions on consumption

On 19 March 2011, MHLW notified local government authorities and regional water suppliers that tap water contaminated above the provisional regulation value should not be consumed, but can be consumed even by infants if its substitute is unavailable (MHLW, 2011e). This notice also indicated that the use of such water in daily life (e.g., for washing hands, bathing and laundry) is safely allowable, because the estimated dose to be received (correctly, a committed effective dose, see Section 4.1) may be of the order of nSv (MHLW, 2011e). This dose estimation assumed dermal contact to water as well as inhalation of air volatilized from water besides drinking, as radionuclide exposure scenarios associated with the use of tap water contaminated at 300 Bq/L of ^{131}I or 200 Bq/L of ^{137}Cs. Given that the body is soaked for 30 min in the bathing water, the dose posed by dermal contact due to bathing were estimated for ^{131}I and ^{137}Cs with equations (1) and (2), respectively, where dose coefficients for water immersion of skin (nSv cm^3 Bq^{-1} s^{-1}) were taken from Eckerman and Ryman (1993), and both yielded 20 nSv/d. Actual dose should be less considering evaporation of water in wet body, hands and clothes after bathing, washing hands and laundry, respectively. Providing the daily use of 100-L water in kitchen and bathroom, closed living space of 40 m^3, inhalation volume of 20 m^3/d, volatilization rate of 0.001, the dose was estimated to be 300 and 390 nSv/d for ^{131}I and ^{137}Cs using equations (3) and (4), respectively, where inhalation dose coefficients (nSv/Bq) were taken from the Ministry of Health and Welfare of Japan (MHW, 2000).

$$0.3\ \left(\mathrm{Bq/cm^3}\right) \times 1800\ (\mathrm{s/d}) \times 0.037\ \left(\mathrm{nSv\ cm^3 Bq^{-1} s^{-1}}\right) = 20\ (\mathrm{nSv/d}) \tag{1}$$

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

Table 1
Provisional regulation values effective as of 12 June 2011.

Radionuclide group	Food category	Provisional regulation value (Bq/kg)
Radioiodine	Drinking water Milk	300 (100 for infants)
	Vegetables except corms, tubers and roots Seafood	2000
Radiocesium	Drinking water Milk	200
	Vegetables Cereals Meats, eggs, seafood and other foodstuffs	500
Uranium	Infant foods Drinking water Milk	20
	Vegetables Cereals Meats, eggs, seafood and other foodstuffs	100
Plutonium and other transuranic α emitters	Infant foods Drinking water Milk	1
	Vegetables Cereals Meats, eggs, seafood and other foodstuffs	10

Provisional regulation values were adopted from the preset index values except those for radioiodines in drinking water and milk consumed by infants and seafood consumed by all age groups.
The provisional regulation value for radioiodines in seafood was set on 5 April 2011, but other values were set on 17 March 2011.
See Section 4.1 for details of foodstuffs that fall under each food category.
Vegetables here refer to mushroom, fruit, edible algae, corms, tubers and roots in addition to vegetables (see Section 4.1). Note that this is different from "vegetables" in Table 7 that only refer to vegetables.
Cereals here include grains and pulses (see Section 4.1), which are different from "cereals" in Table 7 that only refer to cereals.

$$0.2\ \left(\mathrm{Bq/cm^3}\right) \times 1800\ (\mathrm{s/d}) \times 0.055\ \left(\mathrm{nSv\ cm^3 Bq^{-1} s^{-1}}\right) = 20\ (\mathrm{nSv/d}) \tag{2}$$

$$300\ (\mathrm{Bq/L}) \times 100\ (\mathrm{L}) \times 0.001 \times 20\ (\mathrm{nSv/Bq}) \times 20\ \left(\mathrm{m^3/d}\right) \Big/ 40\ \left(\mathrm{m^3}\right) = 300\,(\mathrm{nSv/d}) \tag{3}$$

$$200\,(\mathrm{Bq/L}) \times 100\,(\mathrm{L}) \times 0.001 \times 39\,(\mathrm{nSv/Bq}) \times 20\ \left(\mathrm{m^3/d}\right) \Big/ 40\ \left(\mathrm{m^3}\right) = 300\,(\mathrm{nSv/d}) \tag{4}$$

In response to the FSC report (FSC, 2011a), MHLW issued a notice for policy on the execution of monitoring surveys and enforcement of consumption restrictions on 4 April 2011 (MHLW, 2011i). Regarding monitoring surveys, there were five directives to regional water suppliers: 1) carry out monitoring surveys especially in Fukushima Prefecture and neighboring areas (Miyagi, Yamagata, Niigata, Ibaraki, Tochigi, Gunma, Saitama, Kanagawa, Chiba Prefectures, and Tokyo Metropolis), taking into account the monitoring results in tap water and atmosphere as well as the distance from the Fukushima nuclear power plant 1. 2) Monitor levels of ^{131}I, ^{134}Cs and ^{137}Cs for the meantime. 3) Take water samples from faucets or water filter plants. 4) Conduct monitoring surveys more than once a week, but do everyday when radioactivity levels exceed or are becoming close to provisional regulation values. 5) Increase frequency of monitoring surveys depending on effects of rainfall in water filter plants where river is the source of water. On one hand, MHLW is to request regional water suppliers to impose restrictions on consumption and make public when the mean level in the last three days are above the provisional regulation value, or when a single monitoring datum acquired on a certain day drastically exceeds the provisional regulation value. On the other, regional water suppliers are to remove restrictions, not merely when the mean level in the last three days falls below the provisional regulation value, but also when there has been a trend toward decreasing levels.

3.1.2. *Monitoring data and restrictions on consumption*

As of 12 June 2011, MHLW has issued 94 reports on the monitoring data of a total of 19,703 samples for tap water since 21 March 2011 (MHLW, 2011n). We overviewed all of these data as well as the information on the commencement and withdrawal of restrictions, for which compendium is presented in Table 2.

Local government authorities have monitored levels of ^{131}I (also ^{132}I in some areas), ^{134}Cs and ^{137}Cs in tap water. Of these, ^{131}I was a major contaminant, and levels of ^{134}Cs and ^{137}Cs were consistently far below provisional regulation values. Levels of ^{51}Cr, ^{54}Mn, ^{58}Co, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{95}Zr, ^{95}Nb, ^{106}Ru and ^{144}Ce were also monitored in Fukushima Prefecture, but their radioactivity was below detectable levels. Levels of ^{89}Sr and ^{90}Sr were not monitored. The monitoring data for ^{132}Te, ^{133}I, ^{134}I and ^{135}I were not reported, whereas the γ-ray spectrometry of the target radionuclide should have simultaneously revealed the levels of these γ emitters. Throughout this paper, Bq/kg-wet was referred to as Bq/kg. Levels of ^{131}I became contaminated above the provisional regulation values on 16 March 2011 in Fukushima Prefecture. Thereafter, ^{131}I levels above the provisional regulation values were also detected in Ibaraki, Chiba, Tokyo, Tochigi and Saitama Prefectures, but not in other 41 prefectures in Japan. Among samples analyzed, a maximum ^{131}I level of 965 Bq/kg was recorded in tap water sampled in Fukushima Prefecture on 20 March 2011. First of all, water consumption by all age groups including infants was restricted in Iitate Village of Fukushima Prefecture on 21 March 2011. Only consumption by infants was then restricted in other places. All restrictions began within 6 d (2 d except Fukushima Prefecture) after ^{131}I levels started exceeding 100 Bq/kg. Note that the number of days taken were consistently counted including the

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

Table 2
Levels of ^{131}I detected in tap water and the enforcement of restrictions on consumption (As of 12 June 2011).

Prefecture[a]	^{131}I levels firstly exceeded 100 Bq/kg in tap water sampled on	Maximum Levels of ^{131}I detected		Days taken to order restrictions[f, g]	Restrictions on water consumption in infants[d]		
		Concentration (Bq/kg)	Sampled on		Began on[e]	Lifted on	Duration (d)[g]
Fukushima[b]	3.16.2011	965	3.20.2011	6	3.21.2011	5.10.2011	4∼51
Ibaraki	3.22.2011	298	3.23.2011	2	3.23.2011	3.27.2011	1∼4
Chiba	3.22.2011	370	3.22.2011	2	3.27.2011	3.28.2011	2∼4
Tokyo	3.22.2011	210	3.22.2011	2	3.23.2011	3.24.2011	2
Tochigi	3.24.2011	110	3.24.2011	2	3.25.2011	3.26.2011	1∼2
Saitama[c]	3.22.2011	120	3.22.2011				

Restrictions on water consumption in age groups other than infants were enforced only in Iitate Village from 21 March 2011 to 1 April 2011.

^{131}I levels exceeding 100 Bq/kg have not been detected since 29 March, 2011. All restrictions were lifted by 10 May 2011.

[a] Prefecture herein refers to a certain subareas in each prefecture, but not to whole prefectural area.

[b] Except Iitate Village, all restrictions were withdrawn by 1 April 2011.

[c] MLHW did not order a restriction.

[d] To be precise, duration of restrictions was distinct among subareas in each prefecture. Of these, the earliest date when restrictions began, the latest date when restrictions were lifted, and shortest and longest durations are tabulated here.

[e] Presented are the dates when restrictions were instructed by MHLM, but not those voluntarily imposed by local governments.

[f] Shown are the days from when the tap water firstly exceeded 100 Bq/kg of ^{131}I until when the first restriction began.

[g] The number of days was counted including the initial day (e.g., the days from 23 March 2011 to 24 March 2011 were counted as 2 d but not as 1 d).

initial day throughout the text and all tables in this paper (e.g., the days from 11 March 2011 to 12 March 2011 were counted as 2 d, but not as 1 d). All restrictions were withdrawn by 1 April 2011, except in Iitate village. Levels of ^{131}I exceeding 100 Bq/kg have not been detected in any places including Iitate village since 29 March 2011 (at least by 12 June 2011), but the water supplier in Iitate village voluntarily extended restrictions on water consumption by infants up to 10 May 2011.

3.2. Milk, vegetables, seafood and other foodstuffs

3.2.1. Policy on the enforcement of restrictions on distribution and consumption

Following the FSC report (FSC, 2011a), MHLW (on behalf of NERHQ) issued a notice for policy on the execution of monitoring surveys for milk and vegetables and the enforcement of restrictions on distribution and consumption on 4 April 2011 (MHLW, 2011j). Local governments of Fukushima, Ibaraki, Tochigi, Gunma, Miyagi, Yamagata, Niigata, Nagano, Saitama, Chiba Prefectures and Tokyo Metropolis were requested to perform monitoring surveys basically once a week, but its frequency is subject to alteration when radioactivity levels exceed or are becoming close to provisional regulation values. NERHQ is to instruct restrictions on distribution according to the monitoring results, but consumption should be restricted forthwith after the detection of very highly contaminated food. NERHQ is to order such restrictions for each foodstuff in accordance with Article 20, Item 3 of the Act on Special Measures Concerning Nuclear Emergency Preparedness. Restriction area is basically each whole prefectural area, but can be subareas divided within the prefecture if applicable. Food should be monitored every week in each area where restrictions are ongoing, and the local government is to request NERHQ to lift restrictions when the monitoring result falls below the provisional regulation value (e.g., 100 Bq/kg of ^{131}I for milk) three times successively. Judging from the shape, breadth of surface area, mass, etc of the vegetables, removal of restrictions for a certain vegetables (e.g., spinach) that tend to score high radioactive concentrations should be concomitant with that for other vegetables that tend to score lower concentrations. NERHQ is to lift restrictions basically for each foodstuff, but a distinction between the foodstuff cultivated outdoor and in hothouse is not practical. The unit for withdrawal of restriction is each prefectural subarea. After removal of restrictions, monitoring data should be periodically acquired so long as radioactive releases from the Fukushima nuclear power plant 1 continue. Such policy for other food (e.g., seafood) except milk and vegetables is yet to be documented. Here, it should also be noted that unlike the case for tap water (Section 3.1.1), clear criteria for restrictions have not been provided (e.g., concrete threshold radioactive concentration values each for “highly contaminated” and “very highly contaminated” food to instruct restrictions on distribution and consumption, respectively), so that quantitatively consistent decisions cannot be made to order restrictions.

In March 2002, MHLW provided the manual for food monitoring in a nuclear emergency (MHLW, 2002), where it was documented that vegetables should be gently washed off mud and cut into pieces prior to measurements of radioactivity. On 18 March 2011, MHLW advised that monitoring methods should conform to this manual except that vegetables should be thoroughly washed to remove soil and dusts (MHLW, 2011c). The supplemental manual for washing procedures was then given on 20 April 2011 (MHLW, 2011l). Firstly, it was requested that conspicuous soil should be removed. Secondarily, the surface of mushroom should be gently wiped with the paper towel immersed in tap water. Alternatively, other vegetables should be washed for 20 s in flowing water, and subsequently wiped with the dry paper towel. Finally, it should be verified by the visual observation that soil is removed to an extent such that the vegetables are clean enough to eat or cook, followed by measurements. This was because index values are applicable to food ready to eat or cook (NSC, 1980).

3.2.2. Monitoring data and restrictions on distribution and consumption

As of 12 June 2011, MHLW has issued 95 reports on the monitoring data of a total of 4982 samples for milk, vegetables, seafood and other foodstuffs since 19 March 2011 (MHLW, 2011n). We reviewed all of these data and the information on the commencement and withdrawal of restrictions, for which compendium is provided in Table 3.

In Fukushima and Ibaraki Prefectures, 1190 and 1700 Bq/kg of ^{131}I were detected in unprocessed raw cow’s milk on 16 and 19 March 2011, respectively. In Fukushima Prefecture, distribution restrictions began on 21 March 2011. In Ibaraki Prefecture, distribution was restricted from 23 March 2011 to 10 April 2011. A maximum ^{131}I level of 5300 Bq/kg was recorded in Fukushima Prefecture in milk sampled on 20 March 2011. As of 12 June 2011, the provisional regulation value for radiocesiums has not been exceeded. Radioactivity levels in human mother’s breast milk were also monitored, though the available data are limited. On 24 March 2011, a certain citizen group (2011) obtained 8 samples from 4, 2, 1

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

Table 3
Levels of ^{131}I, ^{134}Cs and ^{137}Cs detected in milk, vegetables, seafood and other foodstuffs, and the enforcement of restrictions on distribution and consumption (as of 12 June 2011).

Prefecture[a]	Food category	Foodstuff	Levels firstly exceeded provisional regulation values in foodstuffs sampled on	Maximum levels detected				Days taken to order restrictions[m, n]	Restrictions on distribution[h]			Restrictions on consumption[h]	
				^{131}I (Bq/kg)[e]	^{134}Cs, ^{137}Cs (Bq/kg)[e]	Sampled on[e]	Cultivation		Began on[i]	Lifted on	Duration (d)[n]	Began on[i]	Duration (d)[n]
Fukushima	Milk	Raw milk	3.16.2011[d]	5300	20	3.20.2011	n.a.	6	3.21.2011[p]		19～		
	Vegetables[o]	Spinach	3.21.2011	19,000	40,000	3.21.2011	n.a.	1	3.21.2011[p]		45～	3.23.2011[p]	36～
		Kukitachi-na[b]	3.21.2011	15,000	82,000	3.21.2011	n.a.	3	3.23.2011[p]		36～		
		Shinobu-fuyu-na[b]	3.21.2011	22,000	28,000	3.21.2011	n.a.	3					
		Broccoli	3.21.2011	17,000	13,900	3.21.2011	n.a.	3					
		Santo-sai[b]	3.21.2011	4900	24,000	3.21.2011	n.a.	3					
		Komatsu-na[b]	3.21.2011	5900[f]	3400[f]	3.21.2011	n.a.	3					
				2000[f]	3600[f]	3.28.2011	n.a.	3					
		Kosaitai[b]	3.21.2011	5400	10,800	3.21.2011	n.a.	3					
		Abura-na[b]	3.21.2011	8200	8900	3.21.2011	n.a.	3					
		Chijire-na[b]	3.21.2011	3700	9000	3.21.2011	n.a.	3					
		Cabbage[b]	3.21.2011	5200[f]	2600[f]	3.21.2011	n.a.	3					
				1100[f]	2700[f]	3.28.2011	n.a.	3					
		Turnip	3.21.2011	1000	4100	4.3.2011	n.a.	3					
		Hana-wasabi[b]	3.24.2011	2500	670	3.24.2011	n.a.	n.a.					
		Mizu-na[b]	3.28.2011	4900	3300	3.28.2011	n.a.	n.a.					
		Vitamin-na[b]	4.4.2011	540	9600	4.4.2011	n.a.	n.a.					
		Shiitake mushroom cultivated on bed logs	4.1.2011	12,000	13,000	4.8.2011	Outdoor	13	4.13.2011[p]		13～	4.13.2011[p]	
		Bamboo shoot	4.27.2011	n.d.	3100	5.19.2011	n.a.	13	5.9.2011[p]		22～		
		Kusa-sotetsu[b]	4.28.2011	n.d.	1460	5.5.2011	Outdoor	12	5.9.2011[p]				
		Ume[b]	5.26.2011	n.d.	690	5.30.2011	n.a.	8	6.2.2011[p]				
		Seri[b, c]	4.11.2011	530	1980	4.11.2011	n.a.						
		Wakame[b, c]	5.16.2011	380	1200	5.16.2011							
		Hijiki[b, c]	5.21.2011	2200	1100	5.21.2011							
		Arame[b, c]	5.21.2011	1100	970	5.21.2011							
	Seafood	Konago[b]	4.7.2011	12,000	12,500	4.13.2011		14	4.20.2011[p]			4.20.2011[p]	
				3900	14,400	4.18.2011		14					
		Yamame[b]	5.17.2011	n.d.	990	5.17.2011[k]		21	6.6.2011[l, p]				
		Ayu[b, c]	5.8.2011	n.d.	2900	5.26.2011							
		Shirasu[b, c]	5.9.2011	19	850	5.9.2011							
		Wakasagi[b, c]	5.10.2011	24	870	5.10.2011							
		Ugui[b, c]	5.20.2011	n.d.	880	6.1.2011							
		Ainame[b, c]	6.6.2011	n.d.	780	6.6.2011							
		Ezo-iso-ainame[b, c]	6.6.2011	n.d.	1140	6.6.2011							
		Uni[b, c]	5.28.2011	54	1280	5.28.2011							
		Murasaki-i-gai[b, c]	5.16.2011	820	650	5.16.2011							
		Hokki-gai[b, c]	5.28.2011	n.d.	940	5.28.2011							
	Other foodstuffs[j]	Raw tea leaf[c]	5.17.2011	n.d.	930	5.17.2011	n.a.						
Ibaraki	Milk	Raw milk	3.19.2011	1700	64	3.19.2011	Pasture	5	3.23.2011	4.10.2011	19		
	Vegetables[o]	Spinach	3.18.2011	54,100[g]	1931[g]	3.18.2011	Outdoor	4	3.21.2011	6.1.2011	28～73		
				11,000[g]	586[g]	3.19.2011	Hothouse	4					
		Parsley	3.21.2011	12,000	2110	3.21.2011	Hothouse	3	3.23.2011	4.17.2011	26		
	Seafood	Konago[b, c]	4.1.2011[d]	4080[d, f]	447[f]	4.1.2011							
				420[f]	1374[f]	4.29.2011							
	Other foodstuffs[j]	Raw tea leaf	5.14.2011	n.d.	1030	5.18.2011	n.a.	20	6.2.2011[p]				

(*continued on next page*)

Table 3 (*continued*)

Prefecture[a]	Food category	Foodstuff	Levels firstly exceeded provisional regulation values in foodstuffs sampled on	Maximum levels detected				Days taken to order restrictions[m, n]	Restrictions on distribution[h]			Restrictions on consumption[h]	
				^{131}I (Bq/kg)[e]	^{134}Cs, ^{137}Cs (Bq/kg)[e]	Sampled on[e]	Cultivation		Began on[i]	Lifted on	Duration (d)[n]	Began on[i]	Duration (d)[n]
Tochigi	Vegetables[o]	Spinach	3.19.2011	5700	770	3.19.2011	Outdoor	3	3.21.2011	4.27.2011	32∼38		
		Kaki-na[b]	not exceeded						3.21.2011	4.14.2011	25		
		Shun-giku[b, c]	3.24.2011	4340	153	3.24.2011	n.a.						
	Other foodstuffs[j]	Raw tea leaf	5.17.2011	n.d.	890	5.17.2011	Outdoor	17	6.2.2011[p]				
Gunma	Vegetables[o]	Spinach	3.19.2011	2630	310	3.19.2011	Outdoor	3	3.21.2011	4.8.2011	19		
		Kaki-na[b]	3.19.2011	1910	555	3.19.2011	Outdoor	3					
	Other foodstuffs[j]	Raw tea leaf[c]	5.24.2011	n.d.	780	5.24.2011	Outdoor						
Chiba	Vegetables[o]	Spinach	3.24.2011	3500	46	3.24.2011	n.a.	12	4.4.2011	4.22.2011	19		
		Shun-giku[b]	3.18.2011	4300	≤50	3.18.2011	n.a.	18					
		Parsley	3.22.2011	3100	162	3.22.2011	n.a.	14					
		Sanchu[b]	3.22.2011	2800	66	3.22.2011	n.a.	14					
		Celery	3.22.2011	2100	92	3.22.2011	n.a.	14					
		Chin-gen-sai[b]	3.22.2011	2200	106	3.22.2011	n.a.	14					
	Other foodstuffs[j]	Raw tea leaf	5.19.2011	n.d.	985	5.19.2011	Outdoor	15	6.2.2011[p]				
Tokyo	Vegetables[o]	Komatsu-na[b, c]	3.24.2011	1700	890	3.24.2011	n.a.						
Kanagawa	Other foodstuffs[j]	Raw tea leaf	5.9.2011	n.d.	780	5.11.2011	Outdoor	25	6.2.2011[p]				
		Dried tea leaf	5.12.2011	n.d.	3000	5.12.2011		22					
Shizuoka	Other foodstuffs[j]	Processed tea[c]	6.9.2011	n.d.	679	6.9.2011							

Unlike the case for tap water (Table 2), distribution and consumption were restricted in all age groups. n.d., not detectable (below detectable levels). n.a., not accounted.

[a] Prefecture herein refers to a certain subareas in each prefecture, but not to whole prefectural area. Foodstuffs listed were those produced in own prefecture.

[b] Shown are Japanese names. See Section 3.2.2 for corresponding English and scientific names.

[c] Restrictions were not ordered by NERHQ, but each local government voluntarily instructed restrictions for most of these foodstuffs.

[d] Food was considered to exceed the provisional regulation value by looking back over the past, because the provisional regulation values for radioiodines in milk and seafood were set on 17 March 2011 and 5 April 2011, respectively.

[e] Presented are a concentration of ^{131}I and total concentrations of ^{134}Cs and ^{137}Cs in the same sample.

[f] For each foodstuff produced in each prefecture, the two data obtained from independent samples are shown when the maximum level of radioiodine was recorded in one sample and that of radiocesiums in another sample, and vice versa.

[g] Shown is each maximum level in spinach cultivated outdoors and that in hothouse.

[h] To be precise, duration of restrictions was distinct among subareas in each prefecture. Of these, the earliest date when restrictions began, the latest date when restrictions were lifted, and shortest and longest durations are tabulated here.

[i] Shown are the dates when NERHQ, but not local governments, instructed restrictions.

[j] Other foodstuffs herein refer to foodstuffs not included in categories of drinking water, milk, vegetables, cereals, meats, eggs and seafood (see Section 4.1).

[k] The same level was also detected in the sample taken on 20 May 2011.

[l] Except hatchery-reared yamame.

[m] Shown are the days from when the foodstuff firstly exceeded the provisional regulation value until when the first restriction began.

[n] The number of days was counted including the initial day (e.g., the days from 23 March 2011 to 24 March 2011 were counted as 2 d but not as 1 d).

[o] Vegetables here refer to mushroom, fruit, edible algae, corms, tubers and roots in addition to vegetables (see Section 4.1). Note that this is different from “vegetables” in Table 7 that only refer to vegetables.

[p] Restrictions are ongoing.

and 1 mothers living in Ibaraki, Fukushima, Miyagi and Chiba Prefectures, respectively. Of these, 36.3 and 31.8 Bq/kg of radioiodine were detected in samples obtained from two mothers each living in Chiba and Ibaraki Prefectures, respectively. Thereafter, levels decreased to 14.8 and 8.5 Bq/kg of radioiodine in samples obtained from these two mothers on 30 March 2011. Radiocesium was below detectable levels in all samples. MHLW reported that maximum levels were 8.0 Bq/kg of ^{131}I, ^{134}Cs below detectable levels and 2.4 Bq/kg of ^{137}Cs among 23 samples, which were collected on 24 or 25 April 2011 from 4, 9, 2, 1 and 7 mothers living in Fukushima, Ibaraki, Chiba, Saitama Prefectures and Tokyo Metropolis, respectively (MHLW, 2011m).

First of all vegetables, spinach exceeded provisional regulation values in Ibaraki and Fukushima Prefectures on 18 and 21 March 2011, respectively (n.b., vegetables herein refer to mushroom, fruit, algae, corms, tubers and edible roots in addition to vegetables, see Section 4.1). Thereafter, provisional regulation values were also exceeded in broccoli, cabbage, celery, turnip, parsley, bamboo shoot, shiitake mushroom (cultivated outdoors on bed logs), ume (Japanese apricot, *Prunus mume*), kusa-sotetsu (ostrich fern, *Matteuccia struthiopteris*), shungiku (garland chrysanthemum, *Glebionis caronaria*), sanchu (celtuce, *Lactuca sativa* var. *angustana*), seri (water dropwort, *Oenanthe javanica*), hana-wasabi (Japanese horseradish, *Wasabia japonica*), kosaitai (purple-stem mustard, *Brassica chinensis* f. *honsaitai*), chin-gen-sai (qing-gengcai, *B. rapa* var. *chinensis*), komatsu-na (Japanese mustard spinach, *B. rapa* var. *perviridis*), chijire-na (rape blossoms, *B. rapa* var. *amplexicaulu*), abura-na (rape, *B. campestris*), mizu-na (potherb mustard, *B. campestris* var. *laciniifoli*), vitamin-na (*B. campestris* cv. *vitamin-na*), santo-sai (Shantung cabbage, *B. campestris* var. *amplexicaulis*), other leafy vegetables belonging to *Brassiaceae* (kaki-na, kukitachi-na, shinobu-fuyu-na), and brown algae such as wakame (*Undaria pinnatifida*), hijiki (*Sargassum fusiforme*) and arame (*Eisenia bicyclis*). In Fukushima Prefecture, consumption and/or distribution of headed and non-headed leafy vegetables, flower-headed brassicas, turnip, bamboo shoot, kusa-sotetsu, log-cultivated shiitake mushroom and ume were restricted. Vegetables whose distribution was restricted in Ibaraki, Tochigi, Gunma and Chiba Prefectures include spinach, kaki-na, shungiku, chin-gen-sai, sanchu, parsley and celery. Among all vegetables, the maximum concentration of ^{131}I (54,100 Bq/kg) and the maximum total concentrations of ^{134}Cs and ^{137}Cs (82,000 Bq/kg) were detected in spinach and kukitachi-na, respectively. Not only vegetables cultivated outdoors but also those in hothouse exceeded provisional regulation values.

The provisional regulation value for radioiodines in seafood (2000 Bq/kg of ^{131}I) was hurriedly set on 5 April 2011 (MHLW, 2011k), by which time such value had not existed (see Section 4). This was because 4080 Bq/kg of ^{131}I was detected in konago (juvenile sand lance, *Ammodytes personatus*) sampled in Ibaraki Prefecture on 1 April 2011. Restrictions on distribution and consumption of konago began on 20 April 2011 in Fukushima Prefecture. In May 2011 or later, other fish and shellfish exceeding 500 Bq/kg of ^{134}Cs and ^{137}Cs started being detected, including yamame (landlocked salmon, *Oncorhynchus masou*), ayu (sweetfish, *Plecoglossus altivelis*), shirasu (general name for the young of sardines, eels, ayu, etc), wakasagi (Japanese pond smelt, *Hypomesus nipponensis*), ugui (Japanese dace, *Tribolodon hakonensis*), ainame (fat greenling, *Hexagrammos otakii*), Ezo-iso-ainame (*Physiculus maximowiczi*), uni (sea urchin, echinoderms belonging to *Echinoidea*) including murasaki-uni (purple sea urchin, *Anthocidaris crassispina*), murasaki-i-gai (blue mussel, *Mytilus galloprovincialis*) and Hokki-gai (Sakhalin surf clam, *Pseudocardium sachalinense*). Of these, distribution and/or consumption of konago and yamame (except hatchery-reared one) were restricted in Fukushima Prefecture. Among all seafood, maximum concentrations (12,000 Bq/kg of ^{131}I, and 14,400 Bq/kg of ^{134}Cs and ^{137}Cs) were detected in konago.

Unprocessed raw tea leaf, dried tea leaf, and processed tea exceeded the provisional regulation value for radiocesiums in other foodstuffs (referring herein to food not included in categories of drinking water, milk, vegetables, cereals, meats, eggs, seafood, see Section 4.1). The distribution of tea leaf was restricted in Ibaraki, Tochigi, Chiba and Kanagawa Prefectures. It should be noted that provisional regulation values for radioiodines in such foodstuffs have not been set, reminiscent of the case for seafood as aforementioned.

Meats including beef have not exceeded the provisional regulation value for radiocesiums. Incidentally, on 14 April 2011, the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF) put the limit to regulate contaminated livestock feed for cattle, which was stipulated as “provisional tolerance values” (MAFF, 2011). Values set were 300 Bq/kg of ^{134}Cs and ^{137}Cs in roughage for beef cattle and daily cattle, and 5000 Bq/kg of ^{134}Cs and ^{137}Cs for other cattle, 70 Bq/kg of ^{131}I for daily cattle (MAFF, 2011). However, the provisional tolerance value for ^{131}I in cattle excluding daily cattle was not set, because there was no provisional regulation value set for radioiodines in meats. Alternatively, it was advised that roughage harvested from areas where restrictions on distribution of crops (i.e., vegetables) on account of excess radioiodines have not been enforced should be fed to cattle excluding daily cattle (MAFF, 2011). According to the monitoring results, pasturage, feeding of contaminated pasture grass, and rearing of some beef and daily cattle were temporarily suspended in the whole area or subareas of Iwate, Miyagi, Fukushima, Ibaraki, Tochigi, Gunma and Chiba Prefectures. Maximum concentrations (170 Bq/kg of ^{131}I, and 9200 Bq/kg of ^{134}Cs and ^{137}Cs) were detected in the pasture grass sampled in Fukushima Prefecture on 27 April 2011.

All together, restrictions on consumption of food (excluding water) were enforced only in Fukushima Prefecture. Distribution restrictions were enforced in Fukushima, Ibaraki, Tochigi, Gunma, Chiba and Kanagawa Prefectures. In Tokyo Metropolis and Shizuoka Prefecture, only one komatsu-na sample taken on 24 March 2011 and one processed tea sample taken on 9 June 2011 exceeded the provisional regulation values for radioiodines and radiocesiums, respectively, and restrictions were not enforced. In the rest of other 39 Prefectures in Japan, no samples exceeded provisional regulation values.

4. Logic behind provisional regulation values

4.1. Approaches taken to calculate the index values

As described in Section 2, provisional regulation values were adopted from the index values, except the value for radioiodines in drinking water and milk consumed by infants as well as that in seafood. Here, approaches taken to calculate the index values are described.

In internal exposure situations, tissues or organs receive radiation emitted during the decay of incorporated radionuclide as a function of time following the intake, and temporal dose distribution should be therefore considered. A committed equivalent dose is the time integral of the equivalent dose rate to be delivered to a particular tissue or organ (ICRP, 1995). A committed effective dose (to the whole body) is the sum of the committed tissue or organ equivalent doses each multiplied by tissue weighting factors (ICRP, 1995). The integration time amounts to a period of 50 y for adults, and the period from intake to the age of 70 y for others (ICRP, 1995).

When off-site members of the public have the possibility to receive excess exposure to radiation released from the crippled

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

nuclear facility, intervention (achievable measures to minimize exposure) for radiation protection needs to be considered. Intervention level (IL) is the avertable dose serving as a basis to judge the necessity of intervention. Derived intervention level (DIL) is the dose secondarily set for the restriction of consumption and distribution not to exceed IL. Herein, IL is expressed in the committed dose per annum (mSv/y), and the index values expressed in radioactive concentrations (Bq/kg) fall under DIL. To determine the index values, the radioactive concentration giving IL (RCIL) was calculated for each radionuclide group using equation (5) (Suga and Ichikawa, 2000).

$$RCIL_{jk} = \frac{IL/G}{FW_{jk}\sum_{i} CF_{ij} f_i \{1-\exp(-\lambda_i T)\}/\lambda_i} \qquad (5)$$

Generations were divided into five age groups: infants (0–1 y of age; representative age at 3 months), children (1–6 y; 5 y), juveniles (7–12 y; 10 y), adolescents (12–17 y; 15 y) and adults (≥17 y). Food was classified into five categories: 1) drinking water, 2) milk (cow's milk, powdered milk, human mother's breast milk, daily products and related others), 3) vegetables (mushroom, fruit, algae, corms, tubers and roots in addition to vegetables), 4) cereals (grains, rice and pulses), and 5) meats (including poultry), eggs, seafood (seawater fish, freshwater fish, shellfish and other fishery products) and other foodstuffs. Factor *G* is the number of food categories considered in each radionuclide group (e.g., $G = 3$ and 5 for radioiodines and radiocesiums, respectively). Factor *F* is the market dilution factor for long-lived radionuclides (i.e., the consumption rate of contaminated food versus non-contaminated food), assuming that the consumption of non-contaminated food reduces overall radionuclide intake (e.g., $F = 1$ and 0.5 for radioiodines and radiocesiums, respectively). Variable *T* (d) is a period of time for food intake per annum ($T = 365$). Factor W_{jk} (kg/d or L/d) is the mean daily food intake (MDFI) for age group *j* and food category *k*. Values of MDFI for adults originate from the data in the National Nutrition Survey conducted in 1986 (MHW, 1988), and those for infants and children were adapted from the data obtained by the National Institute of Radiological Sciences (Chiba, Japan) (Suga and Ichikawa, 2000). MDFI of milk and drinking water consumed by infants includes the mass of breast milk, cow's milk, powdered milk, and water used to dissolve the milk powder.

For radionuclide *i*, λ_i (d^{-1}) is a decay constant. As it is evident that a denominator in the equation (5) contains an exponential function, calculation of index values takes account of the radionuclide decay, such that $\{1\text{-}\exp(\text{-}\lambda_i T)\}/\lambda_i$ reflects the cumulative radioactivity level. It is also assumed that once contaminated prior to the initial intake, no additional contaminations occur subsequently in food. Factor f_i is the postulated radioactivity level of coexisting radionuclide *i* relative to that of indicator radionuclide(s). Namely, f_i is set as 1 for indicator radionuclide(s) that are representative of each radionuclide group. By the use of f_i values, RCIL calculated only from the concentration of indicator radionuclide(s) can take into account the contribution of other coexisting radionuclides to the committed dose.

Factor CF_{ij} (mSv/Bq) is a conversion factor (CF) for radionuclide *i* and age group *j*. CF is a committed dose per unit intake, and can be used as an ingestion dose coefficient to convert the radioactivity level (Bq) into a committed dose (mSv). CF for a committed effective dose is the sum of that for committed tissue or organ equivalent doses each multiplied by tissue weighting factors. Whereas the International Commission on Radiological Protection (ICRP) has provided age-specific CF values each for six age groups (ICRP, 1992b), only three groups (infants, children and adults) were dealt to calculate RCIL (Suga and Ichikawa, 2000). CF values were taken from those listed in ICRP Publication 67 (ICRP, 1992b) and International Basic Safety Standards (BSS) published in 1996 by the International Atomic Energy Agency (IAEA) (IAEA, 1996), with the exception of those for ^{133}I, ^{134}I and ^{135}I. CF for a committed equivalent dose to the thyroid posed by ingestion of ^{133}I, ^{134}I and ^{135}I for adults was calculated using the LUDEP 2.0 program (Jarvis et al., 1996). This resulting value was then approximated to calculate such CF for infants and children, providing the same ratio of a committed equivalent dose to the thyroid in adults to that in infants or children by the ingestion of ^{132}I whose half-life is akin to half-lives of ^{133}I, ^{134}I and ^{135}I.

As far as IL is concerned, ICRP issued Publication 40 (ICRP, 1984), and proposed the concept of upper and lower limits on the dose level in the first one year after a nuclear accident. Implementation of measures would largely be necessary above upper limits, but would not be justified below lower limits. Practical IL values should be set in between. Lower and upper limits recommended for food regulations were effective doses of 5 and 50 mSv, and equivalent doses of 50 and 500 mSv to any selectively exposed individual organ or tissue (n.b., values not limited for the thyroid), respectively. In 1988, the World Health Organization (WHO) indicated that an effective dose of 5 mSv/y and an equivalent dose to the thyroid of 50 mSv/y are IL for food regulations (WHO, 1988). In 1992, ICRP in its Publication 63 (ICRP, 1992a) recommended that an effective dose of 10 mSv/y for any single foodstuff is IL that would almost always be justified, where optimized concrete values are in the range of 1–10 kBq/kg for β/γ emitters and 10–100 Bq/kg for α emitters. Here, 1 kBq/kg (lower limit for β/γ emitters) correspond to 5.5 mSv/y, given the world mean annual food intake (excluding drinking water) of 550 kg by an adult (WHO, 1988) and a rough CF value of 1×10^{-5} mSv/Bq (FSC, 2011a). The same holds true for 10 Bq/kg (lower limit for α emitters) given a rough CF value of 1×10^{-3} mSv/Bq (FSC, 2011a). Taking these situations into account, NSC decided to employ values on the considerably safe side, namely, a committed equivalent dose to the thyroid of 50 mSv/y for radioiodines, and a committed effective dose of 5 mSv/y each for radiocesiums, uranium, plutonium and other transuranic α emitters.

Finally, $RCIL_{jk}$ is the RCIL of indicator radionuclide(s) for age group *j* and food category *k*. To yield the index value, the calculated RCIL value minimal among infants, children and adults for each food category was rounded off to a smaller value on the safe side (Suga and Ichikawa, 2000). Further details of approaches taken to calculate the index values for radioiodines and radiocesiums are provided below, for which parameters used are listed in Tables 4 and 5.

4.1.1. *Radioiodines*

A radioiodine group consists of ^{131}I, ^{132}I, ^{133}I, ^{134}I, ^{135}I and ^{132}Te. Of these, ^{131}I is an indicator radionuclide (i.e., $f_i = 1$ for ^{131}I). f_i values for coexisting radionuclides were calculated as the ratio of each simulated radioactive concentration inside the reactor at 0.5 d after shutdown of the pressurized water reactor (PWR) where fuel having an initial concentration of 3% is burned at 30 GWd/ton. ORIGEN2 code (Croff, 1980) was used to simulate concentrations of each radionuclide, and a time point of 0.5 d was chosen to exclude short-lived radionuclides that are unlikely to contaminate food (Suga and Ichikawa, 2000).

As mentioned in Section 4.1, a committed equivalent dose to the thyroid of 50 mSv/y was employed. Two-thirds were then assigned as IL to three food categories (drinking water, milk, and vegetables excluding corms, tubers and roots) on a per capita basis (i.e., $IL/G = 33.3$ mSv/3 = 11.1 mSv/food category) (NSC, 1980). Corms, tubers and roots growing underground should have less chance of being contaminated through the air than other vegetables, and were therefore excluded from the category of vegetables. The rest one-third (i.e., 16.7 mSv) was assigned to other foods (i.e., seafood,

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

Table 4

Radioactivity ratio of coexisting radionuclides, decay constant, and conversion factors used to calculate index values.

Radionuclide group *g*	Radionuclide *i* [a]	λ_i (d^{-1}) [b]	f_i [c]	CF_{ij} (mSv/Bq)[d]		
				Infants	Children	Adults
Radioiodine	**^{131}I**	8.621×10^{-2}	**1.0000**	3.7×10^{-3}	2.1×10^{-3}	4.3×10^{-4}
	^{132}I	7.232	1.3617	4.0×10^{-5}	1.9×10^{-5}	3.4×10^{-6}
	^{133}I	7.998×10^{-1}	1.4255	9.8×10^{-4}	4.6×10^{-4}	8.3×10^{-5}
	^{134}I	1.897×10^{1}	0.0006	6.5×10^{-6}	3.1×10^{-6}	5.5×10^{-7}
	^{135}I	2.517	0.5532	1.9×10^{-4}	8.9×10^{-5}	1.6×10^{-5}
	^{132}Te	2.127×10^{-1}	1.3191	6.2×10^{-4}	1.6×10^{-4}	2.9×10^{-5}
Radiocesium	^{89}Sr	1.373×10^{-2}	0.28732	3.6×10^{-5}	8.9×10^{-6}	2.6×10^{-6}
	^{90}Sr	6.521×10^{-5}	0.04555	2.3×10^{-4}	4.7×10^{-5}	2.8×10^{-5}
	^{134}Cs	9.210×10^{-4}	**0.54455**	2.6×10^{-5}	1.3×10^{-5}	1.9×10^{-5}
	^{137}Cs	6.330×10^{-5}	**0.45545**	2.1×10^{-5}	9.7×10^{-6}	1.4×10^{-5}

Note that f_i values for indicator radionuclide(s) presented in bold fonts were set to 1.

[a] Indicator radionuclides are indicated in bold fonts.

[b] Decay constant for radionuclide *i*.

[c] The postulated radioactive concentration of coexisting radionuclide *i* relative to that of indicator radionuclide(s).

[d] Conversion factor for radionuclide *i* and age group *j* to convert the radioactive concentration into committed equivalent dose to the thyroid gland (for radioiodine) or committed effective dose (for radiocesium).

cereals, meats, eggs, corms, tubers, roots and other foodstuffs) taking these consumptions into consideration (NSC, 1980).

Collectively, the index values for radioiodines signify that if a radioactive concentration of ^{131}I in food is equal to or less than the index value at the initial date of intake, a committed equivalent dose to the thyroid in any of infants, children and adults who continue to consume the mass of MDFI for 365 d does not exceed 11.1 mSv for each of three food categories.

4.1.2. Radiocesiums

A radiocesium group comprises ^{89}Sr, ^{90}Sr, ^{134}Cs and ^{137}Cs. Cesium-134 and ^{137}Cs are indicator radionuclides, and the sum of their f_i values is set as 1. Values of f_i for coexisting radionuclides were calculated based on two assumptions: 1) the ratio of a radioactive concentration of ^{90}Sr to that of ^{137}Cs is 1:10, and 2) the ratio of a radioactive concentration of ^{90}Sr to ^{89}Sr and that of ^{137}Cs to ^{134}Cs are both consistent with those at 0.5 d after shutdown of PWR where fuel with an initial concentration of 3% is burned at 30 GWd/ton (Section 4.1.1) (Suga and Ichikawa, 2000).

As described in Section 4.1, a committed effective dose of 5 mSv/y served as IL. Then, 5 mSv was evenly assigned to five food categories (i.e., $IL/G = 5$ mSv$/5 = 1$ mSv/food category) (NSC, 1980). Thus, the index values for radiocesiums mean that if total radioactive concentrations of ^{134}Cs and ^{137}Cs in food are equal to or less than the index value at the initial date of intake, a committed effective dose in any of infants, children and adults who continue to consume the half mass of MDFI (because $F = 0.5$) for 365 d does not exceed 1 mSv for each of five food categories. Incidentally, the same approaches were taken to calculate the index values for uranium, plutonium and other transuranic α emitters (NSC, 1980). In this condition, index values were provided for all food, unlike the case for radioiodines.

4.2. Provisional regulation values not adopted from the index values

The provisional regulation value for radioiodines in drinking water and milk ingested by infants was newly set by MHLW on 17 March 2011 (MHLW, 2011b). Whereas this value was adopted from the "guideline level" indicated by the Codex Alimentarius Commission (CAC) in 1995 (CAC, 1995), the logic behind its adoption is quite unclear. This is not only because guideline levels set not to exceed a committed effective dose of 1 mSv/y were the same values for infants and adults (e.g, 100 Bq/kg for ^{131}I and ^{90}Sr, 1000 Bq/kg for ^{89}Sr, ^{134}Cs and ^{137}Cs) (CAC, 1995), but also because index values for radioiodines in drinking water and milk were set not to exceed a committed equivalent dose to the thyroid of 11.1 mSv/y in any of infants, children and adults (Section 4.1.1).

As mentioned in Section 3.2.2, the provisional regulation value for radiodines in seafood was also newly set by MHLW on 5 April 2011 (MHLW, 2011k), and was adopted from that in vegetables excluding corms, tubers and roots. Incidentally, a minimum RCIL giving a committed equivalent dose to the thyroid of 11.1 mSv/y is calculated as 8484 Bq/kg presuming the consumption of MDFI for seafood (Table 5), and its round-off yields a value of 8000 Bq/kg.

Noteworthy is that such case-dependent addition of new values completely perturbs the logic used to define the original index values.

5. Discussion

5.1. Conversion from a radioactive concentration to a committed dose

There has been a surge of interest in radiation and radiation effects following the Fukushima nuclear accident. When food exceeding provisional regulation values started being reported, a certain Japanese mass media and others offered the information on the conversion from a concentration of a single radionuclide in food to a committed dose using equation (6), where t (d) is intake period. A committed dose at the time of t is D_t (mSv). Variable A_i (Bq/kg) is a concentration of radionuclide i in food at the initial intake. Factor M_{jk} (kg/d) is the arbitrary mass of daily food intake (not limited to MDFI $= W_{jk}$ explained in Section 4.1) for age group j and food category k. Factor CF_{ij} (mSv/Bq) is a CF for radionuclide i and age group j.

$$D_t = A_i M_{jk} CF_{ij} t \tag{6}$$

On one hand, calculation with the equation (6) results in dose overestimation especially for short-lived radionuclides (e.g., radioiodines), because the radionuclide decay is not considered. To improve this, t in equation (6) should be replaced with $\{1-\exp(-\lambda_i t)\}/\lambda_i$, as shown in equation (7).

$$D_t = A_i M_{jk} CF_{ij} \{1 - \exp(-\lambda_i t)\}/\lambda_i \tag{7}$$

On the other, calculation with equations (6) or (7) does not allow for the intake of multiple radionuclides, whilst indicator and other coexisting radionuclides were dealt to calculate index values for each radionuclide group (Section 4.1). Also, consistent approaches

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

Table 5
Mean daily food intake used to calculate index values and calculated radioactive concentrations giving intervention levels.

Radionuclide group	Food category *k*	W_{jk} (kg/d or L/d) [a]			$RCIL_{jk}$ (Bq/kg) [b]			Index value (Bq/kg)	Provisional regulation value (Bq/kg)
		Infants	Children	Adults	Infants	Children	Adults		
Radioiodine	Drinking water	0.71	1.0	1.65	**322**	424	1266	300	300 (100 for infants)
	Milk	0.6	0.5	0.2	**381**	848	10,443		
	Vegetables except corms, tubers and roots	0.07	0.17	0.4	3269	**2495**	5222	2000	2000
	Seafood	0.02	0.05	0.1	11,441	**8484**	20,886	not assinged	
Radiocesium	Drinking water	0.71	1.0	1.65	228	421	**201**	200	200
	Milk	0.6	0.5	0.2	**270**	843	1661		
	Vegetables	0.105	0.25	0.6	1540	1686	**554**	500	500
	Cereals	0.055	0.105	0.3	2940	3831	**1107**		
	Meats, eggs, seafood and other foodstuffs	0.05	0.105	0.5	3234	4014	**664**		

Vegetables here refer to mushroom, fruit, edible algae, corms, tubers and roots in addition to vegetables (see Section 4.1). Note that this is different from "vegetables" in Table 7 that only refer to vegetables.
Cereals here include grains and pulses (see Section 4.1), which are different from "cereals" in Table 7 that only refer to cereals.
Values were calculated with equation (5), and minimum values in each food category among infants, children and adults are shown in bold fonts.

[a] Mean daily food intake for age group *j* and food category *k*. To calculate index values for radiocesiums, the half of the mean daily food intake was considered as the mass of contaminated food to be consumed, taking into account that the consumption rate of contaminated food (*F* value) was postulated as 0.5. For radioiodines, the mean daily food intake shown above was considered as the mass of contaminated food because *F* value was set as 1. See Section 4.1 for details.

[b] Radioactive concentrations of indicator radionuclide(s) giving the interventional level per food category (i.e., a committed equivalent dose to the thyroid of 11.1 mSv/y for radioiodine, or a committed effective dose of 1 mSv/y for radiocesium) for age group *j* and food category *k*.

should be taken to compare the dose with index values. For this aim, equation (5) was firstly solved in terms of IL/G, yielding equation (8). Secondarily, replacement of IL/G with D_t, $RCIL_{jk}$ with A_g, W_{jk} with M_{jk}, and T with t in equation (8) obtains equation (9), where A_g (Bq/kg) is total concentrations of indicator radionuclide (s) in food at the initial intake (e.g., ^{134}Cs and ^{137}Cs for radiocesiums, and ^{131}I for radioiodines).

$$IL/G = RCIL_{jk}FW_{jk}\sum_i CF_{ij}f_i\{1-\exp(-\lambda_i T)\}/\lambda_i \tag{8}$$

$$D_t = A_g FM_{jk}\sum_i CF_{ij}f_i\{1-\exp(-\lambda_i t)\}/\lambda_i \tag{9}$$

Equation (9) can calculate the committed dose considering contribution of coexisting radionuclides for each radionuclide group, if A_g value is available. Take Fig. 1, for example, where alterations in committed doses are shown as a function of intake period. This calculation was done with equation (9), providing that $A_g =$ index value for radionuclide group g in drinking water (300 Bq/kg for radioiodines, and 200 Bq/kg for radiocesiums), and $M_{jk} =$ MDFI of drinking water for each age group listed in Table 5. Factor F was set as 1 for radioiodines and 0.5 for radiocesiums. For other parameters, values listed in Table 4 were used. Fig. 1 illustrates that committed doses are below IL/food group (i.e., a committed equivalent dose to the thyroid of 11.1 mSv/y for radioiodines and a committed effective dose of 1 mSv/y for radiocesiums), irrespective of whether infants, children or adults continue to drink such contaminated water throughout the year, unless additional contaminations occur subsequently during intake period.

One may feel that equation (9) is a bit complicated and inaccessible. For use by non-experts, it would be practically desirable if committed doses considering contribution of coexisting radionuclides could be calculated from the initial concentration of indicator radionuclide(s) in food as simply and easily as equation (7). To this end, CF_{gjt} (mSv/Bq) was calculated by equation (10). Conversion factor CF_{gjt} is a CF for radionuclide group g and age group j, and is a function of time, such that whereas CF_{gjt} values for short-lived radioiodines decline with increasing intake periods (Fig. 2A), those for long-lived radiocesiums remain nearly constant (Fig. 2B). With respect to representative intake periods, committed doses considering contribution of coexisting radionuclides can be simply calculated from the initial concentration of indicator radionuclide(s) in food, with equation (11) by using CF_{gjt} values listed in Table 6.

$$\begin{aligned} CF_{gjt} &= \frac{D_t}{A_g M_{jk} t} = \frac{A_g FM_{jk}\sum_i CF_{ij}f_i\{1-\exp(-\lambda_i t)\}/\lambda_i}{A_g M_{jk} t} \\ &= \frac{F\sum_i CF_{ij}f_i\{1-\exp(-\lambda_i t)\}/\lambda_i}{t} \end{aligned} \tag{10}$$

$$D_t = A_g M_{jk} CF_{gjt} t \tag{11}$$

Finally, the following attentions should be paid to dose calculation. 1) Index values (Section 4.1) or doses were calculated presuming that once contaminated prior to the initial intake, no additional contaminations occur subsequently in food. However, multiple contaminations are possible to occur in case the accidental radionuclide release is continuing. If this is the case, integration of the dose given by each contamination is necessary. 2) f_i and F values were postulated for a limited situation (Section 4.1). 3) The dose received by intake of a single radionuclide group was considered

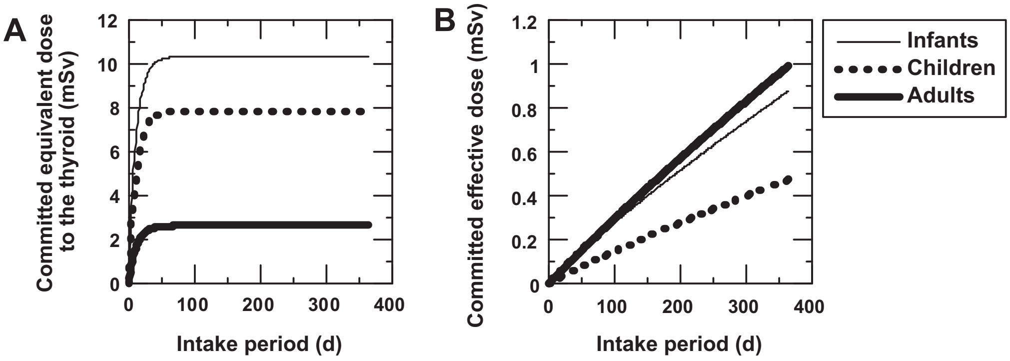


Fig. 1. Changes in the committed dose as a function of time. A committed equivalent dose to the thyroid (A) and a committed effective dose (B) posed by consumption of contaminated drinking water for a period of up to 365 d were calculated with equation (9) considering the contribution of all postulated coexisting radionuclides in radioiodine and radiocesium groups, respectively. See Section 5.1 for details.

here. However, as presented in Table 3, levels of both radioiodines and radiocesiums were above provisional regulation values in some vegetables and seafood. Moreover, inhalation and external exposure may also occur. So, the individual dose should be calculated taking account of superimposed exposure situations via multiple exposure pathways (see Section 6).

5.2. Current issues underlying provisional regulation values

5.2.1. Intervention levels and reference levels

IL/food category considered to calculate the index values was a committed equivalent dose to the thyroid of 11.1 mSv/y for radioiodines, and a committed effective dose of 1 mSv/y for radiocesiums, uranium, plutonium and other transuranic α emitters (Sections 4.1.1 and 4.1.2). On one hand, ICRP recommended in Publication 63 (ICRP, 1992a) that an annual effective dose of 10 mSv for any single foodstuff is IL that would almost always be justified (Section 4.1). It was also indicated that intervention would be justified only at levels of a projected dose much higher than 10 mSv/y in situations where alternative food supplies are not readily obtainable, or where population groups might suffer serious disruption (ICRP, 1992a). On the other hand, operational intervention level 6 (OIL6) values (see Section 5.2.2) were set not to exceed the individual effective dose of 10 mSv/y per person in any age groups (IAEA, 2011a), and index values are nearly one order more conservative compared with OIL6 values. The annual effective dose of 10 mSv has also been applied to radiation protection in existing exposure situations. ICRP stated that a committed effective dose of 10 mSv/y posed by radon inhalation is a reference level (RL) where action would almost certainly be warranted to reduce exposure (ICRP, 2009b). The RL is a dose level above which the planning to allow exposure to occur is judged to be inappropriate, below which optimization of protection should be implemented in emergency or existing controllable exposure situations. In response to this statement (ICRP, 2009b), the same values were applied as RL for radon in BSS of IAEA (2011b), which was jointly sponsored by the Food and Agriculture Organization of the United Nations (FAO), International Labour Organization (ILO), Nuclear Energy Agency of the Organization for Economic Co-operation and Development, Pan American Health Organization (PAHO), WHO and potentially sponsored by European Commission, and United Nations Environment Programme.

Recently, ICRP in its Publication 103 (ICRP, 2007) recommended an approach based on the characteristics of radiation exposure situations instead of the previous process-based approach of practice and intervention (ICRP, 1992a), and more focus was placed on optimization and implementation of protection for what had been categorized as interventions. Further, in both Publication 111 (ICRP, 2009a) and more recent statement (ICRP, 2011), ICRP recommended that RL should preferably be chosen in the band of 20–100 mSv/y in the case of an emergency exposure situation. It was also recommended that for a subsequent existing exposure situation, RL should be chosen in the band of 1–20 mSv/y, and chosen in the lower part of the 1–20 mSv/y band with the long-term goal of reducing RL to 1 mSv/y that is close or similar to planned exposure situations. In this respect, IL/food group in the current Japanese food safety regulations corresponds to the lower part in the 1–20 mSv/y band.

5.2.2. Coverage of food and radionuclides

Provisional regulation values are not much comprehensive and systematic in terms of coverage of foodstuffs and radionuclides.

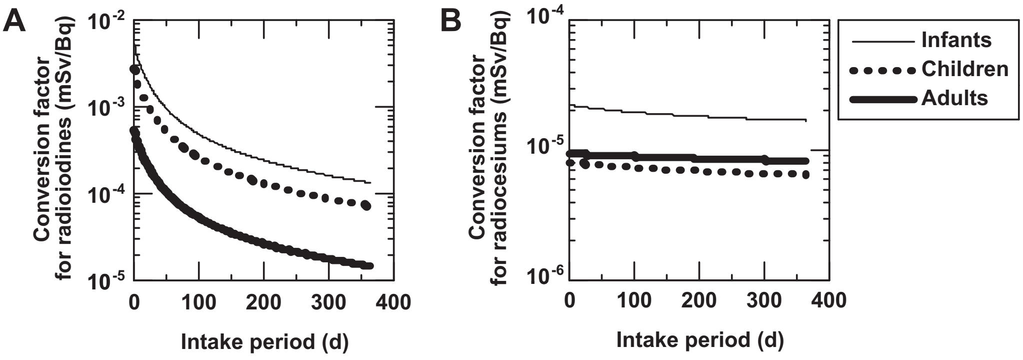


Fig. 2. Alterations in values of conversion factor as a function of time. Equation (10) was used to calculate CF_{gjt} (conversion factor for radionuclide group g and age group j) for radioiodine (A) and radiocesium group (B) to convert the initial concentration of indicator radionuclide(s) in food into a committed equivalent dose to the thyroid and a committed effective dose considering the contribution of all postulated coexisting radionuclides, respectively. Values of parameters used are listed in Table 4.

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

Table 6
Conversion factor for representative intake period.

Intake period (d)	CF_{gjt} (mSv/Bq)[a]					
	Radioiodine			Radiocesium		
	Infants	Children	Adults	Infants	Children	Adults
1	5.32×10^{-4}	2.68×10^{-3}	5.29×10^{-3}	9.37×10^{-6}	8.09×10^{-6}	2.22×10^{-5}
7	3.64×10^{-4}	1.81×10^{-3}	3.46×10^{-3}	9.34×10^{-6}	8.03×10^{-6}	2.20×10^{-5}
30	1.65×10^{-4}	8.12×10^{-4}	1.51×10^{-3}	9.23×10^{-6}	7.82×10^{-6}	2.12×10^{-5}
90	5.91×10^{-5}	2.91×10^{-4}	5.39×10^{-4}	8.99×10^{-6}	7.40×10^{-6}	1.98×10^{-5}
180	2.96×10^{-5}	1.46×10^{-4}	2.70×10^{-4}	8.71×10^{-6}	7.00×10^{-6}	1.84×10^{-5}
365	1.46×10^{-5}	7.18×10^{-5}	1.33×10^{-4}	8.25×10^{-6}	6.50×10^{-6}	1.69×10^{-5}

[a] Conversion factor for radionuclide group g and age group j to convert the initial concentration of indicator radionuclide(s) in food to a committed dose (committed equivalent dose to the thyroid for radioiodine, and committed effective dose for radiocesium) considering contribution of other coexisting radionuclides. Values shown were calculated with equation (10).

Index values and provisional regulation values set on 17 March 2011 for radioiodines were assigned to drinking water, milk and some vegetables (Section 4.1.1), but not to other foodstuffs. Under this condition, new values need to be defined on a case-by-case basis, when each foodstuff without the preset regulation value becomes contaminated at levels of concern. Such additional setting of the value also leads to disruption of the logic used to define the original index values. In actuality, this was indeed the case for the provisional regulation value hastily set for radioiodines in seafood (Section 3.2.2). Also, there might be no logic to divide all food into five categories (Section 4.1).

Index values for each radionuclide group were expressed in concentrations of only indicator radionuclides. This approach was practically convenient in that food can be regulated without monitoring other radionuclides. However, the actual level and composition of some but not all radionuclides in food can be determined by measurements. If the different regulation value is defined for each radionuclide, the necessity of restrictions can be judged without postulating f_i and F values (Section 4.1). Namely, restrictions can be imposed if $\sum_i K_i/R_i > 1$ is satisfied, where K_i and R_i are the concentration of radionuclide i in foodstuff (Bq/kg) and the regulation value for radionuclide i (Bq/kg), respectively. This approach has been widely employed in the field of radiation safety (e.g., for compliance with discharge limits, exemption and clearance levels). Moreover, there were limited coexisting radionuclides whose potential releases from PWR were simulated (Sections 4.1.1 and 4.1.2, n.b., all reactors in the Fukushima nuclear power plant 1 are BWR), and none of ^{51}Cr, ^{54}Mn, ^{58}Co, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{95}Zr, ^{95}Nb, ^{106}Ru and ^{144}Ce monitored in tap water (Section 3.1.2) was considered. Taken together, the possibility cannot be ruled out that the accidental release of other radionuclides generally handled in nuclear industries (e.g., ^{3}H, ^{14}C, ^{32}P, and ^{99m}Tc) happens (JRIA, 2010). In the emergency phase of accident, countermeasures against short-lived radionuclides are indispensable to reduce potential health risks associated with its ingestion or inhalation. For the comprehensive preparedness and response for a nuclear accident or radiological emergency, regulation values should be set to cover all food consumed by the nation and arrays of measurable radionuclides whose accidental release can be expected.

In May 2011, IAEA in its General Safety Guide No. GSG-2 (IAEA, 2011a) proposed the concept of default OIL, and the process for assessing radionuclide concentrations in foodstuff. It was advised that for screening purposes, the gross α and β concentrations in the potentially contaminated food should be firstly determined. If the OIL5 screening levels (5 Bq/kg of gross α or 100 Bq/kg of gross β) are exceeded, the radionuclide-specific concentration should be determined. The OIL6 levels are exceeded if $K_i/OIL6_i$ is greater than 1, where K_i (Bq/kg) and $OIL6_i$ (Bq/kg) are the concentration of radionuclide i in foodstuff and default radionuclide-specific OIL6 value for radionuclide i, respectively. If the OIL6 levels are exceeded, consumption of non-essential food should be restricted. Essential food should be replaced, or the residents should be relocated if replacements are unavailable. If OIL5 and/or OIL6 levels are not exceeded, food is safely consumed during the emergency phase. Then, the suitability for long-term consumption after the emergency phase should be determined using national criteria or WHO guidance (WHO, 2006). In GSG-2, each OIL6 value was defined for 355 different radionuclides, and was independent of food and age (i.e., the same value for all food such as water, milk, and other food, as well as for all age groups including infants, children and expectant mothers). For instance, OIL6 values provided were 3000 Bq/kg for ^{131}I, 1000 Bq/kg for ^{134}Cs and 2000 Bq/kg for ^{137}Cs, which are about one order higher than index values (Table 5). GSG-2 was prepared as international safety standards with agreements of all IAEA Member States including Japan, and was jointly sponsored by FAO, IAEA, ILO, PAHO and WHO. The OIL concept is comprehensive and systematic for food safety regulations in the emergency phase, and should be thence considered in the future designing of regulation values.

5.2.3. *Populations considered*

For the purpose of radiation protection of the public, a hypothetical group of highly exposed group in the population is generally characterized to err on the safe side. To this end, ICRP defined this hypothetical group as “critical group” in Publication 7 (ICRP, 1965), and the guidance for the application of the critical group concept was provided in Publications 26 and 43 (ICRP, 1971, 1985). The critical group could be individuals living in an area near the site, and whose food would be obtained nearby. This concept was introduced because it had been difficult to measure doses to members of the public. However, there have been developments in calculation codes and probabilistic approaches to assess doses with increasing accuracy, and experience gained in the application of concept to the mean dose in the appropriate critical group by setting deterministic parameters. Alternatively, ICRP introduced the concept of “representative person” in Publication 101 (ICRP, 2006), and recommended its use in Publication 103 (ICRP, 2007). As habit data in deterministic calculations, this concept employs either the mean value for the highly exposed group, or the 95th percentile of consumption rates for the dominant route of radionuclide intake. The annual dose to the representative person is assessed in three age groups: infant (0–5 y), child (6–15 y) and adult (16–70 y). Thus far, there has been little if any experience for the application of the representative person concept.

In this regard, MHLW reported the latest data of the National Health and Nutrition Survey conducted in 2008, where the means and standard deviations of daily food intake of all 18 categories are available for each age group (MHLW, 2011a), though drinking water

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

and infants were not included. Table 7 lists part of these data, together with the 95th percentile intake values calculated assuming the Gaussian distribution. As can be seen, the 95th percentile intake is 1.5–3.3 times greater than the mean value (i.e., MDFI). This is in good agreement with ICRP Publication 101 (ICRP, 2006) having documented that the 95th percentile intake is approximately 3 times greater than the mean values. In other words, the regulation value calculated by the 95th percentile intake may become 32–70% smaller than that by the mean value. On the other hand, index values were calculated using MDFI for each age group (Section 4.1). Namely, the average group who receives the mean-level exposure was considered. One may imagine that the 95th percentile intake is preferable to MDFI to define regulation values conservatively. However, the representative person concept is applicable to verification of the prospective compliance with dose constraints in planned exposure situations (ICRP, 2006), but contradicts to the RL concept in existing exposure situations. This is because RL is the level set for optimization of radiation protection considering most but not strictly whole populations by a step-by-step approach (ICRP, 2007). It would be therefore more logical that MDFI is used for calculation of future regulation values, as was done for index values. The same logic also applies to CF used in equations (5)–(11) where age-specific values for each age group are provided as the mean value calculated by the computational biokinetic models in each representative age (ICRP, 1995). The MDFI data reported in 1988 (MHW, 1988) were used for calculation of index values, but the latest data (e.g., ref (MHLW, 2011a)) should be used to calculate future regulation values.

6. Future perspectives

In the Fukushima nuclear accident, it took 7 and 11 d to set the provisional regulation values (17 March 2011) and to order the first restriction on distribution and/or consumption of contaminated food (21 March 2011) after the declaration of nuclear emergency situations dated 11 March 2011, respectively. Although it remains unclear whether or not food monitoring surveys were conducted before 15 March 2011 (but probably not), the monitoring data are available for samples taken on 16 March 2011 or later. These data in Fukushima Prefecture revealed that it took at least 5 and 6 d to restrict consumption and/or distribution of drinking water and milk contaminated above provisional regulation values for radioiodines after detection of the first over-permissible levels (Tables 2 and 3), respectively. It was on 16 March 2011 when as countermeasures against ^{131}I, NERHQ recommended evacuees (younger than 40 years old) leaving the central 20-km zone to take the pills or syrup of stable iodine (a single dose of 12.5 mg for $<$ 1 month old, 25 mg for 1 month to 3 y, 38 mg for 3–13 y and 76 mg for 13–40 y) under the supervision of medical personnel (NERHQ, 2011b). However, it remains unknown how many people actually could take such stable iodine. Anyhow, regulatory limits must come into force and food monitoring surveys should begin immediately upon the declaration (even prior to the event of accidental radionuclide releases) in the future incident. This is because countermeasures against short-lived radionuclides (e.g., ^{131}I) are essential to reduce health risks associated with its intake.

It should also be noted that countermeasures have been taken independently against each exposure pathway in the Fukushima nuclear accident. However, superimposed exposure scenarios via multiple exposure pathways should be considered when applying RL prospectively for planning of protection strategies and also retrospectively as a benchmark to judge the effectiveness of these implementations. Possible exposure pathways may involve external exposure from radionuclides deposited in soil, internal exposure from inhalation of resuspended radionuclides, and that

Table 7
Means, standard deviations and the 95th percentile values of daily food intake in Japan.

Food category	Age (the number of persons analyzed)																			
	1–6 y (421)				7–14 y (704)				15–19 y (360)				≥ 20 y (7644)				≥ 1 y (9129)			
	Intake (kg/d)			Ratio[d]	Intake (kg/d)			Ratio[d]	Intake (kg/d)			Ratio[d]	Intake (kg/d)			Ratio[d]	Intake (kg/d)			Ratio[d]
	Mean	SD	95th percentile[c]		Mean	SD	95th percentile[c]		Mean	SD	95th percentile[c]		Mean	SD	95th percentile[c]		Mean	SD	95th percentile[c]	
Total food[a]	1.186	0.349	1.760	1.48	1.789	0.539	2.675	1.50	1.921	0.646	2.984	1.55	2.114	0.728	3.311	1.57	2.038	0.729	3.238	1.59
Beverages[b]	0.185	0.199	0.513	2.77	0.272	0.330	0.815	3.00	0.422	0.400	1.080	2.56	0.658	0.505	1.489	2.26	0.597	0.501	1.421	2.38
Milk	0.186	0.154	0.439	2.36	0.298	0.174	0.584	1.96	0.131	0.175	0.418	3.20	0.089	0.125	0.295	3.32	0.111	0.145	0.350	3.15
Vegetables[e]	0.153	0.098	0.314	2.05	0.239	0.133	0.457	1.91	0.256	0.165	0.527	2.06	0.295	0.179	0.590	2.00	0.283	0.176	0.571	2.02
Seafood	0.031	0.037	0.091	2.95	0.054	0.053	0.141	2.61	0.062	0.064	0.168	2.71	0.084	0.076	0.208	2.48	0.079	0.074	0.200	2.54

The data for intake by infants under 1 y of age and the data for intake of drinking water were unavailable. SD, standard deviation.

[a] Total food herein refers to the total intake of the following 18 food categories: 1) beverages, 2) milk, 3) vegetables, 4) seafood, 5) cereals, 6) corms, tubers and roots, 7) sugars and sweeteners, 8) pulses, 9) nuts, 10) fruit, 11) mushroom, 12) edible algae, 13) meats, 14) eggs, 15) oils and fats, 16) confectionery, 17) flavoring, spice and condiments, and 18) supplementary nutrients, and food for specified health uses. Note that drinking water is not included.

[b] Beverages include alcoholic drink and non-alcohoric soft drink, but not drinking water.

[c] The 95th percentile value was calculated as the mean value plus the standard deviation value multiplied by 1.645, assuming the Gaussian distribution.

[d] Ratio was calculated as the 95th percentile value divided by the mean value.

[e] Vegetables here refer to only vegetables but do not include mushroom, fruit, algae, corms, tubers and roots. Note that this is different from "vegetables" in Tables 1, 3 and 5 (Section 4.1).

from ingestion of contaminated soil (especially by children), and contaminated food irrespective of whether or not levels are exceeded. Radiation doses should be kept as low as reasonably achievable considering social and economic factors, which would be important not only to optimize radiation protection but also to minimize the social dislocations (see Section 6.2). In the management of existing exposure situations, the participation of relevant stakeholders and effective communication strategies to overcome negative reactions would be both essential.

6.1. Graded triphasic reference level system to improve food safety regulations

Index values were logically designed and practically convenient in that the necessity of restrictions can be judged by monitoring only indicator radionuclides. However, time has passed since the definition of index values, and the original aim of the index value was to provide evaluation criteria to “launch discussion” on whether NERHQ needs to restrict food consumption (Section 2). Furthermore, there have been several issues underlying index values that need to be improved (Section 5.2), and provisional regulation values should be used provisionally. Utilizing lessons learned from the experience of the Fukushima nuclear accident, and considering recent publications by ICRP and IAEA, it would be desirable to renew regulation values for a future nuclear emergency preparedness. To this end, the authors here propose the concept of “the graded triphasic RL system” to optimize radiation protection in emergency and existing exposure situations (Fig. 3). In this concept, the period of emergency and existing exposure situations is divided into early, intermediate and late phases (phases 1, 2 and 3), and graded RL values are defined for each of phases 1, 2 and 3 (RL1, RL2 and RL3), respectively. For practical purposes, operational RL values for phases 1, 2 and 3 (ORL1, ORL2 and ORL3, respectively) are further defined.

An emergency exposure situation and phase 1 begin when the government declares nuclear emergency situations. The emergency exposure situation lasts as long as large-scale radionuclide releases occur, and ends within the time scale in days, followed by an existing exposure situation. However, it would not be practical to set the ORL value specific to the short-term emergency exposure situation, and off-site members of the public may not experience the emergency exposure situation, so that the phase 1 is supposed to end in the early period of the existing exposure situation. Phase 1 lasts for the time scale in weeks, considering not only that all restrictions began within 25 d after the first excess of provisional regulation values (Tables 2 and 3) but also that tap water above 100 Bq/kg of ^{131}I had been detected during a maximum of 13 d (16 March 2011 to 28 March 2011, Table 2). This is also important to minimize social dislocations resulting from the restriction on consumption of drinking water whose emergent replacements are not always readily available. Phase 2 lasts for the time scale in months, considering that food above provisional regulation values continued being detected for at least three months (Table 3). Phase 3 lasts for years during which time the nuclear emergency situation may be lifted with the coincident dissolution of NERHQ. The existing exposure situation may end off the site earlier than near the site, but it would not be practical to set different ORL values for each case. Accordingly, the phase 3 is supposed to end when the existing exposure situation ends near the site. Noteworthy is that social and economic factors may affect the duration of the existing exposure situation. For instance, if soil contaminated at high levels of long-lived radionuclides is replaced with non-contaminated soil, the existing exposure situation ends in a relatively short time. Conversely, the existing exposure

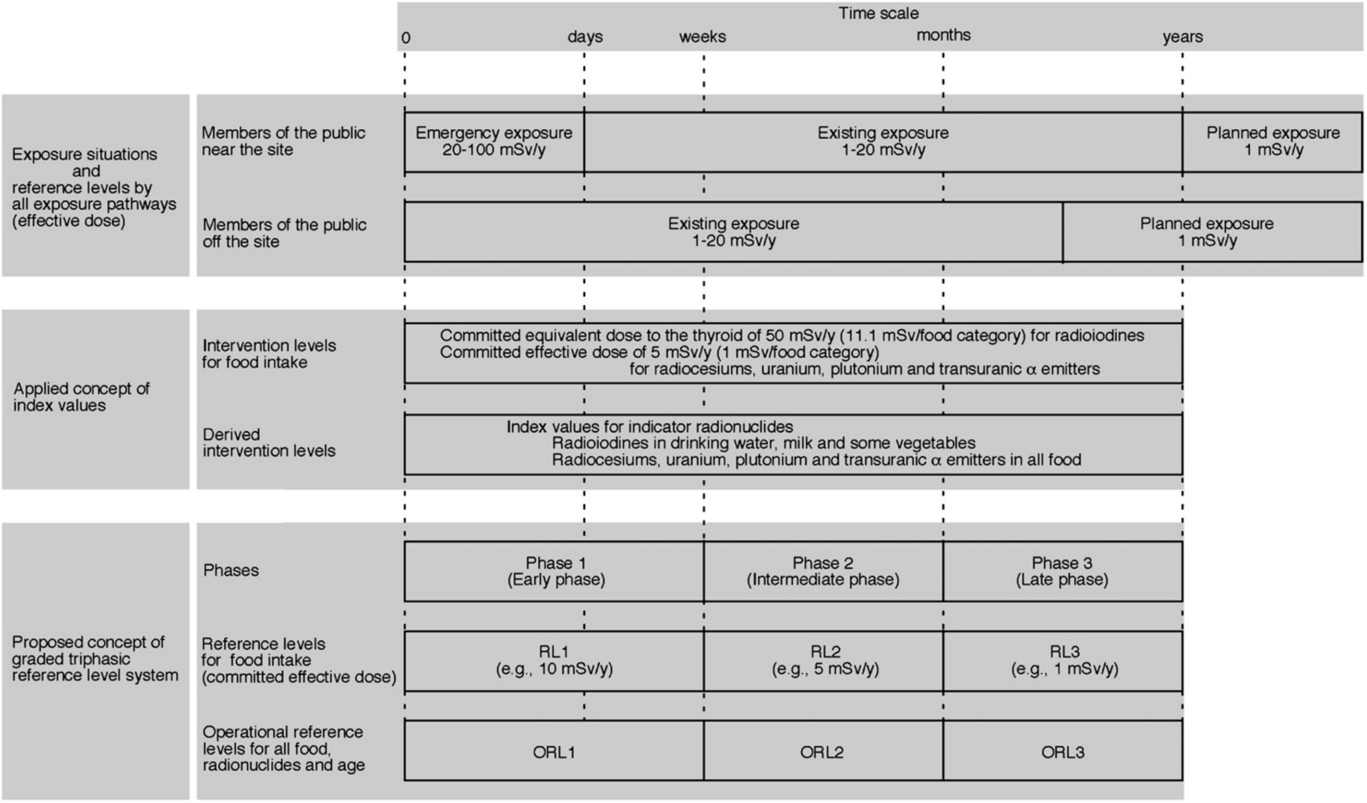


Fig. 3. Concept of the graded triphasic reference level system versus index values. For details, see Sections 4 and 5 about index values, and Section 6.1 about the graded triphasic reference level system.

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

situation lasts according to the half-life of radionuclides, not only if such contaminated soil is not replaced, but also if members of the public (especially evacuees from the site) wish to reside in such environment. In a subsequent planned exposure situation, an effective dose posed by all exposure pathways is set as 1 mSv/y per person, and food safety regulations should no longer be required. NERHQ should determine the duration of each phase (i.e., application period of each ORL values) according to the scale and status of accident and food contamination. In the Fukushima nuclear accident, the example period of phase 1 may be the first three weeks after 11 March 2011. Food contaminated above provisional regulation values have been detected at least for the initial three months (Table 3), and stable cooling of reactors will hopefully be achieved by July 2011 (TEPCO, 2011b). So, the example period of phase 2 may be the four months after the end of phase 1. The period of subsequent phase 3 depends on the social and economic factors as mentioned.

For RL values, an annual individual committed effective dose should be consistently used for simplicity, as recently done by ICRP (2007) and IAEA (2011a). For emergency exposure situations, ICRP previously recommended an annual effective dose of 10 mSv/foodstuff as IL in Publication 63 (ICRP, 1992a). However, a total committed effective dose of 190 mSv will be received by food given consumption of all 19 food categories (18 categories listed in the footnote of Table 7, plus drinking water), so that an annual individual committed effective dose would be preferable to an annual committed effective dose per foodstuff. Recently, the band of 20–100 mSv/y per person was recommended as RL in ICRP Publication 103 (ICRP, 2007) for all countermeasures combined in an overall protection strategy. Accordingly, a committed effective dose of 10 mSv/y per person (the one-tenth of the uppermost part of the band, 0.1 × 100 mSv) is here proposed as the example RL1, and has also been used to calculate the OIL6 values (IAEA, 2011a). The "one-tenth" approach was taken to avoid excess of doses posed by all exposure pathways. For existing exposure situations, ICRP in Publication 103 (ICRP, 2007) recently recommended the band of 1–20 mSv/y per person as RL. Here, a committed effective dose of 1 mSv/y per person (the lowest part of the band, the one-tenth of RL1, and also the same level considered in CAC (1995)) is proposed as the example RL3. Values of RL2 should be set in between RL1 and RL3 values. In this respect, the round-off value of these logarithmic mean is 3.2 mSv, but an effective dose of 5 mSv/y is used as the current Japanese guideline level for commercial jet aircraft crew members in existing exposure situations (Yasuda et al., 2011). So, 5 mSv/y is preferably proposed as the example RL2.

ORL values in each phase should be defined according to the approaches taken to calculate OIL6 values (IAEA, 2011a), but should be set not to exceed each corresponding RL value. For calculation, the latest MDFI data of all food (e.g., 19 categories) consumed by the nation in each age group should be used, and ORL values may be periodically updated using the latest data. All measurable radionuclides whose accidental release can be expected (e.g., 355 radionuclides as considered in OIL6 values (IAEA, 2011a)) should be considered, though this approach still requires the use of the postulated ratio of some radionuclides whose measurement is technically difficult (e.g., ^{90}Sr). Resulting ORL1 and ORL3 values may be of the order similar to OIL6 values (IAEA, 2011a) and provisional regulation values, respectively. Resulting ORL2 values are the half of ORL1 values and five-fold higher than ORL3 values. Like OIL6 values, these ORL values are applicable to all age, food and radionuclides. Application of ORL values should follow the procedure of OIL5 and OIL6 values. Namely, for screening purposes, the gross α and β concentrations should be firstly determined in the potentially contaminated food. If the screening levels (5 Bq/kg of gross α or 100 Bq/kg of gross β, i.e., OIL5 (IAEA, 2011a)) are exceeded, individual radionuclide concentrations should be determined. ORL levels are exceeded if $\sum_i K_i/ORL_{pi}$ is greater than 1, where K_i and ORL_{pi} are the concentration of radionuclide i in foodstuff (Bq/kg) and the ORL value specific to phase p (i.e., $p = 1$, 2 or 3) and radionuclide i, respectively. If ORL levels are not exceeded, food is safely consumed in any age groups in each phase. If exceeded, distribution and/or consumption should be restricted depending on the obtainability of replacements.

6.2. *Justification of the implemented intervention*

The massive social dislocations occurred soon after the commencement of restrictions on consumption of tap water in March 2011. Because of buy-up, bottled drinking water disappeared from grocery stores in many prefectures even where radionuclide concentrations in tap water were below detectable levels (e.g., Fukuoka and Osaka Prefectures). On 23 March 2011, the Tokyo Metropolitan government decided to mitigate the social dislocations by distributing 240,000 bottles of drinking water for free to about 80,000 infant residents of Tokyo Metropolis. The maximum level (210 Bq/kg of ^{131}I) in tap water sampled in Tokyo on 22 March 2011 was above the provisional regulation value for infants (100 Bq/kg) but still below the index value (300 Bq/kg) (Tables 2 and 5). As described in Section 4.2, the logic behind the adoption of 100 Bq/kg is quite unclear. If all provisional regulation values were to faithfully conform to logically designed index values, restrictions on consumption of water would not be necessary except Fukushima and Chiba Prefectures, and less social dislocations might be observed. Incidentally, other food such as instant noodles and milk also became sold out in many prefectures, and various false rumors were circulated such that "drinking" povidone iodine gargle is a good countermeasure for radioiodines.

On 18 March 2011, MHLW assigned 13,000 counts/min as the screening level for surface decontaminations of evacuees from the central 20-km and surrounding stay-indoor zones or others who have passed through these zones (MHLW, 2011d). However, only 3 d later, MHLW (2011f) hurriedly changed such screening level to 100,000 counts/min by employing the international standard indicated by IAEA (2006). This value corresponds to a γ-ray dose rate of 1 μSv/h at 10 cm away from the skin (IAEA, 2006), and has been applied as OIL4 in GSG-2 (IAEA, 2011a). Conversely, this was not the case for food safety regulations, and provisional regulation values were not eased. Tap water above 100 Bq/kg of ^{131}I had been detected during $\leq$13 d (Section 6.1). If the provisional regulation value were to employ the internationally agreed OIL6 level for the emergency phase (IAEA, 2011a), such restrictions would not be required even in Fukushima and Chiba Prefectures.

Taking into account radiological and social impacts, the justification of restrictions on consumption enforced following the Fukushima nuclear accident needs to be verified by the future retrospective reviewing of overall countermeasures.

7. Conclusions

Here we have outlined the food monitoring data of 24,685 samples and the enforced restrictions, predicated on the information available as of 12 June 2011 (Section 3). All restrictions on consumption of tap water began within 6 d after the first excess of the provisional regulation value for radioiodines (Table 2), but the commencement of restrictions was concurrent with the massive social dislocations manifested as the buy-up of bottled water (Section 6.2). This may be attributable at least in part to illogical adaptation of index values. The justification of enforced

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

restrictions should be hereafter verified retrospectively. All restrictions were lifted within 51 d, whereas tap water exceeding 100 Bq/kg of ^{131}I had been detected for $\leq$13 d (Table 2). Radiocesium levels in tap water were consistently far below the provisional regulation value. All restrictions on distribution and/or consumption of milk, vegetables, seafood and tea leaf began within 25 d after the first excess of provisional regulation values (Table 3), but some of such restrictions have yet to be withdrawn in Fukushima, Ibaraki, Tochigi, Chiba and Kanagawa Prefectures as of 12 June 2011. Among all items, the maximum concentration of ^{131}I (54,100 Bq/kg) was detected in spinach and the maximum total concentrations of ^{134}Cs and ^{137}Cs (82,000 Bq/kg) in kukitachi-na. Collectively, food contaminated above provisional regulation values must have been consumed for $\leq$3 weeks.

We also have demonstrated the logic and issues behind food safety regulations implemented following the Fukushima nuclear accident (Sections 2, 4 and 5). Index values were logically designed and practically convenient. However, food and radionuclides were not comprehensively covered, and the same values were given to emergency and existing exposure situations. Also, different provisional regulation values for radioiodines in drinking water and milk were set to infants and others. To address these issues, we have proposed the concept of the graded triphasic RL system so as to optimize food safety regulations in each of early, intermediate and late phases, where example phase-specific graded RL values and the logic for corresponding phase- and radionuclide-specific ORL values applicable to all food, radionuclides and age were provided (Section 6.1).

This paper was devoted to the aspect of food safety regulations, but the information on other aspects of the Fukushima nuclear accident also starts to be reported (NERHQ, 2011a). The overall lessons learned from the experience of this accident should lead to an improved nuclear emergency preparedness all over the world. Comprehensively planned countermeasures against multiple exposure pathways should be taken immediately upon the occurrence of the future incident.

Conflict of interest

The authors hereby declare that there are no conflicts of interest.

Acknowledgments

Thanks are due to Drs. Kazuo Yoshida, Takatoshi Hattori, Toshiyasu Iwasaki and other members in the Radiation Safety Research Center of CRIEPI for comments on the manuscript.

References[1]

CAC, 1995. Codex General Standard for Contaminants and Toxins in Food and Feed. Codex Standard, Rome, Italy. http://www.codexalimentarius.net/download/standards/17/CXS_193e.pdf last accessed on 12 June 2011, pp. 193–1995.

Citizen group for breast milk inspection and for mother and child supports, 2011. http://bonyuutyousa.net/, last accessed on 12 June 2011, (in Japanese).

Croff, A.G., 1980. ORIGEN2 – A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code. Tennessee, USA, ORNL-5621. http://www.ornl.gov/info/reports/1980/3445603828473.pdf last accessed on 12 June 2011.

Eckerman, K.F., Ryman, J.C., 1993. External Exposure to Radionuclides in Air, Water and Soil. United States Environmental Protection Agency. Federal Guidance Report No. 12, EPA-402-R-93–081.

FSC, 2011a. Emergency Report on Radioactive Nuclides. http://www.fsc.go.jp/sonota/emerg/iicho_danwa_20110408.pdf last accessed on 12 June 2011, (in Japanese).

FSC, 2011b. On the Occasion of Completing an Emergency Report on Radioactive Nuclides in Foods. http://www.fsc.go.jp/english/emerg/radiolog_iincho_danwa.pdf last accessed on 12 June 2011.

IAEA, 1996. International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources. IAEA. Safety Series No. 115.

IAEA, 2006. Manual for First Responders to a Radiological Emergency. http://www-pub.iaea.org/MTCD/publications/PDF/epr_Firstresponder_web.pdf last accessed on 12 June 2011.

IAEA, 2011a. Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, General Safety Guide No. GSG-2. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1467_web.pdf last accessed on 12 June 2011.

IAEA, 2011b. International Basic Safety Standards 2011 Edition, General Safety Requirements Part 3, No. GSR Part 3. http://www-ns.iaea.org/committees/files/bsscomments/1035/DS379-Draft5.0-21Mar2011.pdf last accessed on 12 June 2011.

ICRP, 1965. Principles of Environmental Monitoring Related to the Handling of Radioactive Materials. ICRP Publication 7. Ann. ICRP/ICRP Publication 7, 1965.

ICRP, 1971. Recommendations of the ICRP. ICRP Publication 26. Ann. ICRP 1(3).

ICRP, 1984. Statement from the 1984 Meeting of the ICRP. ICRP Publication 40. Ann. ICRP 14(2).

ICRP, 1985. Principles of Monitoring for the Radiation Protection of the Public. ICRP Publication 43. Ann. ICRP 15(1).

ICRP, 1992a. Principles for Intervention for Protection of the Public in a Radiological Emergency. ICRP Publication 63. Ann. ICRP 22(4).

ICRP, 1992b. Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 2 Ingestion Dose Coefficients. ICRP Publication 67. Ann. ICRP 22(3–4).

ICRP, 1995. Age-Dependent Doses to the Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Coefficients. ICRP Publication 72. Ann. ICRP 26(1).

ICRP, 2006. Assessing Dose of the Representative Person for the Purpose of Radiation Protection of the Public and the Optimization of Radiological Protection: Broadening the Process. ICRP Publication 101. Ann. ICRP 36(3).

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37(2–4).

ICRP, 2009a. Application of the Commission's Recommendations to the Protection of People Living in Long-Term Contaminated Areas after a Nuclear Accident or a Radiation Emergency. ICRP Publication 111. Ann. ICRP 39(3). http://www.icrp.org/docs/P111(Special%2520Free%2520Release).pdf.

ICRP, 2009b. Statement on Radon. http://www.icrp.org/docs/ICRP_Statement_on_Radon(November_2009).pdf last accessed on 12 June 2011.

ICRP, 2011. Fukushima Nuclear Power Plant Accident. http://www.icrp.org/docs/Fukushima%2520Nuclear%2520Power%2520Plant%2520Accident.pdf last accessed on 12 June 2011.

Jarvis, N.S., Birchall, A., James, A.C., Bailey, M.R., Dorrian, M.-D., 1996. LUDEP 2.0: Personal Computer Program for Calculating Internal Doses Using the ICRP Publication 66 Respiratory Tract Model. National Radiological Protection Board, Chilton, UK. NRPB-SR287.

JRIA, 2010. Statistics on the Use of Radiation in Japan. http://www.jrias.or.jp/index.cfm/6,1246,c,html/1246/20101222-144214.pdf last accessed on 12 June 2011, (in Japanese and English).

MAFF, 2011. Production and Use of Livestock Feed Following the Nuclear Accident. http://www.maff.go.jp/j/kanbo/joho/saigai/c_minasama_3.html last accessed on 12 June 2011, (in Japanese).

MHLW, 2002. Manual for Monitoring of Food in a Nuclear Emergency. http://www.mhlw.go.jp/stf/houdou/2r9852000001558e-img/2r98520000015cfn.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011a. Report on the 2008 National Health and Nutrition Survey. http://www.mhlw.go.jp/bunya/kenkou/eiyou/dl/h20-houkoku-01a.pdf last accessed on 20 12 June 2011, (in Japanese).

MHLW, 2011b. Handling of Radionuclide-Contaminated Foods. http://www.mhlw.go.jp/stf/houdou/2r9852000001558e-img/2r9852000001559v.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011c. Notice with Regard to Inspection Based on the Manual for Monitoring of Food in a Nuclear Emergency. http://www.mhlw.go.jp/stf/houdou/2r98520000014tr1-img/2r98520000015is5.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011d. Request for Health Consultations in Terms of Radiation Effects. http://www.mhlw.go.jp/stf/houdou/2r98520000014tr1-img/2r98520000015fth.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011e. Response to Contamination of Tap Water following Accidents at the Fukushima Nuclear Power Plants 1 and 2. http://www.mhlw.go.jp/stf/houdou/2r98520000014tr1-img/2r98520000015k18.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011f. Revised Request for Health Consultations in terms of Radiation Effects. http://www.mhlw.go.jp/stf/houdou/2r98520000015ox9-img/2r98520000015pqe.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011g. Handling of Provisional Regulation Value for Radionuclides in Tap Water. http://www.mhlw.go.jp/stf/houdou/2r98520000017x7l-img/2r98520000017xbh.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011h. Handling of Provisional Regulation Value for Radionuclides in Food. http://www.mhlw.go.jp/stf/houdou/2r98520000017tmu-att/2r98520000017trg.pdf last accessed on 12 June 2011, (in Japanese).

---

[1] Titles in Japanese documents were translated by the authors when the English title was unavailable. For some Japanese documents, the provisional translated versions were also available, but most of them provided less information than the original Japanese versions. Therefore, the Japanese documents were preferably referenced here for most cases. For convenience, URL is provided for freely downloadable documents.

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008

MHLW, 2011i. Policy on the Monitoring of Radionuclides in Tap Water. http://www.mhlw.go.jp/stf/houdou/2r98520000017x7l-img/2r98520000017xbn.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011j. Concepts of Inspection Planning and the Instruction and Cancellation of Items and Areas to which Restriction on Distribution and/or Intake of Food Concerned Applies. http://www.mhlw.go.jp/stf/houdou/2r98520000017tmu-att/2r98520000017ts1.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011k. Provisional Regulation Value for Radioiodines in Seafood. http://www.mhlw.go.jp/stf/houdou/2r98520000017z1u-att/2r98520000017z7d.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011l. Notice with Regard to Inspection Based on the Manual for Monitoring of Food in a Nuclear Emergency. http://www.mhlw.go.jp/stf/houdou/2r98520000019v70-img/2r9852000001a0nj.pdf last accessed on 12 June 2011, (in Japanese).

MHLW, 2011m. Inspections on Radioactive Concentrations in Breast Milk. http://www.mhlw.go.jp/stf/houdou/2r9852000001azxj.html last accessed on 12 June 2011, (in Japanese).

MHLW, 2011n. Information related to the Great East Japan Earthquake. http://www.mhlw.go.jp/stf/houdou/2r98520000014j15.html last accessed on 12 June 2011, (in Japanese).

MHW, 1988. Report on the 1986 National Nutrition Survey. http://www.nih.go.jp/eiken/chosa/kokumin_eiyou/1986.html last accessed on 12 June 2011, (in Japanese).

MHW, 2000. Methods for Dosimetry and Calculations of Effective and Equivalent Doses, Notification No. 398 of the Ministry of Health and Welfare of Japan. http://web.sapmed.ac.jp/rco/download/ko12.12.26-3.pdf last accessed on 12 June 2011, (in Japanese).

NERHQ, 2011a. Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety – The Accident at TEPCO's Fukushima Nuclear Power Stations. http://www.kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html last accessed on 12 June 2011.

NERHQ, 2011b. The Great East Japan Earthquake. http://www.kantei.go.jp/saigai/pdf/201106021700jisin.pdf last accessed on 12 June 2011, (in Japanese).

NISA, 2011a. INES (the International Nuclear and Radiological Event Scale) rating on the events in Fukushima Dai-ichi Nuclear Power Station by the Tohoku District – off the Pacific Ocean Earthquake. http://www.nisa.meti.go.jp/english/files/en20110412-4.pdf last accessed on 12 June 2011.

NISA, 2011b. Evaluation for the Status of Reactor Cores in Units 1-3 of the Fukushima Nuclear Power Plant 1. http://www.meti.go.jp/earthquake/nuclear/pdf/20110606-1nisa.pdf last accessed on 12 June 2011, (in Japanese).

NSC, 1980. Guideline for Nuclear Disaster Measures. http://www.nsc.go.jp/shinsashishin/pdf/history/59-15.pdf last accessed on 12 June 2011, (in Japanese).

NSC, 2011. A Testing Estimate for the Amount of ^{131}I and ^{137}Cs Released from the Fukushima Nuclear Power Plant 1 into the Atmosphere. http://www.nsc.go.jp/info/20110412.pdf last accessed on 12 June 2011, (in Japanese).

NPA, 2011. Damage Situation and Police Countermeasures Associated with 2011 Tohoku District – off the Pacific Ocean Earthquake. http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf last accessed on 12 June 2011.

Suga, S., Ichikawa, R., 2000. On the revision of control index levels on the ingestion of food and water in the guidelines for radiological emergency preparedness and countermeasures in Japan. Jap. J. Health Phys. 35, 449–466. http://www.journalarchive.jst.go.jp/jnlpdf.php%3Fcdjournal=jhps1966&cdvol=35&noissue=4&startpage=449&lang=ja&from=jnltoc last accessed on 12 June 2011, (in Japanese with English title and abstract).

TEPCO, 2011a. Outflow of Radioactive Water from the Concrete Crack Near Intake Canal for Unit 2 of Fukushima Daiichi Nuclear Power Station. http://www.tepco.co.jp/en/press/corp-com/release/betu11_e/images/110421e2.pdf last accessed on 12 June 2011.

TEPCO, 2011b. Roadmap Towards Restoration from the Accident at Fukushima Daiichi Nuclear Power Plant Station. http://www.tepco.co.jp/en/press/corp-com/release/11041707-e.html last accessed on 12 June 2011.

WHO, 1988. Derived Intervention Levels for Radionuclides in Foods – Guidelines for Application After Widespread Radioactive Contamination Resulting from a Major Accident, Geneva, Switzerland.

WHO, 2006. Guidelines for drinking-water quality: incorporating first and second addenda, vol. 1, Recommendations – third ed., Geneva, Switzerland.

Yasuda, H., Sato, T., Yonehara, H., Kosako, T., Fujitaka, K., Sasaki, Y., 2011. Management of cosmic radiation exposure for aircraft crew in Japan. Radiat. Prot. Dosim 146, 123–125.

Please cite this article in press as: Hamada, N., Ogino, H., Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity (2011), doi:10.1016/j.jenvrad.2011.08.008