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ARTICLE

Evaluation of averted doses to members of the Public by tap water restrictions after the Fukushima Daiichi Nuclear Power Plant accident

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The effectiveness of urgent protective measures such as tap water restrictions and bottled water supplies in the early stage of an emergency exposure situation was studied after the Fukushima Daiichi nuclear power plant accident. Temporal changes in the concentration of an important radionuclide –iodine 131– in tap water were analyzed using published data in Fukushima, Ibaraki and Tokyo. Averted doses to members of the public due to chronic intakes of iodine 131 through tap water restrictions were also evaluated using an internal dose calculation code, DSYS-chronic code. In addition, the costs of bottled water supplies were calculated approximately. Consequently, it was found that the apparent half-life of iodine 131 in tap water was 2.8±1.2 days. The averted equivalent doses to the thyroid of members of the public–1-year-old children– were found to have a maximum value of 8.2 mSv in a local area of Fukushima. In comparison with Fukushima, the bottled water supplies might be a large sum of money regardless of the low doses in Tokyo. In conclusion, apart from the bottled water supplies, the tap water restrictions implemented by the authorities would be effective after the Fukushima Daiichi nuclear power plant accident.

Keywords: Fukushima; chronic exposure ; nuclear accident; iodine; tap water; infant; thyroid; dose; DSYS

1. Introduction

The Fukushima Daiichi nuclear power plant accident has resulted in the radionuclide releases to the atmosphere and the contamination of large areas. Many urgent protective measures such as tap water restrictions and bottled water supplies were implemented to reduce consumption of certain types of refreshments with higher levels of contamination. There would be some need to review the effectiveness of making decisions on the implementation of tap water restrictions and bottled water supplies in the emergency exposure situations[1]. To identify the success of the protection strategy for the emergency exposure situation, it is required to determine the features of radionuclides, particularly iodine 131 in tap water and the dose prevented by the application of tap water restrictions and bottled water supplies –averted doses to members of the public. Information on the costs of bottled water supplies is also needed. The objective of the present study is to provide data relevant to an understanding of urgent protective measures that come close to the optimum protection.

2. Water restrictions and bottle water supplies

2.1. Actions by national authorities

The Ministry of Health, Labor and Welfare (MHLW) of Japan notified "Guideline values for food and drink intake restrictions (iodine 131: 300 $Bq \cdot kg^{-1}$)" provided by the Nuclear Safety Commission (NSC) of Japan to some prefectures on March 19, 2011[2]. Furthermore, MHLW requested prefectures to notify the relevant residents of the restrictions in the case that radioactive iodine in the tap water exceeded a guideline value for infants (100 $Bq \cdot kg^{-1}$) on March 21, 2011.

2.2. Actions by local authorities

Local authorities in Fukushima, Ibaraki and Tokyo issued water restrictions, based on the guideline values provided by NSC and MHLW of Japan. The water restrictions were terminated by each local authority at later phases that radioactive iodine in the tap water was below the guideline values. **Table 1** shows the water restrictions implemented by local authorities in Fukushima, Ibaraki and Tokyo in 2011. In addition, bottled water supplies were carried out under the conditions of the water restrictions.

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Table 1. Tap water restrictions in Fukushima, Ibaraki and Tokyo in 2011.

Prefecture	Authority	The first day	The last day	Days
Fukushima	Iitate	March 21	May 10*	50
	Koriyama,	March 22	March 25	3
	Kawamata	March 22	March 25	3
	Minamisoma	March 22	March 30	8
	Iwaki	March 23	March 31	8
Ibaraki	Tokai	March 23	March 26	3
Tokyo	23 wards and 5cities	March 23	March 24	1

*for infants. The restriction for adults was terminated by the authority on April 1, 2011.

3. Material and Methods

Temporal changes in the concentration of the iodine 131 in tap water were studied using published data from five authorities in Fukushima (Iitate, Koriyama, Kawamata, Minamisoma and Iwaki), Ibaraki (Tokai) and Tokyo (Shinjuku) after the Fukushima Daiichi nuclear power plant accident[2]. An apparent half-life of iodine-131 in tap water was evaluated using the exponential decay curves from maximum concentrations. The study period was from March 16 to April 16, 2011 except for Iitate (from March 16 to May 10, 2011). Averted doses to members of the public due to chronic intakes of iodine 131 through tap water restrictions were also evaluated using an internal dose calculation code, DSYS-chronic[3]. The DSYS-chronic code, which was developed at the Japan Atomic Energy Agency, can treat internal dosimetry for chronic exposures using the International Commission on Radiological Protection's (ICRP's) respiratory tract, GI-tract, tissue dosimetry, biokinetic and bioassay models for ICRP Publ.71[4]. The averted doses to 1-year-old-children were evaluated for each restriction period. For comparison, the members of the public at Iitate were considered to be individuals for six representative age groups defined in ICRP: 3 months, 1, 5, 10, 15 years and adult. Water ingestion rates used in intake evaluations were from a report of the Japan radiation council[5] – The water ingestion rates are 1,400 $cm^3 \cdot day^{-1}$ for 3 months and 1 year, 1,600 $cm^3 \cdot day^{-1}$ for 5 years, 1,800 $cm^3 \cdot day^{-1}$ for 10 years, 2,400 $cm^3 \cdot day^{-1}$ for 15 years and 2,650 $cm^3 \cdot day^{-1}$ for adult. Daily intake was assumed to be the product of concentration of iodine 131 and ingestion rate. In addition, the monetary costs of the bottled water supplies were calculated approximately on the basis of the published data from the local authorities[6].

4. Results and Discussion

Figure 1 shows the concentrations of iodine 131 in tap water at some local areas of Fukushima, Ibaraki and Tokyo. The concentrations above detection limits present an infinite variety. At Iitate where the concentration of iodine 131 in tap water was 965 $Bg \cdot kg^{-1}$ on March 20, 2011, the concentration decreased gradually and was below a detection limit after April 11, 2011. At Shinjuku which is located about 230 km away

Table 2. Averted doses to 1-year-old children due to chronic intakes of iodine 131 by tap water restrictions (Sv).

Authority	Thyroid equivalent dose	Effective dose
Fukushima		
Iitate	8.2×10^{-3}	4.1×10^{-4}
Koriyama	5.1×10^{-4}	2.5×10^{-5}
Kawamata	1.1×10^{-3}	5.6×10^{-5}
Minamisoma	1.7×10^{-3}	8.7×10^{-5}
Iwaki	2.9×10^{-3}	1.5×10^{-4}
Ibaraki		
Tokai	2.1×10^{-3}	1.0×10^{-4}
Tokyo		
Shinjuku	1.3×10^{-4}	6.5×10^{-6}

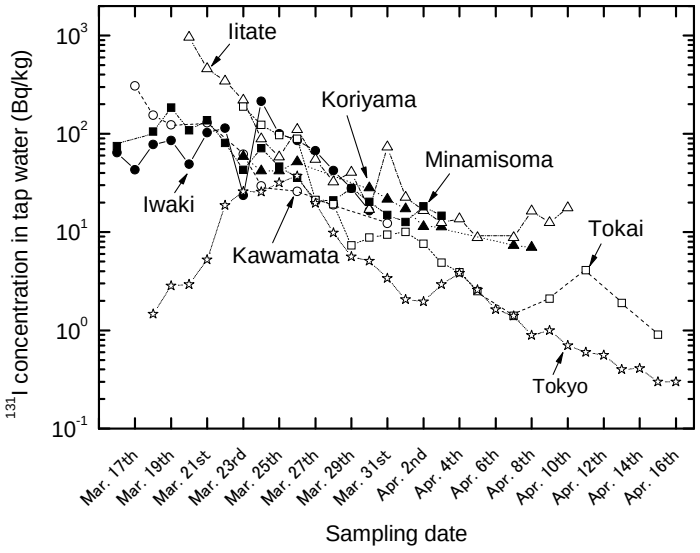

Figure 1. Concentration of iodine 131 in tap water at Fukushima (Iitate, Koriyama, Kawamata, Minamisoma and Iwaki), Ibaraki (Tokai) and Tokyo (Shinjuku).

Table 3. Averted equivalent doses to organs in 1-year-old children due to chronic intakes of iodine 131 by tap water restrictions (Sv).

Organ	Equivalent dose
Adrenals	7.9×10^{-7}
Brain	8.8×10^{-7}
Breasts	9.7×10^{-7}
Colon	3.5×10^{-6}
ET region	9.2×10^{-7}
Kidneys	6.7×10^{-7}
Liver	7.7×10^{-7}
Lungs	1.3×10^{-6}
Muscle	1.5×10^{-6}
LLI_wall	5.0×10^{-6}
Oesophagus	4.0×10^{-6}
Ovaries	7.7×10^{-7}
Pancreas	8.6×10^{-7}
Skin	7.8×10^{-7}
Small intestine wall	8.4×10^{-7}
Stomach wall	4.6×10^{-6}
Spleen	7.8×10^{-7}
Testes	5.8×10^{-7}
Thymus	4.0×10^{-6}
Thyroid	8.2×10^{-3}
ULI_wall	2.4×10^{-6}
Uterus	7.5×10^{-7}
Urinary bladder wall	3.5×10^{-6}
Remainder	1.3×10^{-6}
Skeleton	1.1×10^{-6}
Red bone marrow	8.6×10^{-7}
Effective dose	4.1×10^{-4}

from the Fukushima Daiichi nuclear power plant, the concentration of iodine 131 in tap water had a maximum on March 26, 2011 and then was followed by a decrease. On the whole, the concentration of iodine 131 in tap water shows a gradual decrease with an apparent half-life of 2.8±1.2 days which is shorter than the physical half-life of 8.0 days.

Averted doses to members of the public –1-year-old children– due to chronic intakes of iodine 131 through tap water restrictions are shown in **Table 2**. From the

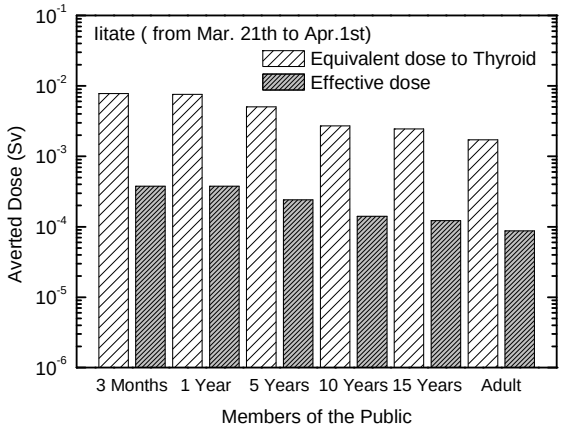

Figure 2. Averted doses to members of the public due to chronic intakes of iodine 131 by tap water restrictions.

Table 4. Bottled water supplies in Fukushima, Ibaraki and Tokyo.

Authority	Infant (persons)	PET Bottle (/person)	Costs (thousand yen)
Fukushima			
Iitate	30	2L	300
Koriyama	200	Water wagon	---
Kawamata	160	2L	96
Minamisoma	200	4L	640
Iwaki	2,473	4L *2	400
Ibaraki			
Tokai	1,275 *1	2L	765
Tokyo			
23 wards and 5 cities	80,000	0.55L×3	13,200

*1 less than 3-years-old children. *2 8,000 PET bottles were supplied. A PET bottle, of which volume was 2L, was assumed.

table, it can be stated that water restrictions implemented at each areas would be effective, resulting in more good than harm. The averted equivalent doses to 1-year-old children at Iitate are listed in **Table 3**. The result indicates that the equivalent dose to the thyroid would be the main contributor to the effective dose. Hence, it was confirmed that the maximum reduction of the equivalent dose to the thyroid is important in emergency exposure situation resulting in the release of radioactive iodine.

Averted doses to members of the public at Iitate due to chronic intakes of iodine 131 through tap water restrictions are shown in **Figure 2**. To compare the averted doses, the evaluation period was taken to be same among members of the public –from March 21 to April 1, 2011. From a comparison with the results, it may be concluded that the dose shows an age dependence. The older the affected population is, the less the affected population receives doses. This fact indicates that water restrictions would be effective for specific critical groups, in particular children in the early stage of the emergency exposure situation.

Table 4 summarizes bottled water supplies implemented by authorities in Fukushima, Ibaraki and Tokyo under the conditions of the water restrictions. All authorities did not necessarily implement the daily bottled water supplies since they seemed not to have a plenty of emergency stores. The monetary costs of the bottled water supplies, which were calculated approximately on the condition that 1L bottled water was valued at 100 yen, were shown in the table. In comparison with Fukushima, the bottled water supplies might be a large sum of money regardless of the low doses in Tokyo. It would appear that the application of tap water restrictions and bottled water supplies should depend on degree of doses, particularly restriction periods and concentrations of iodine 131 in tap water. The result leads to a conclusion that the bottled water supplies might not be optimum from cost viewpoint.

5. Conclusions

The features of iodine 131 in tap water and averted doses to members of the public due to chronic intakes of iodine 131 through tap water restrictions and bottled water supplies were studied after the Fukushima Daiichi nuclear power plant accident. Consequently, it was found that the apparent half-life of iodine 131 in tap water was 2.8±1.2 days which is shorter than the physical half-life of 8.0 days. The averted equivalent doses to the thyroid of 1-year-old children were found to have a maximum value of 8.2 mSv in a local area of Fukushima. In conclusion, apart from the bottled water supplies, the tap water restrictions implemented by the authorities in Fukushima, Ibaraki and Tokyo would be effective in the early stage of the emergency exposure situation.

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