Food Ingestion Standards for Nuclear Emergency Exposure Situations

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ABSTRACT

Background: This study presents food ingestion standards for radioactivity that can be applied in nuclear emergency exposure situations, and discusses the validity of the current domestic standards.

Materials and Methods: This study derived food ingestion standards for radiocesium and radioiodine using domestic food intake rates and intervention levels, which serve as a basis for determining the necessity of public protective actions, and then compared them with the existing guidelines. Operational intervention levels were also derived using domestic food intake rates, and were compared with those of the International Atomic Energy Agency.

Results and Discussion: The derived activity concentrations for food ingestion standards of radiocesium for infants were higher than those in the Act on Physical Protection and Radiological Emergency (APPRE) for all food categories, while for adults, the derived activity concentrations for drinking water and milk appeared to be slightly lower. The derived activity concentrations for vegetables, fruits, and grains were greater than those in the guidelines of the APPRE, while the derived activity concentrations for meat and seafood were similar to those in the APPRE. The derived activity concentrations for radioiodine were greater than both domestic and global standards. The calculated operational intervention levels (OILs) based on domestic food intake rates were greater than the IAEA's default OIL6 values for most radionuclides, except for a few α -radionuclides.

Conclusion: The current domestic guidelines turned out to be conservative overall, compared to the present results that were calculated using domestic food intake rates. It is recommended that the domestic guidelines should be revised and complemented transparently through an in-depth review by stakeholders on a solid scientific basis.

Keywords: Nuclear accident, Domestic food intake rate, Food ingestion standard of radioactivity, Operational intervention levels

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Introduction

In the event of a nuclear accident, public protective actions are one of the essential responses for ensuring public safety. Detailed guidelines according to the progression of the accident should be developed in advance, in the preparedness stage, in order for public protective actions to be implemented effectively in a real accident situation.

The International Commission on Radiological Protection (ICRP) proposed reference levels for protecting people from ionizing radiation according to the exposure situation [1, 2]. The proposed reference levels for the management of emergency exposure fall into the range of 20-100 mSv·y⁻¹, and an action level should be preferably se-

lected in this band for accidental situations. For instance, for the management of the Fukushima accident, the government of Japan applied a reference level of $20 \text{ mSv}\cdot\text{y}^{-1}$, which is the lower limit of the reference band for emergency exposure situations recommended by the ICRP. This means that the Japanese government managed the individual exposure from all exposure pathways, including ingestion, within $20 \text{ mSv}\cdot\text{y}^{-1}$ during the initial emergency period.

Restrictions on the consumption and distribution of food in the contaminated area after a nuclear accident are an important public protective action. In the case of the Chernobyl disaster in 1986, the Soviet government did not take appropriate protective actions for local residents in the initial phase of the accident, meaning that many infants and children consumed milk contaminated with radioiodine, which caused thousands of people to develop thyroid cancer. This case clearly demonstrates the importance of food restrictions after a nuclear accident [3].

The International Atomic Energy Agency (IAEA) proposed general safety guidelines to be used for protecting people after a nuclear accident, and advised member states to adopt these recommendations considering the environmental factors of each country [4]. Accordingly, the Republic of Korea has established its own guidelines for public protective actions in case of a nuclear accident, including food ingestion standards of radioactivity in the Act on Physical Protection and Radiological Emergency (APPRE) (Article 15-1, attached Table 4).

Additionally, the Ministry of Food and Drug Safety (MFDS) proposed food ingestion guidelines for radioiodine and radiocesium (<http://www.mfds.go.kr>). However, the guidelines of the APPRE and MFDS are not aligned with each other, and both are inconsistent with those of the Codex Alimentarius Commission (CAC) of the World Health Organization (WHO) [5]. The APPRE proposes guidelines in terms of 5 categories of radionuclides and 4 categories of food, while MFDS uses 2 and 4 categories and the CAC utilizes 4 and 3 categories, respectively. In general, radionuclides are classified by the radiation risk that they pose when ingested from food. The guidelines of the APPRE and CAC contain the following major differences: 1) the APPRE classifies ^{103}Ru and ^{106}Ru in the same radionuclide group, while CAC classifies ^{103}Ru in a higher risk group; 2) the APPRE classifies ^{235}U and ^{238}U in a separate radionuclide group with strengthened criteria, while CAC classifies ^{235}U as having the same risk as ^{131}I without considering ^{238}U ; 3) the APPRE does not give criteria

for ^{14}C , ^{99}Tc , ^{192}Ir , ^{35}S , and ^{60}Co , which are included in the CAC guidelines.

Individual countries have their own food ingestion guidelines to be used in emergencies, but the guidelines are different [6]. This is owing to the different dietary customs and practices of each country, including differences in the types and amount of food consumed. It is therefore necessary to set up nation-specific guidelines that consider domestic dietary characteristics, rather than following a general global standard.

This study focuses on the methodology of determining food ingestion standards of radioactivity for the protection of people in nuclear emergency situations, and discusses the food ingestion guidelines for radiocesium and radioiodine by comparing the present results calculated using the domestic food intake rate with the current APPRE and MFDS guidelines. Furthermore, this study proposes derived operational intervention levels (OILs) calculated using domestic food consumption rates, and presents an investigation of their validity through a comparison with those of IAEA.

Materials and Methods

Protecting people through restricting food ingestion should be justified on radiation protection principles; that is, the benefits of the intervention must outweigh the loss. Restrictions on food consumption would be unnecessary if the activity concentration of food is so low that it would not be likely to have any harmful effects on people's health. In such a case, the expected cost of replacing contaminated food with clean food may outweigh the benefits of preventing possible harmful effects on public health. There are no absolute guidelines for supporting whether an intervention is appropriate because individuals may perceive radiation risks differently even with the same level of contamination. Thus, intervention levels should be derived reasonably based on scientific facts and within the reference guidelines that are supported by a global consensus.

Once the intervention levels are set up, the derived radioactivity concentration for a restriction on food consumption can be calculated as:

$$RCIL_{jk} = \frac{IL/G}{FW_{jk} \sum CF_i f_i (1 - e^{-\lambda_i T}) / \lambda_i} \quad (1)$$

where,

$RCIL_{jk}$: Derived activity concentration of food by age (j)

and food (k) ($\text{Bq}\cdot\text{kg}^{-1}$)

IL : Intervention level ($\text{mSv}\cdot\text{y}^{-1}$)

G : Number of foods

F : Market dilution factor of foodstuffs

W_{jk} : Average daily food intake by age (j) and food (k) ($\text{kg}\cdot\text{d}^{-1}$)

CF_i : Ingestion dose coefficient of radionuclide (i) ($\text{mSv}\cdot\text{Bq}^{-1}$)

T : Time for food consumption per annum ($T = 365$ days)

f_i : Radioactivity level of coexisting radionuclide i relative to that of the index radionuclide

λ_i : Radioactive decay constant of radionuclide (i) (d^{-1})

For food regulation in emergency exposure situations, the ICRP recommended a band of effective doses between 5 and 50 $\text{mSv}\cdot\text{y}^{-1}$, and equivalent doses of 50 and 500 $\text{mSv}\cdot\text{y}^{-1}$ to any selectively exposed organ or tissue, respectively, in its Publication 40 [7] in 1984. The WHO proposed an effective dose of 5 $\text{mSv}\cdot\text{y}^{-1}$ and an equivalent dose to the thyroid of 50 $\text{mSv}\cdot\text{y}^{-1}$ [8]. The intervention level of the WHO corresponds to the lower limit of the ICRP bands. In 1992, the ICRP suggested in its Publication 63 [9] that an effective dose of 10 $\text{mSv}\cdot\text{y}^{-1}$ for any single foodstuff would almost always be justified. The corresponding concentration levels of radionuclides are 1,000–10,000 $\text{Bq}\cdot\text{kg}^{-1}$ for β and γ radionuclides, and 10–100 $\text{Bq}\cdot\text{kg}^{-1}$ for α nuclides. The level of 1,000 $\text{Bq}\cdot\text{kg}^{-1}$, the lower limit for β and γ radionuclides, is equivalent to 5.5 $\text{mSv}\cdot\text{y}^{-1}$ when calculated using the global average annual food intake (not including drinking water) of 550 kg and the effective dose conversion factor of 1×10^{-5} $\text{mSv}\cdot\text{Bq}^{-1}$ for adults. The same dose is approximately obtained for 10 $\text{Bq}\cdot\text{kg}^{-1}$, the lower limit for α radionuclides, when using the effective dose conversion factor of 1×10^{-3} $\text{mSv}\cdot\text{Bq}^{-1}$. Considering the above international intervention levels for food regulations, in the present study, an effective dose of 5 $\text{mSv}\cdot\text{y}^{-1}$ for the ingestion of radiocesium and an equivalent dose to the thyroid of 50 $\text{mSv}\cdot\text{y}^{-1}$ for the ingestion of radioiodine were selected as the reference intervention levels to derive domestic food ingestion guidelines for emergency exposure situations.

The number of foods (G) can vary according to the radionuclide, as foods may not be contaminated practically by certain radionuclides due to their short half-life. A guideline for a single food would be so simple that it would be likely to facilitate communication between stakeholders. However, at the same time, guidelines for a single food are exposed to uncertainty regarding the determination of the representative activity concentration of food, and can lead to the risk of overexposure from foods that are consumed in large quanti-

ties. Moreover, such guidelines could result in excessive measures, such as restricting the consumption of other foods with low-level activity that may be safe, even when only a small portion of food is highly contaminated with radioactivity. On the other hand, if all kinds of food consumed are considered independently in guidelines, the guidelines would be too complex to be applied, and the derived activity concentrations can be biased by applying an identical effective dose (IL/G) to all foods, as well as by uncertainty in the consumption rate of each food. Therefore, it is reasonable to group foods by similar characteristics.

In this study, 5 food groups (drinking water, milk, vegetable/fruits, grains, and meat/seafood) were considered for both radiocesium and radioiodine in order to maintain consistency with the APPRE guidelines. Then, the intervention level for each foodstuff was applied, using an effective dose of 1 $\text{mSv}\cdot\text{y}^{-1}$ for radiocesium and an equivalent dose to the thyroid of 10 $\text{mSv}\cdot\text{y}^{-1}$ for radioiodine. For reference, it is noted that the Japanese guidelines consist of 5 food categories for radiocesium and 4 for radioiodine [10].

There are no standardized domestic food ingestion rates for radiation ingestion dose calculations. In the present study, the food intake rates presented by the Korea Institute of Nuclear Safety (KINS) [11], which were obtained from domestic nutrition studies to be used for ingestion dose assessments for regulatory purposes, were applied. Processed food was not considered in the calculations under the assumption that the raw material would not be contaminated with radionuclides. For planned exposures, ICRP Publication 101 [12] recommends the use of 95th percentile values of the food consumption rate for a conservative assessment, but in an emergency exposure situation, using the mean food consumption rate is logical to prevent excessive protective actions, and to consider average individuals who receive mean-level exposure.

The ICRP advises the use of 3 age ingestion dose coefficients, for 1-year old infants, 10-year-old children, and adults, but this study applied the dose coefficient for 3-month old infants instead of 1-year old infants for a conservative calculation.

In the study, the market dilution factor of food (F) was set to 1 for radioiodine and 0.5 for radiocesium, which were taken from a Japanese study [10], due to the absence of Korean data. The WHO applied a market dilution factor of 0.1, which means that 10% of food in the market would be contaminated with radioactivity. Thus, the present study applied a more

Table 1. The Input Data Used in the Calculation of the Food Intake Restriction Levels

Group	Radionuclide	Decay constant (d^{-1})	Ratio of coexisting radionuclides, f_i	Ingestion dose coefficient*, $mSv \cdot Bq^{-1}$		
				3 months	10 years	Adult
Iodine	^{131}I	8.62×10^{-2}	1.0	3.7×10^{-3}	1.0×10^{-3}	4.3×10^{-4}
	^{132}I	7.232	1.3617	4.0×10^{-5}	8.3×10^{-6}	3.4×10^{-6}
	^{133}I	7.998×10^{-1}	1.4255	9.6×10^{-4}	2.7×10^{-4}	8.2×10^{-5}
	^{134}I	18.97	0.0006	6.3×10^{-6}	1.3×10^{-6}	5.4×10^{-7}
	^{135}I	2.517	0.5532	1.9×10^{-4}	3.9×10^{-5}	1.6×10^{-5}
	^{132}Te	2.127×10^{-1}	1.3191	6.5×10^{-4}	7.5×10^{-5}	3.1×10^{-5}
Cesium	^{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	1.23×10^{-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}

*The ingestion dose coefficients for iodine are that for the thyroid, which were taken from the ICRP Database of Dose Coefficient: Workers and Members of the Public Version 3.0, 2011 (<http://www.icrp.org>).

conservative approach than that of the WHO. It should be noted that the combination of an F of 1 with an intervention level of $10 \text{ mSv} \cdot \text{y}^{-1}$ produces the same derived activity concentration for the guidelines as the combination of an F of 0.1 with an intervention level of $1 \text{ mSv} \cdot \text{y}^{-1}$.

By using the ratio of the radioactivity of coexisting radionuclides relative to an index radionuclide (^{131}I and $^{137+134}Cs$) in food (f), the contribution of coexisting radionuclides to the committed dose can implicitly be considered in the derived activity concentration of the index radionuclide. In this study, f was deduced from 2 assumptions: 1) the ratio of the radioactivity concentration of ^{90}Sr to ^{137}Cs is 1:10, and 2) the ratio of radioactivity of ^{89}Sr to ^{90}Sr (6.308) and the ratio of radioactivity of ^{137}Cs to ^{134}Cs (0.836) are equal to the corresponding ratios inside the reactor at 0.5 days after shutdown of the pressure water reactor (PWR), where fuel with an initial concentration of 3% is burned at $30 \text{ GWd} \cdot \text{ton}^{-1}$ [10].

Results and Discussion

1. Calculation results

The input data used in the calculation are summarized in Table 1 and 2, and the calculated food ingestion guidelines by age group are shown in Table 3. The lowest values for each radionuclide and food group are highlighted in bold, and these can be used as index values for guidelines.

The lowest activity concentrations for radiocesium calculated using the domestic food consumption rates were 348, 905, 758, 968, and $2,003 \text{ Bq} \cdot \text{kg}^{-1}$ for drinking water, milk, vegetables/fruits, grains, and meat/seafood, respectively. Of these values, the lowest value, for drinking water ($348 \text{ Bq} \cdot \text{kg}^{-1}$), can be proposed as an index value for a representa-

Table 2. Domestic Daily Food Intake Rates ($\text{kg} \cdot \text{d}^{-1}$)

Food		1 year	10 years	Adults
Group 1	Drinking water	0.51	0.85	1.0
Group 2	Milk	0.22	0.2	0.06
Group 3	Vegetables	0.05	0.22	0.37
	Fruit	0.063	0.091	0.09
Group 4	Grain	0.126	0.32	0.36
Group 5	Seafood	0.016	0.037	0.074
	Meat	0.029	0.115	0.1
	Processed food	0.163	0.175	0.27
Total		1.177	2.008	2.324

tive guideline for all kinds of food since it satisfies the criteria of other foods as well. The proposed index value is slightly lower than the MDFS guideline for adults of $370 \text{ Bq} \cdot \text{kg}^{-1}$, but about 3.5 times higher than the APPRE guideline for infants of $100 \text{ Bq} \cdot \text{kg}^{-1}$. In comparison with the APPRE guidelines, it can be shown that the present results for drinking water and milk for adults were approximately 1.7 times higher, while for vegetable/fruits for adults, our results were 25% lower than those contained in the APPRE guidelines. The index value for grains was estimated to be 50% lower than the value in the APPRE guidelines, whereas the index value for meat/seafood appeared to be similar. In short, the current APPRE guidelines apply very conservative criteria for infants, and rather conservative criteria for drinking water and milk for adults, compared to the index values in this study calculated using the domestic food intake rate. However, a comparison between the WHO and the APPRE guidelines shows that the APPRE guidelines are more conservative, except for meat/seafood. This is ascribed to the application of different intervention levels and food consumption rates between the APPRE and WHO.

Table 3. Calculated Levels and Comparison with Other Guideline Levels

Radionuclide	Food	Calculated level, Bq·kg ⁻¹			APPRE* (Korea)		CAC† (WHO/FAO)	
		Infants	10 years	Adults	Infants	Adults	Infants	Adults
¹³⁴⁺¹³⁷ Cs		IL: effective dose of 5 mSv			100	200	1,000	1,000
	Drinking water	390	551	348				
	Milk	905	2,341	5,808	100	200	1,000	1,000
	Veg., fruit	1,810	1,510	758	100	1,000	1,000	1,000
	Grains	1,580	1,463	968	100	2,000	1,000	1,000
	Meat, seafood	4,424	3,080	2,003	100	2,000	1,000	1,000
	Single food	985	1,278	848				
¹³¹ I		IL: thyroid dose of 50 mSv (effective dose of 5 mSv)			10	100	100	100
	Drinking water	403 (792)	937 (1,748)	1,876 (3,488)				
	Milk	933 (1,836)	3,982 (7,429)	31,267 (58,137)	10	100	100	100
	Veg., fruit	1,866 (3,672)	2,569 (4,793)	4,078 (7,583)	10	500	100	100
	Grains	1,629 (3,206)	2,489 (4,643)	5,211 (9,689)	10	1,000	100	100
	Meat, seafood	4,562 (8,976)	5,240 (9,774)	10,782 (20,047)	10	1,000	100	100
	Single food	1,015	2,174	4,567				

*Act on Physical Protection and Radiological Emergency of Korea (Article15-1, attached Table 4).

†In the derivation of the Codex Alimentarius Commission (CAC) guidelines, 550 kg and 200 kg of food is assumed to be consumed by an adult and infant in a year, respectively, and the generic intervention level is 1 mSv for individuals [5].

IL, intervention level; WHO, World Health Organization; FAO, Food and Agriculture Organization of the United Nations.

For radioiodine, the lowest activity concentration was 403 Bq·kg⁻¹ for drinking water for infants, which is 4 to 10 times higher than the existing levels of domestic and international organizations. The present index levels for radioiodine were higher for all foods than those in the APPRE guidelines, indicating that the current Korean and global guidelines seem to be very conservative. The WHO presents very strict guidelines for radioiodine. The purpose of this seems to control carefully the consumption of food contaminated with radioactive iodine in the initial phase of a nuclear accident, based on the lessons learned from the Chernobyl accident.

2. The effect of the input data on the calculation results

1) The effect of the market dilution factor of foodstuffs (*F*)

In general, the value of *F* decreases with time owing to restrictions on food consumption and the withdrawal of contaminated food from the market. To investigate the temporal effect of the market dilution factor, the activity concentration of foodstuffs was calculated with *F* as a function of time ($F = e^{-0.0063t}$, $F = 0.1$ at $t = 365$), and the results were compared with those calculated using a constant value of *F*, as shown in Figure 1. It was found that the calculated activity concentration increased by 21% for adults and 12% for infants for radiocesium, and by 7% for both adults and infants for radioiodine, compared to the assumption of a constant value ($F = 1$ for radioiodine, $F = 0.5$ for radiocesium). These results suggest that the present approach using a constant value of *F*

may be more conservative than using time-variant *F*. The committed dose from radioiodine almost reaches its annual limit (equivalent dose to the thyroid of 10 mSv) within the first 40 days after the accident. In other words, radioiodine no longer contributes to radiation risk after 40 days due to its short half-life. Thus, the assumption of $F = 1$ for radioiodine is reasonable. In contrast, radiocesium has a long half-life, meaning that its committed dose peaks at 1 mSv at 365 days. It would therefore be acceptable to assume *F* of 0.5, considering the decrease of *F* with time.

2) The effect of coexisting radionuclides

Coexisting radionuclides were introduced into the model to reflect their impact on the activity concentration of index radionuclides. When coexisting radionuclides were not considered, the derived activity concentration for radioiodine increased by 7% and 13% for adults and infants, respectively, and the derived activity concentration for radiocesium increased by 4% and 28%, respectively, compared with when coexisting radionuclides were considered (Figure 2). As a result, the derived activity concentration for index radionuclides became lower when accounting for the additional contributions of coexisting radionuclides to the committed dose.

3) The effect of the number of foods (*G*)

The difference in the index value between a single food and multiple foods was investigated. A single food ($G = 1$)

Fig. 1. Effect of market dilution factor of foodstuffs (F) on food guidelines: (A) Iodine (adult), (B) Cesium (adult), (C) Iodine (infant), and (D) Cesium (infant).

Fig. 2. Effect of coexisting radionuclides on food guidelines: (A) Iodine (adult), (B) Cesium (adult), (C) Iodine (infant), and (D) Cesium (infant).

Fig. 3. Comparison of food guidelines between single food and multiple foods.

means that foodstuffs are not classified; that is, the guidelines only apply to the group of radionuclides without any classification of foods. The activity concentration for a single food is conceptually similar to the average value of the derived activity concentrations for multiple foodstuffs. Thus, the derived activity concentration for a single food would be larger than that of a highly-consumed food such as drinking water, but lower than that of a less-consumed food such as meat in guidelines for multiple foods (Figure 3). For instance, in this study, which considered 5 food groups, the index value of radiocesium for drinking water was estimated to be 348 Bq·kg⁻¹. The index value for a single food would be 2.4 times greater, at 848 Bq·kg⁻¹ (Table 3). Guidelines for a single food are obviously simple and easy to use, but can face a certain degree of difficulty when a representative activity concentration is selected from monitoring results of food for implementing protective actions. Additionally, it can bring about excessive protective actions, such as banning the consumption of all foods, even though only small portions of food are highly contaminated.

4) The effect of the intervention level for radioiodine

This study applied an equivalent dose of 50 mSv to the thyroid (10 mSv for each food category) as the intervention level to determine the derived activity concentration of radioiodine. Figure 4 shows the comparison of the derived activity concentration of foods between a thyroid equivalent dose of 10 mSv and an effective dose of 1 mSv as the intervention reference level. The derived concentration levels obtained using an effective dose of 1 mSv for each food type (a total of 5 mSv) were about twice as large as those derived using the thyroid equivalent dose (a total of 50 mSv) for both adults

Fig. 4. Comparison of food guidelines for radioactive iodine between the equivalent dose to thyroid and the effective dose for intervention level.

and infants. This result indicates that applying the thyroid equivalent dose as the intervention reference level for radioiodine would result in more conservative results.

3. Operational intervention levels

The guidelines for radiocesium and radioiodine are practically convenient in an emergency situation because the monitoring of other radionuclides is not necessary. However, as shown in the previous section, the derived activity concentration for the index radionuclides can vary tremendously according to the values of input parameters, such as the number and ratio of coexisting radionuclides relative to the index radionuclides and the market dilution factor of food. Alternatively, the operational intervention levels (OILs) developed by the IAEA may be used as guidelines for public protective actions if the activities of all radionuclides in food can be evaluated. OILs are suitable for use when responding to an emergency based on the measured radioactivity levels in soil and food.

The derived intervention level to implement public protective actions has generally been determined by model predictions. However, the model prediction often results in a quite different result from the real situation due to uncertainties in the input parameters of the model or in the model itself. Recently, the IAEA recommended that public protective actions should be implemented based on measured activities to the extent possible, based on the lessons learned from the Fukushima accident, which exhibited very different results between model predictions and the measured data for the initial contamination pathway [13]. Therefore, it is desirable to conduct public protective actions using OILs if possible.

IAEA's default OILs consist of 6 sets of values, OIL1 to OIL6 [4]. The default OIL5 and OIL6 apply to radionuclides in food, milk, or water destined for human consumption that warrant the consideration of restrictions on consumption to keep the effective dose to any person below 10 mSv per annum. The default OIL5 (100 Bq·kg⁻¹ for gross β and 5 Bq·kg⁻¹ for gross α) serve as a benchmark for initial screening. If the measured radioactivity levels for gross β and α of potentially contaminated food are below the default OIL5 values, it would be determined to be safe for consumption; on the contrary, if the measured gross β and α radioactivity exceeds the default OIL5, then the radioactivity of radionuclides in food (K) should be measured (Figure 5). If the condition of $\sum \frac{K_i}{OIL_i} > 1$ (OIL_i is the default OIL6 of radionuclide *i*) is satisfied, the consumption of non-essential food should be restricted. Essential food, milk, and drinking water should be replaced, or residents should be relocated to a different region if alternative food is unavailable. However, when restrictions on food consumption are expected to result in severe malnutrition or dehydration due to the absence of replacement food, the contaminated food may be consumed for a short time until replacements become available. Such an action must be based on a determination that the potential health risks caused by malnutrition would be higher than the risks of radiation exposure by consuming contaminated food.

The IAEA has proposed default OIL6 values for 355 radionuclides. In general, the OIL6 can be calculated by the following equation.

$$RCIL_i = \frac{IL}{W \times CF_i \times (1 - e^{-\lambda_i T}) / \lambda_i} \quad (2)$$

where $RCIL_i$ is the OIL6 value of radionuclide *i*. IL is the operational intervention level for the regulation of food, and

Fig. 5. Process of assessing radionuclide concentrations in food, milk and water [4].

Table 4. The OIL6 Based on the Domestic Food Intake Rate, and Its Comparison with the Default IAEA OIL6 Values

Radionuclide	Calculated infant OIL6	Calculated adult OIL6	Domestic proposed OIL6	IAEA default OIL6*
²³⁸ Pu	14	113	10	50
²³⁹ Pu	13	104	10	50
²⁴⁰ Pu	13	104	10	50
²⁴¹ Am	15	130	10	50
⁹⁰ Sr	620	2,435	600	200
¹⁰⁶ Ru	770	4,420	700	600
¹²⁹ I	302	236	300	NA
¹³¹ I	9503	37,179	9,000	3,000
²³⁵ U	155	553	100	200
³⁵ S	81,076	387,698	80,000	10,000
⁶⁰ Co	1,042	7,911	1,000	800
⁸⁹ Sr	7,618	50,436	7,000	6,000
¹⁰³ Ru	26,703	124,190	20,000	30,000
¹³⁴ Cs	2,462	1,611	2,000	1,000
¹³⁷ Cs	2,619	2,023	2,000	2,000
¹⁴⁴ Ce	1,029	6,247	1,000	800
¹⁹² Ir	8965	39,806	8,000	8,000
³ H	861,893	1,465,382	800,000	200,000
¹⁴ C	38,830	44,818	30,000	10,000
⁹⁹ Tc	5,436	4,545	5,000	4,000

*The IAEA (International Atomic Energy Agency) default OIL6 was calculated using the most restrictive age-dependent dose conversion factors and ingestion rates (i.e. those for infants), and the generic criterion of 10 mSv·y⁻¹ [4].

in this study, an intervention level of $10 \text{ mSv}\cdot\text{y}^{-1}$ was applied, as was done by the IAEA. T was set to 365 days to consider the annual ingestion dose. W is the daily food intake rate, and CF_i is the dose conversion factor for radionuclide i . In the present calculation, the dose conversion factor for 3-month-old infants was used instead of the dose conversion factor for 1-year old infants.

Table 4 summarizes the calculated OIL6 values of infant and adults for domestic food intake rates, in comparison with the IAEA's default OIL6 values. The lowest OIL6 for each age group may be used as the domestic default OIL6. The IAEA default OIL6 values were derived with the agreement of all IAEA members and jointly with the Food and Agriculture Organization of the United Nations, International Labor Organization, Pan-American Health Organization, and the WHO. The IAEA's default OIL6 values for ^{131}I , ^{134}Cs , and ^{137}Cs are $3,000 \text{ Bq}\cdot\text{kg}^{-1}$, $1,000 \text{ Bq}\cdot\text{kg}^{-1}$, and $2,000 \text{ Bq}\cdot\text{kg}^{-1}$, respectively, and these levels are about 10 times greater than the guidelines for restrictions on food consumption in Japan implemented after the Fukushima accident. This may be explained by the fact that the Japanese authorities strengthened the intervention levels to keep the public ingestion dose below 1 mSv per annum.

The IAEA's default OIL6 values for most radionuclides were lower than those derived in the present study, except for some α radionuclides such as ^{238}Pu and ^{235}U . This difference seems to have been caused by the application of the dose conversion coefficient for 3-month-old infants and by the domestic food intake rate. From the perspective of providing conservative guidelines, the present results for α radionuclides and the IAEA's default OIL6 values for other radionuclides are recommended as domestic OIL6 values. However, an in-depth review by experts and stakeholders regarding the logic and input data for calculations is required to develop final guidelines suitable to circumstances in Korea.

Conclusion

The derived activity concentrations of radiocesium and radioiodine for food regulation in emergency exposure situations were calculated using domestic food consumption rates.

It is suggested that the current APPRE guidelines for radiocesium should be set as conservative levels for infants. For adults, the APPRE guidelines are rather conservative for drinking water and milk, while the guidelines are similar for

vegetables, fruits, and grains, compared to the derived activity concentrations of food in the present study. In contrast, the current Korean guidelines for radiocesium are more conservative for all food groups than those of the WHO, except the values for meat/seafood in the APPRE. The index values for radioiodine turned out to be very conservative in both the Korean and global guidelines.

The derived OIL6 values for domestic food intake rates turned out to be greater for most radionuclides than the IAEA's default OIL6 values, except for some α radionuclides.

In summary, the current APPRE and MDFS guidelines for radiocesium and radioiodine are overall conservative, compared to the derived activity concentrations of food based on domestic food intake rates. Combining the IAEA's default OIL6 values with the present OIL6 values for α radionuclides is suggested as a way to generate a new set of OIL6 values for domestic application. However, comprehensive and open discussions among stakeholders, incorporating regulatory authorities, are necessary to rebuild the domestic guidelines on a solid logical basis.

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