Proposal for Reference Soil Concentrations of Radiocesium Applicable to Accidentally Contaminated Rice and Soybean Fields

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1. Introduction

If arable soil is contaminated with radionuclides, a decision should be made on the use of the soil. It was demonstrated through the Chernobyl and Fukushima accidents that radiocesium (^{134}Cs and ^{137}Cs) are almost totally accountable for a long-term contamination of arable land after a severe nuclear power plant (NPP) accident. Radionuclides in arable soil can be transferred to food plants via root uptake. If radionuclide concentrations in food plants to be grown in contaminated soil are estimated to be higher than the authorized food standards, their culture needs to be cancelled or ameliorating practices need to be taken. Therefore, it is necessary to establish soil concentration limits or reference soil concentrations of radiocesium standing with the food standards in preparation for potential severe NPP accidents in this and adjacent countries. In the present study, reference soil concentrations of radiocesium for rice and soybean, two of the most important food plants in Korea, were provisionally established using all relevant domestic data of soil-to-plant transfer factor (TF) [1-5].

2. Collection of Relevant TF Data

TF (dimensionless) is defined as the ratio of the radionuclide concentration in food plant (Bq/kg) to that in soil (Bq/kg-dry) [1,6]. TF data can be produced through greenhouse or outdoor experiments and field studies. The plant concentration is measured for mature edible parts, whereas the soil concentration is measured for the plowed zone or the effective root zone. At KAERI (Korea Atomic Energy Research Institute), TF values of ^{137}Cs for staple-food plants have been measured through greenhouse experiments and field studies over the past 30 years. Fig. 1 shows rice plants growing in greenhouse experiments.

Fig. 1. Rice plants growing in greenhouse experiments.

Table 1 summarizes the collected data of ^{137}Cs TF for rice and soybean.

Table I: Summary of the collected data of ^{137}Cs TF for rice and soybean

Plant part	No. of soils	TF value of ^{137}Cs		
		Min.	Max.	GM [c]
Brown rice	13 [a]	0.0081	0.16	0.029
	12 [b]	0.0012	0.011	0.0045
Soybean seed	6 [a]	0.050	0.50	0.15

[a] greenhouse experiment [b] field study for fallout ^{137}Cs
[c] Geometric mean.

In general, the TF values from greenhouse experiments were several times higher for soybean seeds than for brown rice. For brown rice, the values from field studies were generally several times lower than those from greenhouse experiments. This is attributable to irreversible soil fixation of fallout ^{137}Cs during many years after its deposition [5].

3. Calculation of Reference Soil Concentrations

As implied by the definition of TF, reference soil concentrations (RSCs) as the derived activity limits can be calculated by applying appropriate TF values to the food standards. The geometric mean (GM) of all relevant TF values is generally accepted as a representative TF value [6]. For this reason, the GMs were used in calculating RSCs. TF values of the same radionuclide for the same plant species can vary widely for different environmental conditions, and particularly for different soils [6]. Accordingly, there may be great uncertainty in RSCs determined using single representative TF values. If the mean TF values are applied without any modification, there is a maximum of 50% probability that the plant concentration will be higher than the food standard. To reduce this risk, safety factors (SFs) need to be introduced. As a result of the above-mentioned consideration, RSCs (Bq/kg-dry) were calculated as follows;

$$RSC = \frac{\text{Food standard of } ^{137}\text{Cs (Bq/kg)}}{GM \times SF} \quad \text{----------(1)}$$

For the SF, different values higher than 1 can be adopted. In the present study, five different kinds of RSC were calculated by introducing three different SF values based on geometric deviations. The food standard applied was 100 Bq/kg, which was the Japanese standard for the Fukushima accident, and also adopted by the Korean government.

4. Calculated RSCs for Rice and Soybean

Table 2 presents five kinds of ^{137}Cs RSC for rice and soybean calculated as explained above. These RSCs are based on the TF values from greenhouse experiments, indicating that they are useful in the year of an accidental deposition.

Table 2. Calculated RSCs of ^{137}Cs for rice and soybean

Plant	Reference soil concentration (Bq/kg-dry) [b]				
	RSC-O	RSC-I	RSC-II	RSC-III	RSC-M
Rice	3411	1193	417	146	625
Soybean	647	285	126	55	200
Risk (%) [a]	50	16	2.3	0.2	-

[a] the maximum probability that the plant concentration will be higher than the food standard

[b] RSC-O: no SF; RSC-I: SF=GSD: RSC-II: SF=GSD(2); RSC-III: SF=GSD(3); RSC-M: Maximum TF value was used without applying SF.

Note) GSD(2) is the exponential of 2 σ of the natural logarithms of relevant TF values.

The RSCs for rice are 3-5 times higher than those for soybean. The higher the RSC is, the higher the risk defined as the maximum probability that the plant concentration will be higher than the food standard. The RSC-M, which was based on the maximum TF value, lies between the RSC-I and RSC-II in both plant species. An increase in the amount of TF data may make the RSC-M reach closer to, or go below, the RSC-II.

5. Discussion

The present RSCs are provisionally applicable to rice and soybean fields when a severe NPP accident occurs prior to plowing the fields for planting. However, decisions based only on the present RSCs should be limited to the soils contaminated almost entirely with radiocesium. These accidental situations are very similar to those of the Chernobyl and Fukushima nuclear accidents.

In the application of the present RSCs, they should be compared with the concentrations of total radiocesium (^{134}Cs plus ^{137}Cs) in soil. The soil-to-plant transfer of radiocesium can decrease significantly as years go by after its deposition. Therefore, the RSC needs to be recalculated for aged depositions on the basis of such data as the TF values from field studies.

The worse the situations regarding the environmental impact and food supply are, the higher may have to be the RSCs. The necessity of checking plant concentrations after harvest increases as the RSC becomes higher. This indicates that the national capacity of food monitoring for radioactive contamination also needs to be considered in selecting the RSC for application.

The RSC-III can give an almost 100% guarantee that the plant concentration will be lower than the food standard. It will be desirable if even the use of the RSC-III or a lower RSC does not lead to the prohibition of planting in any rice or soybean fields. Accordingly, the RSC needs to be lowered further as long as the area of the land under the prohibition does not increase. At this point, it should be considered that there may be substantial uncertainty in the measurement and prediction of soil contamination level in an emergency situation.

6. Conclusions

The reference soil concentrations of radiocesium for rice and soybean were calculated using available domestic TF data, and were proposed for provisional use at the time of a severe NPP accident. The present RSCs are based on limited numbers of ^{137}Cs TF values. More amounts of relevant TF data should be produced to have more reliable RSCs. For other staple-food plants such as Chinese cabbage and radish, RSCs of radiocesium should also be established. However, only a couple of relevant domestic TF values are available for these vegetables. Therefore, it is necessary that additional data of ^{137}Cs TF for them be experimentally produced as soon as possible.

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