Korean Ingestion Dose Assessment Model for Level 3 PSA

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Abstract: This paper describes a food ingestion dose assessment model (K-PUBDOSE), which has been developed based on the farming characteristics of Korea for a Level 3 PSA. The model consists of three sub-modules: agricultural plant contamination assessment model, animal product contamination assessment model, and ingestion dose assessment model. The model considers eight human foodstuffs (grain, vegetables, fruit, milk, beef, chicken, egg, and pork), and three livestock feedstuffs (rice-straw, pasture, and corn) in order to ensure consistency with the existing domestic regulatory system. The performance of the model has been tested through the calculation of the activity concentration of ^{137}Cs for crops and animal products, and subsequently, the ingestion dose for five age groups for unit deposition. The calculated results represented well the contamination characteristics of crop and ingestion dose according to the deposition date. In conclusion, the model is expected to be effectively used as an ingestion dose assessment model for the Korean Level 3 PSA, which is currently being developed.

Keywords: Nuclear Accident, Chronic Exposure, Ingestion Dose, Level 3 PSA.

1. INTRODUCTION

The ingestion dose for the public due to the consumption of food contaminated with radionuclides is very useful information to manage the contaminated agricultural system, to determine the public protective measures after a nuclear accident, or to establish guidelines for the nuclear emergency in the preparedness stage. To evaluate the ingestion dose, a suitable assessment model and the relevant input parameters are necessarily required

The purpose of the present study aims at presenting the model to assess the ingestion dose as the result of a nuclear accident, considering the Korean farming characteristics, such as the growth characteristics of rice and stockbreeding.

2. MODELS

The summary of the present model (K-PUBDOSE) is described below. Details of the model are given elsewhere [1].

2.1. Contamination Pathways of Agricultural Plants

Figure 1 shows the contamination pathways of agricultural plants. The plants are modelled differently according to the type of crop. Rice and corn, of which a stem is used as feedstuffs of a livestock, is separated with the body (stem) and grain to evaluate the respective activity concentration of stem and grain, while vegetables and pasture, of which the whole part are edible, are divided into the surface and inner part of the plant.

The transfer characteristics of radionuclides in paddy fields are somewhat different from that in dry-fields owing to the presence of the flooded irrigation water on the paddy field during most of the growing period. To model this characteristic for a paddy field, a surface water compartment, which corresponds to the surface soil compartment of dry fields, is introduced. In addition, the shoot base absorption from the surface water, which was indirectly identified from the rice experiments [2], is considered as an additional transfer pathway of radionuclides to rice.

On the other hand, when surface water contaminated with radionuclides is used for irrigation, the contaminated irrigation water is an additional source for the contamination of plants. In the present model, the effects of the contaminated irrigation water are considered for only rice and vegetables because surface water such as rivers and lakes are normally used for irrigation for the crops, whereas they are not considered for fruit under the assumption that groundwater with no contamination is used for irrigation. It is assumed that pastures are naturally wild and thus there is no artificial plowing or irrigation for raising pasture. Fruit trees are perennial, and thus there is no plowing. No plowing leads to no soil mixing.

The soil is divided into four parts, namely, surface soil (surface water for only rice), root zone soil, fixed soil, or deep soil (sink term). The fixed soil is introduced to consider the radionuclides unavailable for root uptake by a fixation to the soil mineral, and deep soil is a sink term of radionuclides disappearing out of the soil system. In the case of rice and corn, root uptake is assumed to occur simultaneously through both the body and grain from the root zone soil, and in the case of vegetables and pasture, root uptake is assumed to occur through only the inside of the crops from the root zone soil.

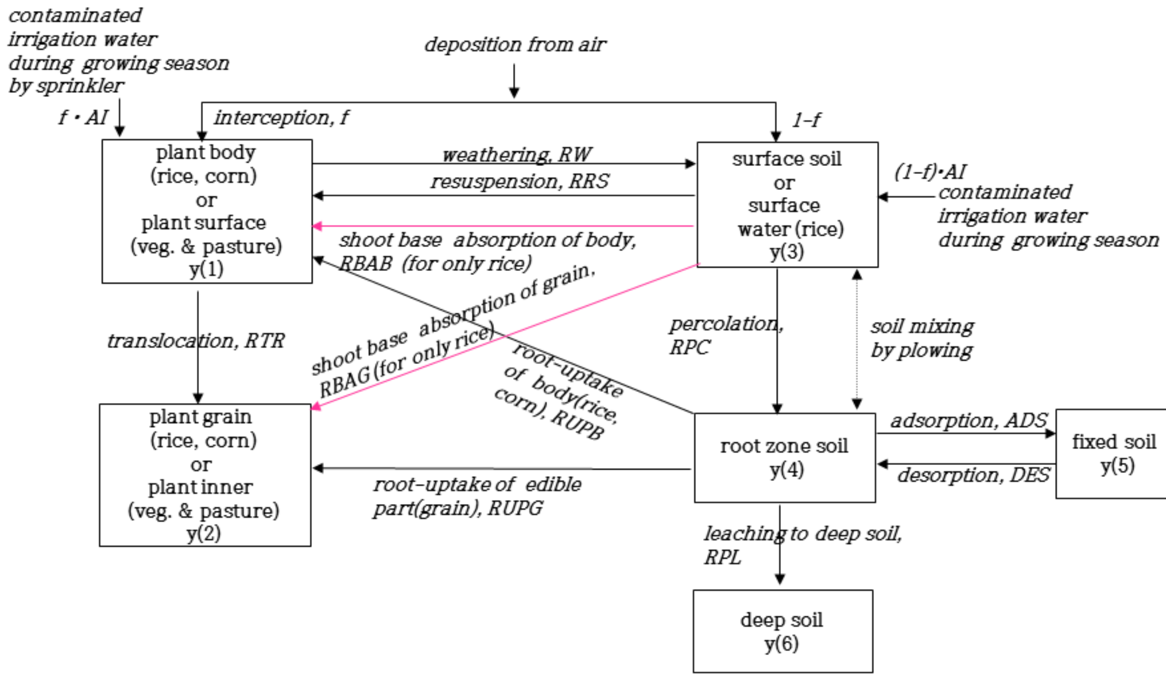

Figure 1 Contamination Pathways of Agricultural Plants

2.2. Contamination Pathways of Animal Products

The contamination of animal products occurs when livestock feed on contaminated crops and grasses. Figure 2 shows the contamination pathways of animal products used in the present study. The animal products considered in the model are milk, beef, chicken, egg, and pork. Rice straw, corn, and pasture are considered as feed for livestock because in Korea, dairy and beef cattle ingest rice-straw and wild pasture as fodder and because corn is used as a major raw material to produce an assorted feed in a factory.

On the other hand, cattle are mostly bred indoors rather than grazing outdoors in order to meet the food taste of Koreans who like greasy meat. Thus, the ingestion of contaminated soil is assumed to be insignificant.

The activity concentration of animal products is determined by the product of feed intake and feed activity concentration, and feed-livestock transfer coefficient under the assumption of the equilibrium between feed and livestock.

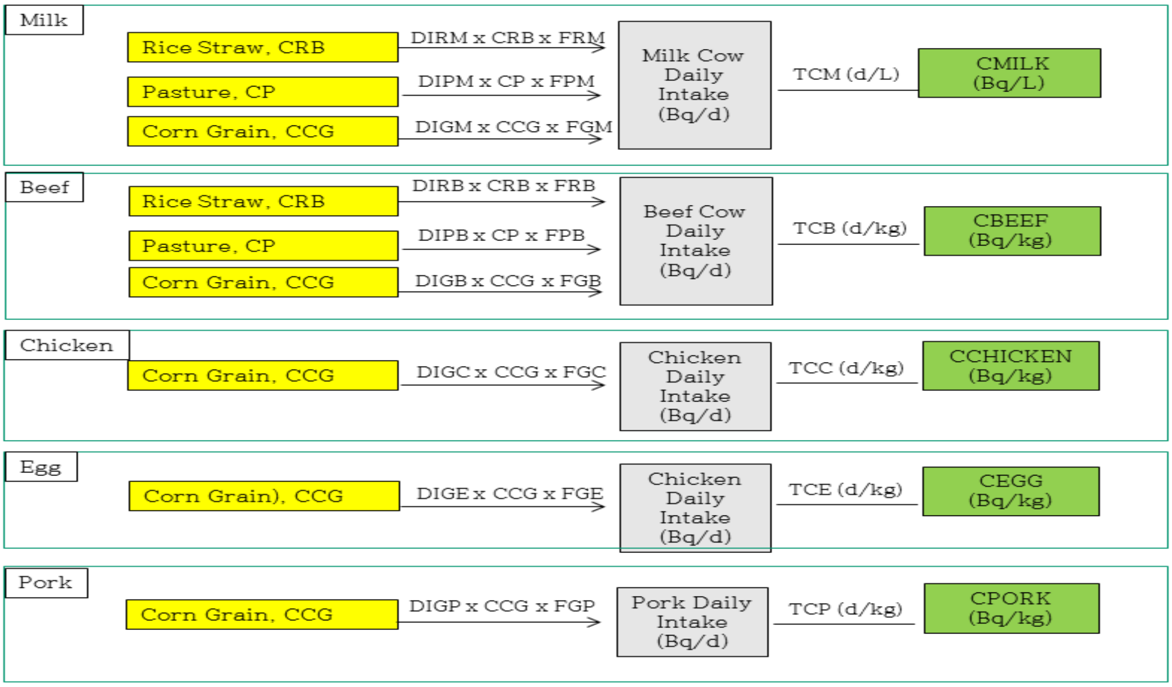

Figure 2 Contamination Pathways of Animal Products

3. RESULTS AND DISCUSSIONS

3.1. Activity Concentration of Foodstuffs

Figure 3 shows the temporal ^{137}Cs activity concentration of rice for 10 years following two different deposition dates. When a deposition occurs on March 2 (Julian day 61), before the transplanting of rice, the radionuclide is deposited onto the root zone soil because irrigation has not started yet. In this case, the transfer of the deposited radionuclides on the soil to rice starts to occur through the root uptake and short base absorption after the transplanting of rice. The activity concentration of a rice body shows a peak by balancing of radionuclide between the gain due to absorption and the loss due to weathering. After an ear emergence, the activity concentration of the body is further decreased until harvest by translocation from the body to the grain, whereas the activity concentration of ear is increased continuously until harvest by the translocation process. On the other hand, when deposition occurs on July 2 (Julian day 183) in the growing season of rice, the direct deposition occurs on a rice body (straw). Consequently, the activity concentration of the body and grain at first harvest after deposition becomes larger, compared with the case of the deposition before rice planting.

The initial activity concentration of the root zone soil varies depending on the time of deposition (in the case of deposition during the non-growth season of rice, radionuclides are deposited on the surface of the root zone soil, whereas in the case of deposition during the growth, a portion of radionuclides are deposited on the flooded surface water). After the initial deposition, the activity concentration of the root zone soil is decreased gradually by soil immobilization and leaching processes. The activity concentration of the flooded surface water is instantaneously increased by its mixing with the root zone soil owing to plowing before transplanting. After the plowing, the activity concentration is decreased again by the transfer of radionuclides to the root zone soil (percolation). More than 80% of the deposited ^{137}Cs remain in the fixed soil even 5 years after deposition, indicating a significant reduction of radionuclides available for root absorption. This result is consistent with the fact that most radioactive cesium was present in the soil within a 5 cm depth even after the recent 5 years after the Fukushima accident.

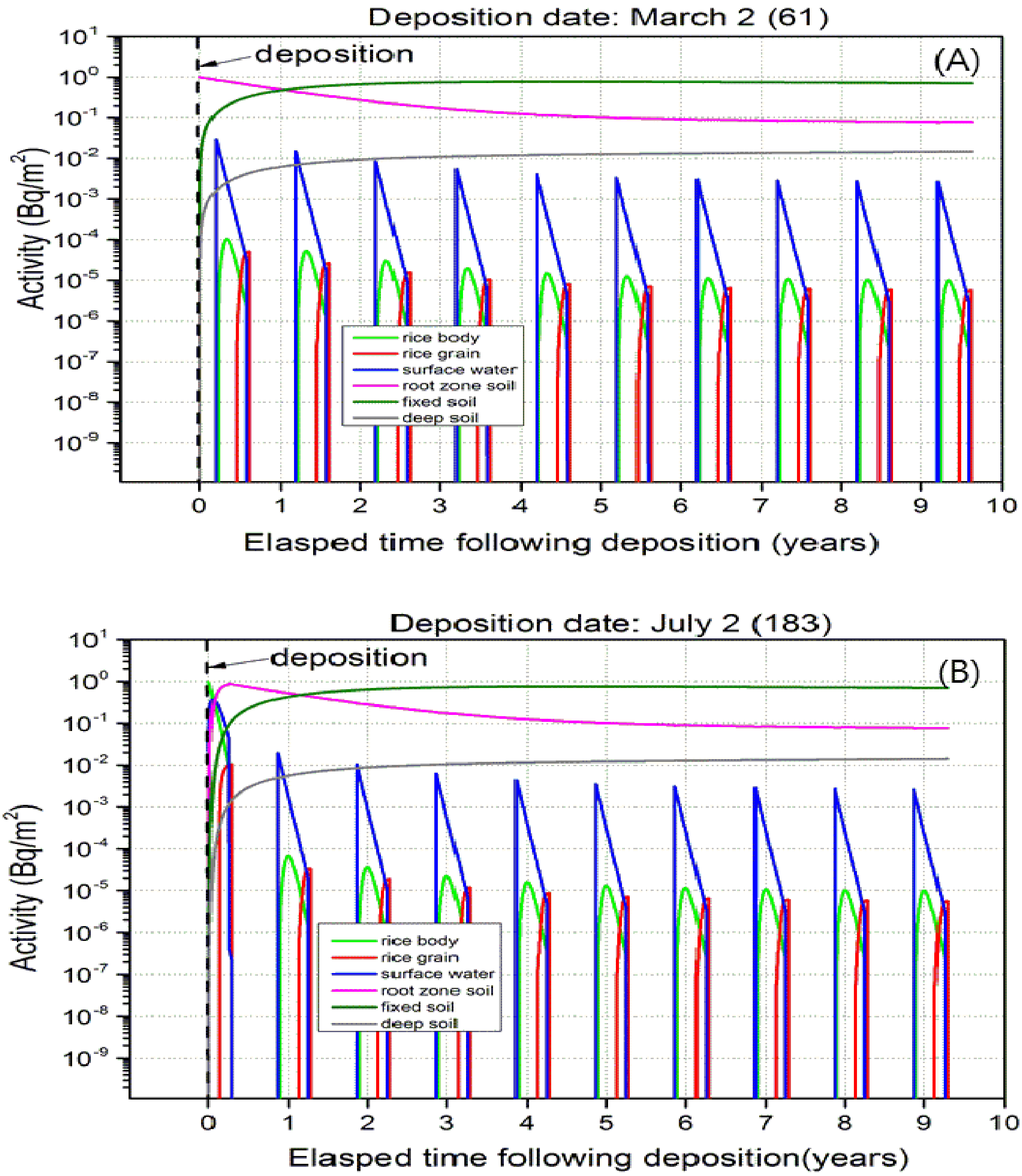

Figure 3 Temporal ^{137}Cs activity concentration of rice for 10 years following two different deposition dates

Figure 4 shows the temporal ^{137}Cs activity concentrations of pastures for 10 years following the deposition on October 2. Pasture 3 was growing at the time of deposition. Therefore, the first harvest activity concentration appeared to be in the order of pasture 3> pasture 1> pasture 2. There was almost no difference in the activity concentration between pastures after the second year following deposition.

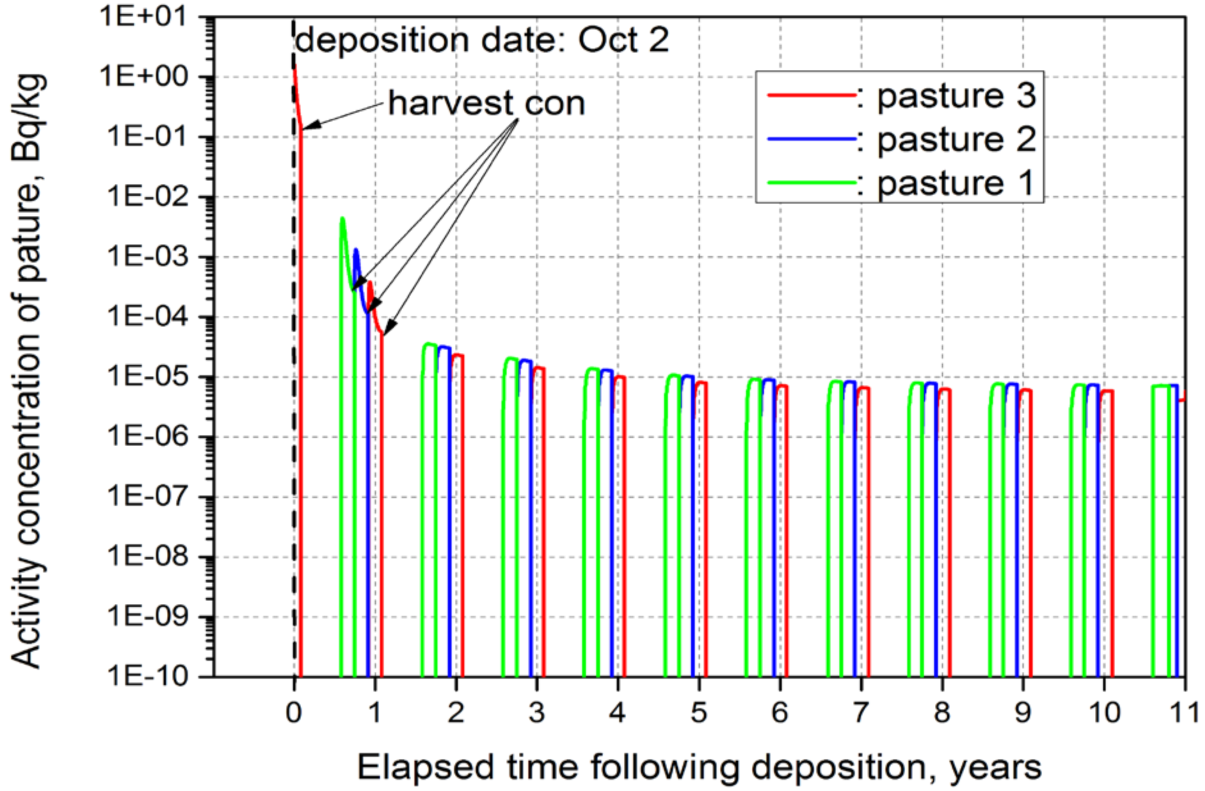

Figure 4 Temporal ^{137}Cs activity concentrations of pastures for 10 years (deposition on Oct 2).

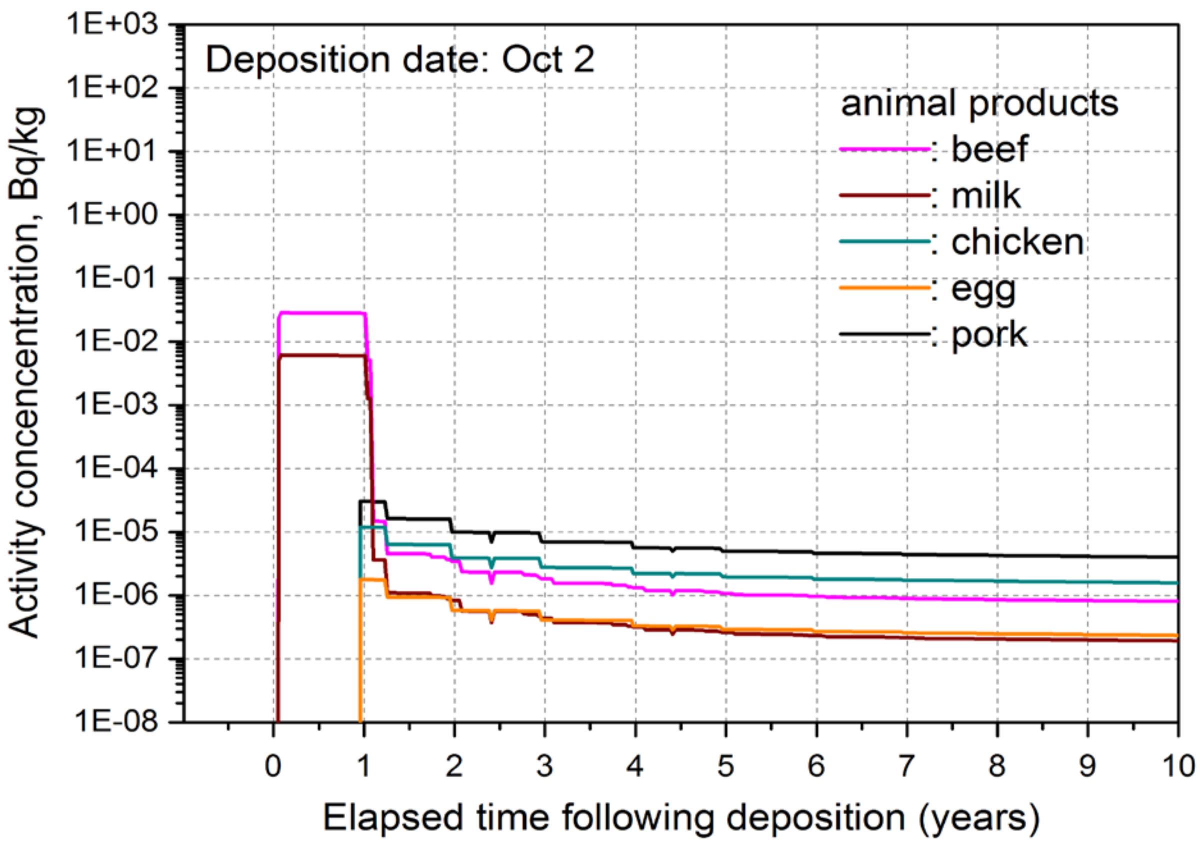

Figure 5 Temporal ^{137}Cs activity concentrations of animal products for 10 years (deposition on Oct 2).

Figure 5 shows the temporal ^{137}Cs activity concentrations of animal products for 10 years following the deposition on Oct 2. Rice and pasture 3 are growing on October 2. The first year activity concentration of these crops increased owing to the direct deposition onto the surface of the crops, and thus the activity concentrations of milk and beef also increased with the activity concentration of feedstuffs. The activity concentration of animal products increases when the deposition approaches the harvest date of crops, which will lead to a higher activity concentration of crops.

3.2. Ingestion Dose by Age Groups

Figure 6 shows the cumulative effective dose over a 10-year period by age groups. The cumulative effective dose increased for the case of deposition during the growing season of the crop. The type of food contributed to the ingestion dose appears differently depending on the deposition date. In this study, the harvest of vegetables was assumed to be on November 19. Therefore, the maximum ingestion dose was obtained for adults who have the largest vegetable intake among foodstuffs for the case of the deposition on November 19. For the one-year-old age group with the largest milk intake, the received ingestion dose reduced slightly for the case of deposition on November 2 owing to the decrease in the activity concentration of milk through the ingestion of clean pasture, whereas it increased slightly again for the deposition on November 18 because of the increased activity concentration of vegetables.

On the other hand, there was almost no difference in the cumulative effective ingestion dose for three years from that for ten years after deposition, regardless of the date of deposition. This result indicates that the whole life ingestion dose received as the consequence of a nuclear accident takes place mostly in the first three years following deposition.

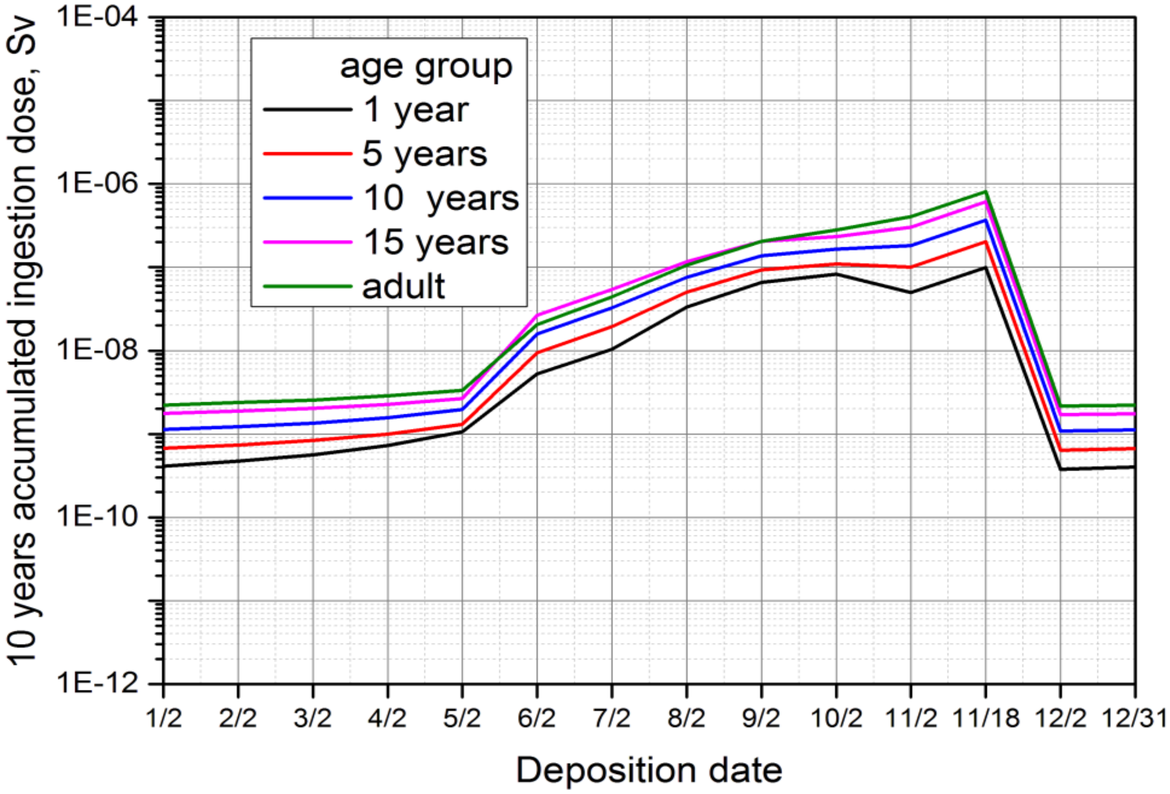

Figure 6 Cumulative effective ingestion doses for 10 years by age groups

3.3. Comparison with COMIDA

A model comparison was made between the present model [1] and COMIDA [3], although two models differ in the types of crops, growth characteristics, and the contamination pathways. The results for COMIDA were taken from the previous study [4], whereas the results for the present model were calculated using the data applied to the calculations of COMIDA.

Figure 7 shows a comparison of the effective ingestion dose for adults received for one year after deposition depending on the deposition dates. For the calculations, the growth periods of the crops were assumed to be from May 1 to September 30 irrespective of the crop type. In the case of pastures, the growth periods were assumed to be from April 15 to October 15, and the pastures were harvested three times from April 15 every two months until October 15. The calculated ingestion dose showed a similar trend between both models but it exhibited somewhat different values depending on the deposition dates. The ratio of calculated ingestion dose for COMIDA to that for the present model was 16.7, 11.3, 5.6, 2.1, 3.1, 1.5, 1.0, 4.1, and 41.5 for the case of deposition on March 1, March 17, April 25, May 19, June 24, July 24, August 31, October 7, and November 6, respectively. The relatively large difference for the non-growing season deposition can be explained by the fact that the ingestion of pasture was the main pathway for the contamination of cattle, and COMIDA considered the soil intake and direct ingestion of pasture during grazing.

On the other hand, the results obtained using default data of K-PUBDOSE showed a different tendency from those of COMIDA. The highest ingestion dose for K-PUBDOSE was obtained for the case of deposition on November 19, which is the harvest date of vegetables consumed by most adults (see also Figure 6). This result indicates that the growth period for the largest intake crop is a very important factor to determine the deposition date resulting in the highest ingestion dose for one year following deposition.

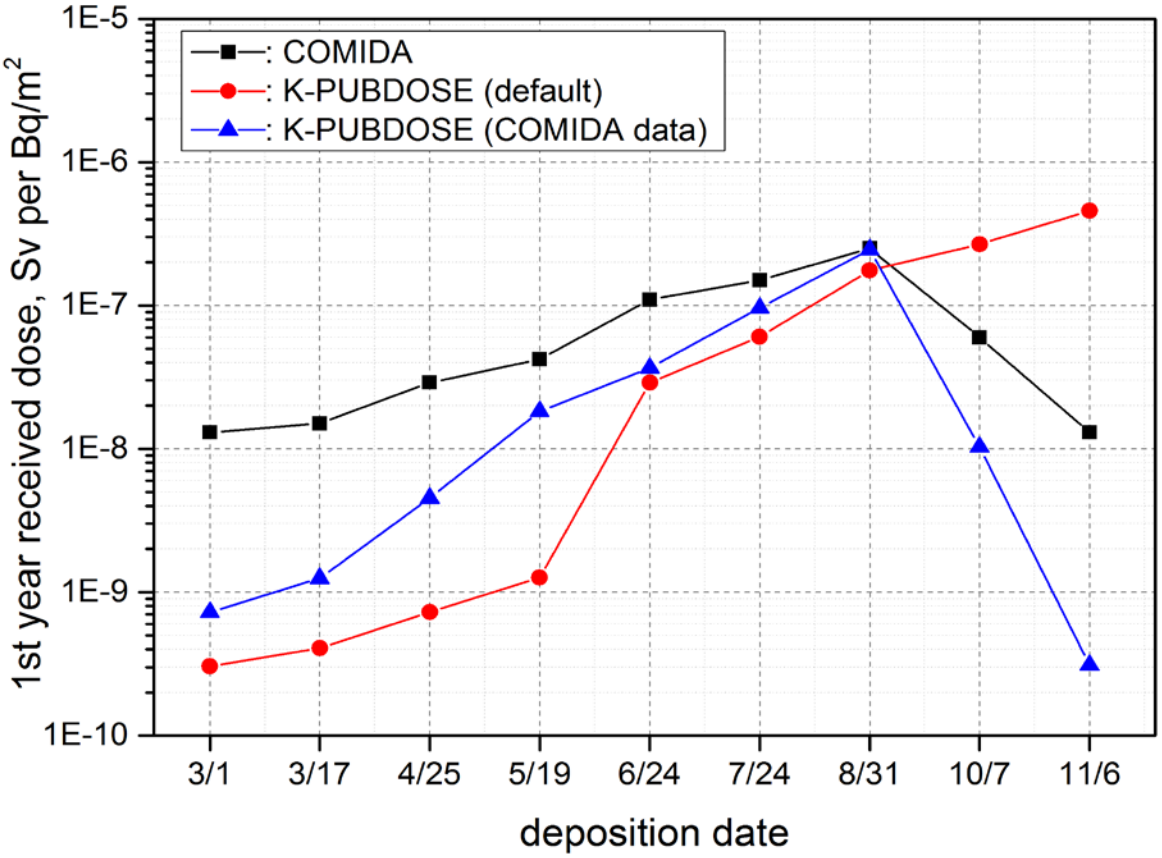

Figure 7 Comparison of the present model (K-PUBDOSE) with COMIDA

4. CONCLUSION

A food ingestion dose assessment model based on the farming characteristics of Korea has been developed for a Level 3 PSA. The model has the following characteristics: 1) Considering the flooded surface water on rice fields during the growth of rice, which is a staple crop in Korea, the effects of soil mixing by the irrigation water supply and plowing, and the shoot base absorption from the surface water is considered. 2) Considering a domestic stockbreeding environment, rice straw, pasture (raw materials of forage), and corn (source of concentrated feed) are considered as dominant feedstuffs for livestock. 3) To calculate the activity concentration of rice straw, rice is divided into rice straw and grain. 4) For corn, the corn stem can be used as a feed of livestock like rice straw (for this purpose, corn is separated into corn stem and grain). 5) For cereals, it is assumed that the root uptake takes place simultaneously through the plant body and edible part (grain), and for vegetables and pasture, root uptake only occurs through the inside of the crop. Finally, 6) the contamination effects of crops owing to the supply of contaminated irrigation water during crop cultivation are considered.

The result of application study showed that the present model can represent well the contamination characteristics of crops and the ingestion dose following a nuclear accident according to the deposition date. In conclusion, it is expected to be used effectively as an ingestion dose assessment model for the Korean agricultural contamination management system as well as the Level 3 PSA code, which is currently being developed**.**

Acknowledgments

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References

[1] D.K. Keum, I. Jun K.M. Lim Y.H. Choi, H.J. Jeong, J.E. Lee, H.S. Jeong, W.T. Hwang, and S.J. Han, “Model (K-PUBDOSE) to Evaluate the Ingestion Dose following a Nuclear Accident,” KAERI/TR-7181/2018, Korea Atomic Energy Research Institute (2018).

[2] D.K. Keum, H. Lee, H.J. Choi, H.S. Kang, K.M. Lim, Y.H. Choi, and C.W. Lee, “A Dynamic Compartment Model for Assessing the Transfer of Radionuclide Deposited onto Flooded Rice-Fields.” J. of Environmental Radioactivity. 76, pp349-367 (2004).

[3] M.L. Abbott and A.S. Rood, “COMIDA: A Radionuclide Food Chain Model for Acute Fallout Deposition,” Health Physics, 61(1), pp17-29 (1994).

[4] S.J. Han, M.H. Han, D.K. Keum, and S.C. Jang, “A Study on Dose Assessment System for Level 3 PSA,” KAERI/TR-5568/2014, Korea Atomic Energy Research Institute (2014).