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Predictive Contamination of Animal Products Due to the Inhalation of Air and the Ingestion of Soil of Cattle in an Accidental Release of Radioactive Materials - Focusing on Contaminative Influence of Milk

Won Tae HWANG†, Eun Han KIM, Kyung Suk SUH, Hyo Joon JEONG and Moon Hee HAN

*Nuclear Environment Research Division, Korea Atomic Energy Research Institute**

In an accidental release of radioactive materials to the environment, the contaminative influence of animal products due to the inhalation of air and the ingestion of soil of cattle, both of which are considered as minor contaminative pathways in most radioecological models but may be important ones, was investigated with the improvement of the Korean radioecological model DYNACON. Although mathematical models for both contaminative pathways have been established for considering all animal products and incorporated into the model, investigation was limited to milk. As a result, it was found that both pathways are influential in the contamination of milk during the non-grazing period of dairy cows. Precipitation was an influential factor in milk contamination due to the ingestion of soil, especially for ^{137}Cs. In the case of an accidental release during the grazing period of dairy cows, the contaminative influence due to the inhalation of air was negligible irrespective of the existence of precipitation during an accidental release.

KEYWORDS: Korean radioecological model, milk, inhalation of air, ingestion of soil

I. Introduction

Radioactive materials released into the environment during a nuclear accident can lead to the widespread contamination of agricultural ecosystems, and subsequently may cause significant radiation-induced health impacts to man through the ingestion of agricultural products. A number of mathematical models that simulate the transfer of radionuclides in agricultural ecosystems have been developed in accordance with their respective purposes. In such models, the behavior of radionuclides in the environment is described in terms of the transfers between compartments which represent different parts of the agricultural ecosystems. In the case of an accidental release of radioactive materials, the transfers of radionuclides between compartments have to be taken into account dynamically since radionuclide concentration in the compartments does not reach a steady-state in a short time for long-lived radionuclides[1]. We developed a Korean radioecological model DYNACON[2] to simulate dynamically radionuclide behavior in agricultural ecosystems as a module to evaluate the dose by ingestion of contaminated foodstuffs in a Korean real-time dose assessment system FADAS[3], which is a system to evaluate the comprehensive radiological consequences of an accidental release. In the initial version of DYNACON, one of the initial input variables to predict time-dependent radionuclide concentrations in agricultural products was radionuclide concentrations on the ground when deposition had taken place. Thereafter, the model has been improved so as to predict the contamination of agricultural products from radioactive concentrations in air as well as on the ground, both of which are measurable quantities in the environment, by incorporating it with the contaminative processes due to precipitation which may be encountered during an accidental release[4].

Animal products may be contaminated through not only the ingestion of feedstuffs but also the inhalation of air and the ingestion of soil. In most radioecological models, the former is considered as a major pathway in the contaminative contribution of animal products, while the latter may be considered as minor or negligible ones. In the present DYNACON, the contaminative pathway due to the ingestion of soil is considered by limiting the duration of the grazing season of cattle, and the contaminative pathway due to the inhalation of air is not considered. Both contaminative pathways are continuous events taking place over a whole year, therefore these should be carefully addressed in the case of an accidental release during the non-grazing season.

In this study, mathematical models to predict the contamination of animal products due to the inhalation of air and the ingestion of soil are described and incorporated into DYNACON. Predictive results obtained by the simulation using the improved model are investigated for milk as a function of radionuclides, existence of precipitation during an accidental release, and the season when an accidental release takes place.

II. Material and Methods

1. General Description of DYNACON

Radionuclides can reach humans from a great many potential exposure pathways in the environment. The

†Corresponding author, Tel. +82-42-868-2344, Fax. +82-42-868-2370, E-mail: wthwang@kaeri.re.kr

movement of radionuclides along a particular pathway can be envisioned as proceeding through a series of pathway steps. Each step or compartment of a pathway represents some physical entity or process by which radionuclides are received from a donor compartment. DYNACON is such a compartmental model, which describes radionuclide movements between the compartments by ordinary differential equations as follows :

$$\frac{dX_i}{dt}=\sum_{\substack{j=1\\j\neq i}}^{n}\lambda_{ji}X_j-X_i\sum_{j=1}^{n}\lambda_{ij}\,, \tag{1}$$

where X_i : radionuclide concentration in compartment i (Bq $\mathrm{kg^{-1}}$ or Bq $\mathrm{m^{-2}}$),

λ_{ij} : radionuclide transfer rate from compartment i to compartment j ($\mathrm{d^{-1}}$; d stands for day).

A number of site-specific parameter values are representative of the Korean agricultural and environmental conditions, and are dependent on radionuclides and plant species. Detailed mathematical formulations and relevant parameter values including the schematic diagram of DYNACON have been described well in a reference[2].

2. Predictive Contamination of Animal Products

Five kinds of animal products (milk, beef, pork, chicken, egg) are considered in DYNACON. Animal products may be contaminated through not only the ingestion of feedstuffs but also the ingestion of soil and the inhalation of air. In most radioecological models, the contaminative influence due to the latter is neglected as minor pathways or is partly considered. In DYNACON, a contaminative pathway due to the ingestion of soil is considered by limiting the duration of the grazing season for beef and dairy cows, and the contaminative pathway due to the inhalation of air is not considered. It is assumed that pigs and chickens are contaminated by the ingestion of only stored grains as feedstuffs. Radionuclide concentrations in animal products including the ingestion of soil and the inhalation of air can be estimated as follows :

$$\begin{aligned}C(t)&=C(t-\Delta t)e^{-(\lambda_d+\lambda_b)\Delta t}\\&+TF\left\{\left[X_A(t)+X_B(t)\right]F_v+X_c(t)\frac{F_s}{\rho_s L_s}\right\}\\&+BR\ TF\left[A(t=0)+X_C(t)RF\right],\end{aligned} \tag{2}$$

where $C(t)$: radionuclide concentration in animal products at time t (Bq dry-$\mathrm{kg^{-1}}$ or Bq $\mathrm{L^{-1}}$),

Δt : time interval for the calculation (=1 d),

λ_b : biological removal rate ($\mathrm{d^{-1}}$),

λ_d : radioactive decay constant ($\mathrm{d^{-1}}$),

TF : transfer rate of feed-animal products (d $\mathrm{kg^{-1}}$),

$A(t=0)$: average radioactive air concentration during an accidental release (Bq $\mathrm{m^{-3}}$),

$X_A(t)$: radioactive concentration on the outer tissue of feedstuffs (Bq dry-$\mathrm{kg^{-1}}$),

$X_B(t)$: radioactive concentration in the inner tissue of feedstuffs (Bq dry-$\mathrm{kg^{-1}}$),

$X_C(t)$: radionuclide concentration on the surface of the soil (Bq $\mathrm{m^{-2}}$),

RF : resuspension factor ($\mathrm{m^{-1}}$),

BR : breathing rate of cattle ($\mathrm{m^3\ d^{-1}}$),

F_v : feedstuffs ingestion rate of cattle (dry-kg $\mathrm{d^{-1}}$),

F_s : soil ingestion rate of cattle (dry-kg $\mathrm{d^{-1}}$),

ρ_s : density of the soil (dry-kg $\mathrm{m^{-3}}$),

L_s : depth of the surface soil (m).

The first term on the right hand side in Eq. (2) represents the contamination of animal products due to previous breeding practices. The second term including $X_A(t)$ and $X_B(t)$ and the third term represent the contamination due to the ingestion of feedstuffs and the ingestion of soil, respectively, from the present breeding practices. The forth and the last terms represent the contamination due to the inhalation of air during an accidental release and due to the inhalation of radioactive materials resuspended from the surface soil following release, respectively. It is assumed that radioactive contamination due to the ingestion of soil and the inhalation of air is a continuous event taking place over a whole year. Contaminative influence due to the inhalation of air and the ingestion of soil are not considered for chicken and pork, respectively, from the inherent breeding practices of the respective cattle and the subjective judgement of the authors which may be substantially negligible. **Table 1** shows the breathing rate and soil ingestion rate of cattle applied to this study[2,5], and the other characteristic variables of cattle have been described in a reference[2]. The time-dependent radionuclide concentrations in compartment i, $X_i(t)$ can be predicted from the numerical solutions using the ordinary differential equations as described in Eq. (1) and the respective initial conditions.

Table 1 Breathing rate and soil ingestion rate of cattle[2,5]

Cattle	Breathing rate of air ($\mathrm{m^3\ d^{-1}}$)	Ingestion rate of soil (kg $\mathrm{d^{-1}}$)
Beef cows	130	0.5
Dairy cows	170	0.5
Chicken	NG†	0.01
Pig	30	NG†

†NG : substantially negligible pathway

III. Results and Discussion

The contaminative influence of animal products due to the inhalation of air and the ingestion of soil was investigated with the improved DYNACON, which can predict time-dependent radionuclide concentration in animal products in accordance with the date or season when an accidental release takes place. In this study, predictive influence due to both contaminative pathways focused on milk, although the mathematical models have been established for other animal products and are incorporated in the previous model. Two different representative dates for accidental releases were selected to investigate the seasonality of the contaminative influence due to both pathways ; 15th August (227th in Julian day) as the growing season of the pasture (1st May ~ 31st October) and 15th March (74th in Julian day) as the non-growing season. It was assumed that the average radionuclide concentration in the air is 1 Bq m^{-3} during an accidental release irrespective of the existence of precipitation, and it is sustained for 24 hours. For the postulated accidental scenarios with precipitation, it was assumed that the precipitation rate of 0.1 mm hr^{-1} is sustained over a whole release period.

Figure 1 shows the radionuclide concentrations in milk for four different cases under the assumption that an accidental release has taken place in a specified non-growing season (15th March) with no precipitation.

Case 1 : predictive results using the previous model
Case 2 : predictive results by incorporating the contaminative pathway due to the inhalation of air into the previous model
Case 3 : predictive results by incorporating the contaminative pathway due to the ingestion of soil into the previous model
Case 4 : predictive results by incorporating the contaminative pathway due to the inhalation of air and the ingestion of soil into the previous model

After the first day of grazing, the long-lived radionuclide ^{137}Cs (radioactive half-life = 30 years) concentration increased for a certain period owing to an additional contaminative pathway, *i.e.*, ingestion of contaminated pasture. Contaminative influence due to the inhalation of air was greater than that of the ingestion of soil in the early days following an accidental release, but it declined rapidly with the lapse of time. Therefore, we can draw an inference that the influence due to the inhalation of resuspended radionuclides is a relatively minor contributor in radioactive contamination. Except for the early days following an accidental release, the ingestion of soil was an important contaminative pathway over a long period of time. In the meantime, for the short-lived radionuclide ^{131}I (radioactive half-life = 8 d), the ingestion of soil was a dominant contaminative pathway until the first day of grazing. It was more distinct than the predicted results for ^{137}Cs. It is because the elemental iodine considered in this study is approximately ten times as high as the aerosol particulate ^{137}Cs for dry deposition velocity[4].

Figure 2 shows the radionuclide concentrations in milk for the same cases as in Fig. 1, but with precipitation. Compared with the predictive results of Fig. 1, the contaminative influence of ^{137}Cs due to the ingestion of soil was more distinct because of a greater deposition caused by

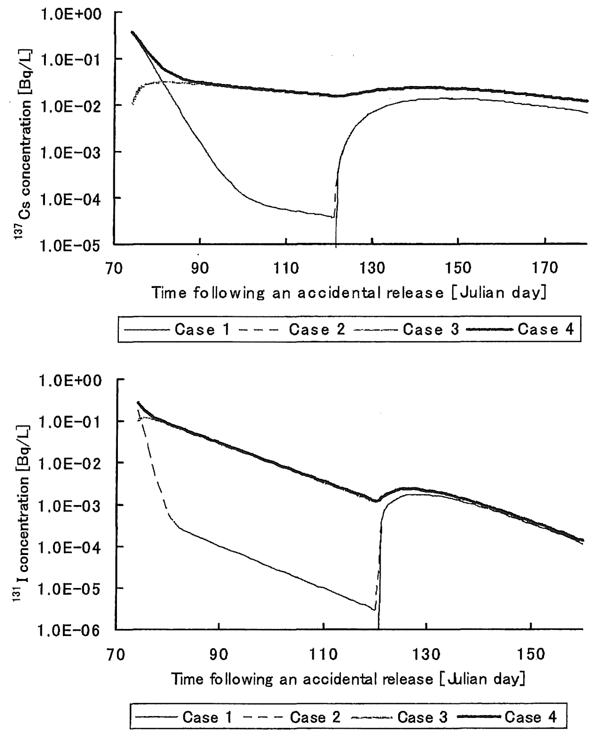

Fig. 1 Radionuclide concentrations in milk for four different cases under the assumption that an accidental release has taken place in a specified non-growing season with no precipitation

precipitation. Therefore, the ingestion of soil was a dominant pathway in milk contamination over most of the period until the first day of grazing. In the meantime, precipitation was no longer an influential factor in ^{131}I contamination. It is because the ratio of wet deposition to dry deposition of ^{131}I is lower by far than that of ^{137}Cs. For example, wet deposition velocity of ^{137}Cs for precipitation of 0.1 mm hr^{-1} is approximately twenty times as high as the dry deposition velocity, while it is nearly the same for ^{131}I. The lesser influence of ^{131}I contamination for precipitation has also been found in a reference[4].

Figure 3 shows the radionuclide concentrations in milk for two different cases under the assumption that an accidental release has taken place in a specified growing season with no precipitation.

Case 1 : predictive results using the previous model
Case 2 : predictive results by incorporating the contaminative pathway due to inhalation of air into the previous model

Unlike in Figs. 1 and 2, the predictive results between Case 1 and Case 2 were nearly the same. It means that the contaminative influence due to the inhalation of air is negligible for the total contamination of milk. Similar results were found for the same accidental scenario as in Fig. 3, but with precipitation.

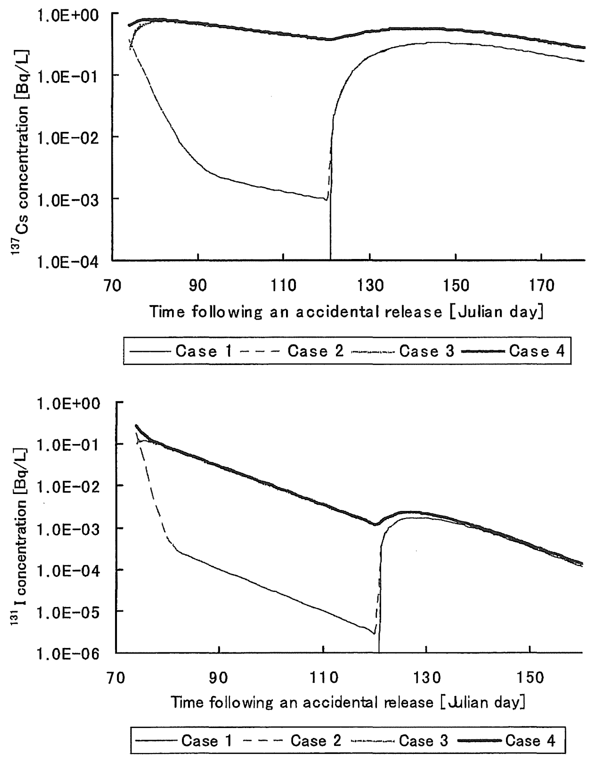

Fig. 2 Radionuclide concentrations in milk for the same cases as in Fig. 1, but with precipitation of 0.1 mm hr^{-1}

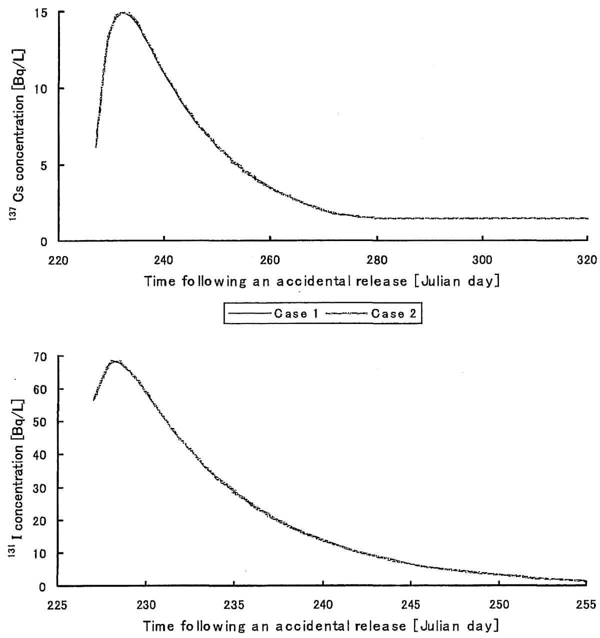

Fig. 3 Radionuclide concentrations in milk for two different cases under the assumption that an accidental release has taken place in a specified growing season with no precipitation ; the difference of predictive results from both cases is very small

Ⅳ. Conclusions

The contaminative influence of animal products due to the inhalation of air and the ingestion of soil of cattle in an accidental release of radioactive materials to the environment was investigated with the improvement of the Korean radioecological model DYNACON.

As a result, it was found that both pathways are influential in the contamination of milk in the case of an accidental release during the non-grazing period of dairy cows. Precipitation was an influential factor in milk contamination due to the ingestion of soil, its influence was stronger for the long-lived radionuclide ^{137}Cs than for the short-lived radionuclide ^{131}I. In the case of an accidental release during the grazing period of dairy cows, the contaminative influence due to the inhalation of air was negligible irrespective of the existence of precipitation during an accidental release. Depending on the radionuclides and the season when an accidental release takes place, the different influences of both contaminative pathways originates from the breeding and metabolism characteristics of the dairy cows, and the different behaviors of the radionuclides according to the environmental characteristics.

It should be kept in mind that the investigation of predictive results is limited to milk and to the postulated accidental scenarios. Nevertheless, this study will serve not only for a higher reliability in predictive results but also a better understanding of the contamination pathways.

References

1) R. E. Faw and J. K. Shultis, "Radiological assessment ; source and exposures", PTR Prentice-Hall, Englewood Cliffs, New Jersey, 523 (1993).
2) W. T. Hwang, G. S. Cho and M. H. Han, "Development of a Dynamic food chain model DYNACON and its application to Korean agricultural conditions", Journal of Nuclear Science and Technology, 35[6], 454 (1998).
3) M. H. Han, et al., Development of environmental radiation protection technology : development of radiological emergency preparedness and biological dosimetry technology, KAERI/RR-1913/98, Korea Atomic Energy Research Institute (KAERI), (1998), [in Korean].
4) W. T. Hwang, et. al, "Influence of predictive contamination to agricultural products due to dry and wet processes during an accidental release of radionuclides", Annals of Nuclear Energy, 30[14], 1457 (2003).
5) S-R. Peterson, Model description of CHERPAC (Chalk River environmental research pathways analysis code) ; results of testing with post-Chernobyl data from Finland, AECL-11089, Atomic Energy of Canada Limited (AECL) (1994).