Development of An Ingestion Pathways Model For Consequence Analysis Using System Dynamics

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1. Introduction

Contamination of agricultural products by radioactive materials has a mechanism, which causes exposures of the population following the deposition of radioactive materials in environment. Several studies regarding continuous release from nuclear power plants and the subsequent food contamination have been reported. Equilibrium is assumed to be eventually reached between the release rate and the radioactivity concentrations in the compartments of the environment. However, the equilibrium model is not suitable for describing the behavior of radioactive effluents following accidents of nuclear power plant. Radioactivity concentrations in foodstuffs and feedstuffs after an accident are assumed to vary with respect to time. Therefore, dynamic models based on the system analysis method have been developed in order to investigate the transfer of radionuclides in the food-chain model realistically [1].

2. Model and Results

2.1 System Dynamics

A system approach is very useful to conceptualize a comprehensive understanding and explanation of human interactions and complicated phenomena. First, the system dynamics approach methodologically includes a dynamic behavior approach which ensures a causal relationship for structuring the elementary feedback loops. Secondary the system dynamics approach is useful for analyzing the phenomenon of the complex system as well as the behavior of structure value with respect to time. System dynamics focus on a pattern of system behavior based on time dependency and dynamic behavior. System dynamics concentrates on analyzing the change, development, progress, or decline of systems with practical aspects [2].

2.2 Transport Mechanism

Transport mechanism is simulated both discrete events and continuous processes. Discrete events include fallout deposition, soil tillage, crop harvest, and livestock diet changes. Continuous processes include resuspension and rainsplash of contaminated soil to plant surfaces, weathering and senescence of radionuclides from plants to soil, percolation and leaching of radionuclides down through the soil profile, adsorption and desorption of radionuclides within the soil, uptake of radioactivity by roots, absorption of surficial radioactivity by plant tissues, ingestion and excretion of plant or soil-bound contamination by animals, and radioactive decay. Continuous processes are represented by ordinary first order differential equations. The time derivative of the radionuclide quantity in compartment may be generally stated as

$$Q_h' = \sum_{i=1}^{n} R_{in,i} - \sum_{j=1}^{m} R_{out,j} \qquad (1)$$

$R_{in,i}$ = ith inflow rate to compartment h

$R_{out,j}$ = jth inflow rate to compartment h

A differential equation of this form is written for each compartment. The resulting set of coupled differential equation is then solved numerically on daily time steps using an algorithm to yield time-dependent inventories for each compartment. Inventories are converted to concentration units for subsequent calculations of human intake and dose [3].

2.3 The Model of Dynamic Ingestion

The transfer kinetic of radionuclides is described by set of linear first-order differential equations. Each equation corresponding to each compartment, which represents an environment element, described the change of the radioactivity concentration with time base on the mass balance.

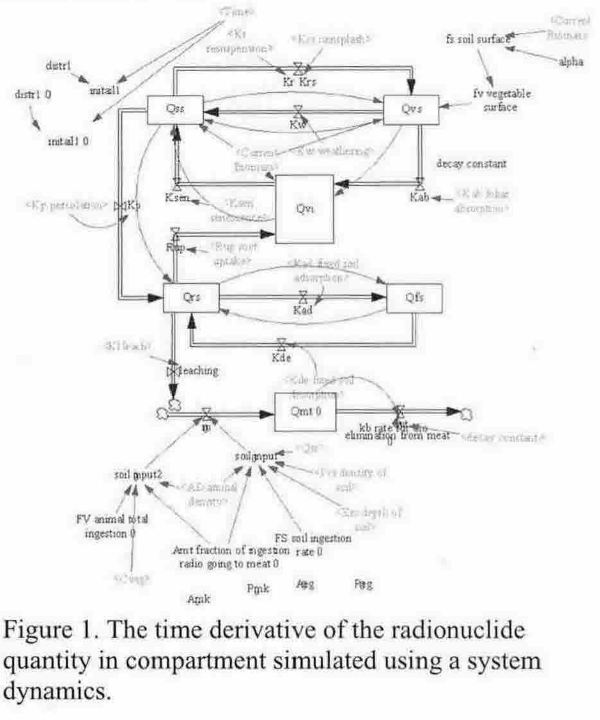

Figure 1. The time derivative of the radionuclide quantity in compartment simulated using a system dynamics.

The system dynamics method is useful for the changes over time in radionuclides behavior. The established compartment scheme model and the transfer mechanisms of radionuclide are shown in Fig. 1. The radionuclide concentrations in foodstuffs are calculated from time dependent inventory (Q_i). A model of compartment in foodstuffs is shown in Fig. 2.

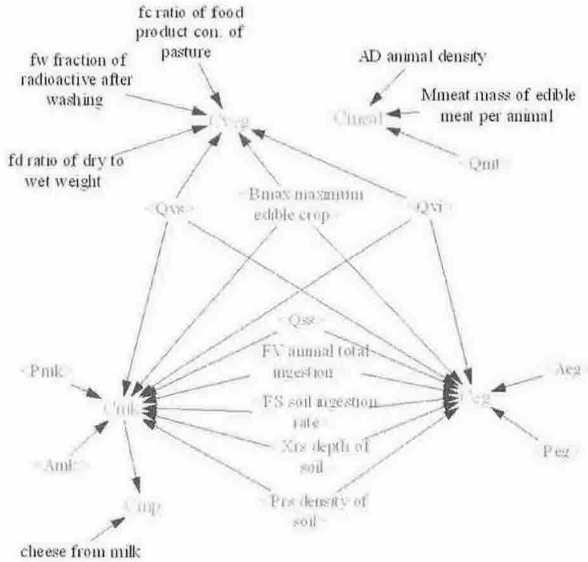

Figure 2. Radionuclide concentrations in foodstuffs

2.4 Sample Calculations

The sample calculations were performed in order to evaluate the transfer of radionuclides through the food-chain model after deposition of unit Becquerel per area. The time-specific and time-integration concentrations of radionuclides in foods per unit fallout deposition vary by radionuclides, timing of deposition. Differences among radionuclides relate primarily to physical half-life and physiological mobility. Physical persistence permits the various transport pathways time to function and the time-integrated concentration reflect this [4].

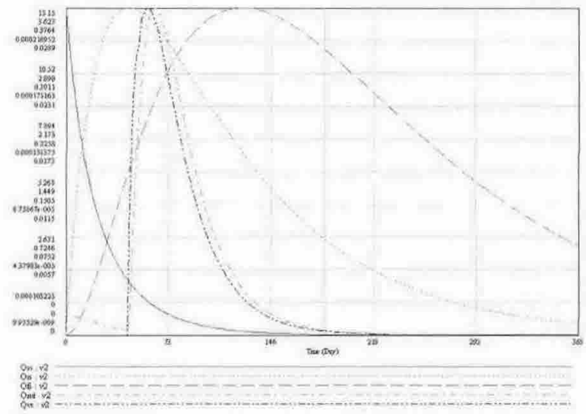
Figure 3. Inventory of compartment soil surface, vegetation surface, fixed soil, meat (Unit: Bq m^{-2})

Selected radionuclides were Cs-137 which used to contribute significantly to the ingestion doses in the case of nuclear accident. Fig. 3 shows the variation of specific activities of Cs-137 for each compartment. During the pasture growth season, the model results are shown in Fig. 4.

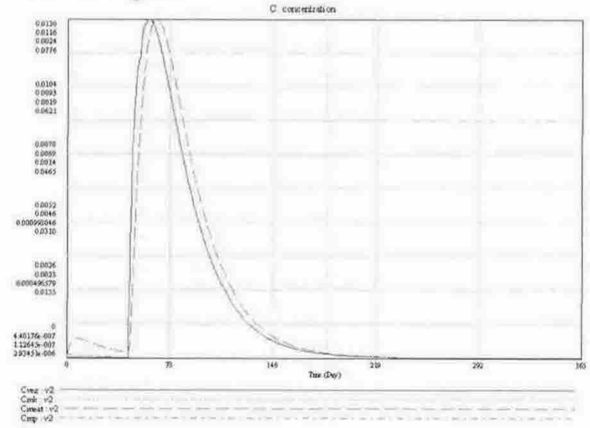
Figure 4. Time-integrated concentrations of radionuclides in foodstuffs (Unit: Bq kg^{-1})

3. Conclusion

Since the ingestion doses are very important in the consequence analysis associated with long-term exposures, it is necessary that that dynamic behaviors of radioactive nuclides released in an accident of nuclear power plant should be analyzed following accidents in the site-specific environment. In this study, a dynamic model for ingestion pathway has been developed in order to consider several agricultural practices, and food consumption behavior, etc. It is shown that the dynamic radiological model can be used as a tool for comprehensive ingestion dose assessment during accidental release of radionuclides.

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