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# Comparative Study Between a Dynamic Food-Chain Model (DYNACON) and an Equilibrium Model (NRC Model)

Won-Tae Hwang, Kyung-Suk Suh, Eun-Han Kim, Young-Gil Choi, Moon-Hee Han,
Korea Atomic Energy Research Institute

Gyuseong Cho
Korea Advanced Institute of Science and Technology

## Abstract

The predictive results between a dynamic food-chain model (DYNACON) and an equilibrium model (NRC model) were compared to show the physical validity of DYNACON. Although the mathematical formulations and transport processes of radionuclides in the environment are different between two models, the comparative study shows good agreement for deposition events that occur during the growing season of plants.

## I. Introduction

The deposition of radionuclides in agricultural environment may be a significant exposure pathway to human via ingestion of contaminated crops and animal products. It may result from routine or accidental releases of radionuclides from nuclear facilities as well as from nuclear explosions. Equilibrium models applicable to routine releases, such as NRC (U. S. Nuclear Regulatory Commission) model based on Regulatory Guide 1.109 [1], describe steady-state radionuclide concentrations in each environmental compartment. However these models are not suitable for describing of short-term radionuclide releases characterized by large variation of radionuclide concentrations in each compartment with the date of deposition and time following deposition. Therefore, we have developed a dynamic model DYNACON (new version of KORFOOD [2]) to estimate radionuclide concentrations in agricultural food chains following short-term depositions of radionuclides. The site-specific parameters of the model are representatives of agricultural conditions in Korean environment.

The most existing dynamic models, such as ECOSYS-87 [3], PATHWAY [4], COMIDA [5], were verified by the comparative study between predictive results of the models and measured data after Chernobyl accident. But in case of DYNACON, it is almost impossible to make a comparison study using Chernobyl data collected in Korea. Therefore, the comparative study between DYNACON and NRC model has been made to show the physical validity of DYNACON.

## II. General Description of DYNACON and NRC model

In DYNACON, the ecological system consists of a set of interconnected compartments representing various environmental elements. The radionuclide concentration in each compartment is described by a set of first-order linear differential equations [2].

$$\frac{dC_i}{dt} = \sum_{\substack{j=1 \\ j\neq i}}^{K} r_{ji}\, C_i - C_i \sum_{\substack{j=1 \\ j\neq i}}^{K} r_{ij} \tag{1}$$

where,

$K$ = number of compartments

$C_i$ = radionuclide concentration in compartment $i$

$r_{ij}$ = a set of rate-constants

Dynamic processes in the model include foliar interception, weathering, translocation, plant growth, root uptake, harvest, soil resuspension, percolation, leaching, radioactive decay, soil ingestion of animals, absorption and excretion of animals. The radionuclide concentrations in vegetables are numerically calculated using GEAR method.

NRC model which is based on Regulatory Guide 1.109 is a typical steady-state or equilibrium model. The radionuclide concentrations in vegetables are estimated from the following analytic solution [1].

$$C_v = d \left\{ \frac{r\,[1-e^{-(\lambda_d+\lambda_w)\,t_e}]}{Y\,\lambda_e} + \frac{B_v\,[1-e^{-\lambda_d\,t_b}]}{p\,\lambda_d} \right\} e^{-\lambda_d\,t_h} \tag{2}$$

where,

$C_v$ = radionuclide concentration in vegetable [ $Bq/kg$]

$d$ = average deposition rate [ $Bq/(m^2 \cdot day)$]

$r$ = fraction of deposited activity retained on vegetable

$Y$ = yield of vegetable [ $kg/m^2$]

$t_e$ = length of time that vegetable is exposured to contaminated air [ $day$]

$t_h$ = length of time between harvest and consumption [ $day$]

$\lambda_w$ = environmental loss constant for removal of radionuclides from surface of vegetable [ $day^{-1}$]

$\lambda_d$ = decay constant of radionuclide

$B_v$ = vegetable/soil concentration ratio

$t_b$ = length of time that soil is exposured to contaminated air [ $yr$]

$p$ = effective surface density of soil [ $kg/m^2$]

The radionuclide concentration in milk is calculated as the following equation [1].

$$C_m = F_m Q_p C_v \tag{3}$$

where,

$C_m$ : radionuclide concentration in milk $[Bq/L]$

$F_m$ : transfer factor from feed into milk $[day/L]$

$Q_p$ : amount of feeds consumed by dairy cattle $[kg/day]$

## III. Comparative Study

The predictive results between DYNACON and NRC model were compared. The radionuclide concentrations in grain (typically barley) and milk were estimated using two models for Cs-137 and Sr-90. NRC model is based on radionuclide concentrations in foods for a unit deposition rate from a steady-state release, while DYNACON is based on a unit acute deposition. To compare the results of two models, the radionuclide concentration calculated from DYNACON should be integrated to infinity [6]. The radionuclide concentrations in foods calculated from DYNACON were integrated for 100 years. These take into account about 90% of the Cs-137 and Sr-90 concentration in foods [5]. The input values of DYNACON were applied to NRC model. Time-integrated concentrations were calculated with DYNACON for the dates of deposition occurring each month of the year. Since the results of NRC model were obtained using input values of growing season (*e.g.*, $r/Y > 0$), outputs from DYNACON are only compared for deposition that occur during the growing season (grain : 1 January to 31 May, pasture : 1 May to 30 September).

The radionuclide concentrations in grain for Cs-137 and Sr-90 calculated from two models are shown in Fig. 1 and Fig. 2, respectively. The results of DYNACON show a strong seasonal dependence relative to the date of deposition. The maximum Cs-137 and Sr-90 concentrations calculated from DYNACON were about 4 times and 7 times lower than those from NRC model, respectively. These can be explained by the following major reasons.

(1) In case of NRC model, the amount of radionuclide deposited on plant surfaces at maximum yield of plant contributes totally to the contamination of edible parts.

(2) In case of DYNACON, the radionuclides deposited on plant surfaces contaminate edible parts through translocation process.

Fig. 3 and Fig. 4 show the radionuclide concentrations in milk estimated from two models for Cs-137 and Sr-90, respectively. During the growing season of pasture, the results of DYNACON are very similar to those of NRC model within 5 times at maximum. Unlike grain, the results of DYNACON were slightly higher in some dates of deposition during the growing season of pasture because of the difference of contamination sources considered between the two models for milk. The following contamination sources for milk are considered in DYNACON.

(1) contamination of plant surfaces

(2) soil ingestion of dairy cattle

(3) contamination of inner tissues through translocation process and root uptake

The agreement between DYNACON and NRC model within one order of magnitude is not surprising because of the difference of mathematical formulations, transport processes considered, and purposes of models. Considering the magnitude of uncertainty to be expected in the results of complex food chain models as well as in real world system, the differences between predictive results do not unduly large.

## IV. Conclusions

The predictive results between DYNACON and NRC model were compared to show the physical validity of DYNACON. Although the mathematical formulations and transport processes of radionuclides in the environment are different between two models, the predictive results show good agreement within one order of magnitude for deposition events that occur during the growing season of plants. DYNACON may be used for providing useful information to decide protective measures after the contamination of soil and foods by radioactive materials.

## References

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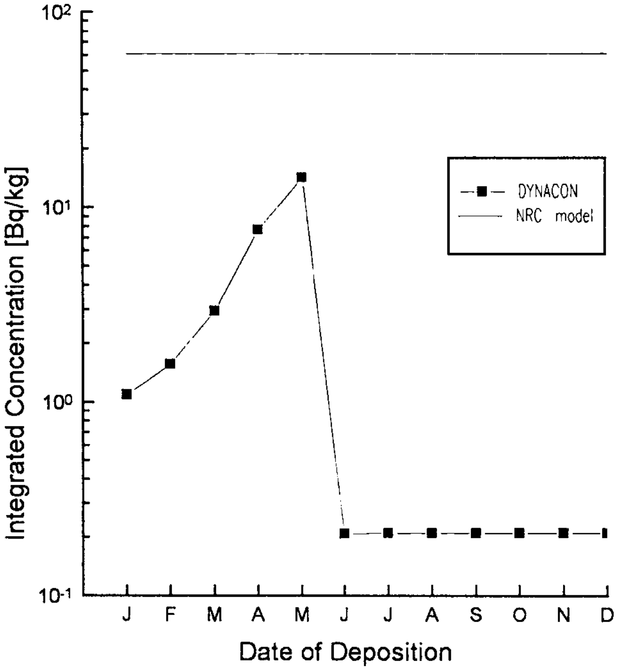

Fig. 1. The radionuclide concentrations in grain calculated from DYNACON and NRC model for Cs-137

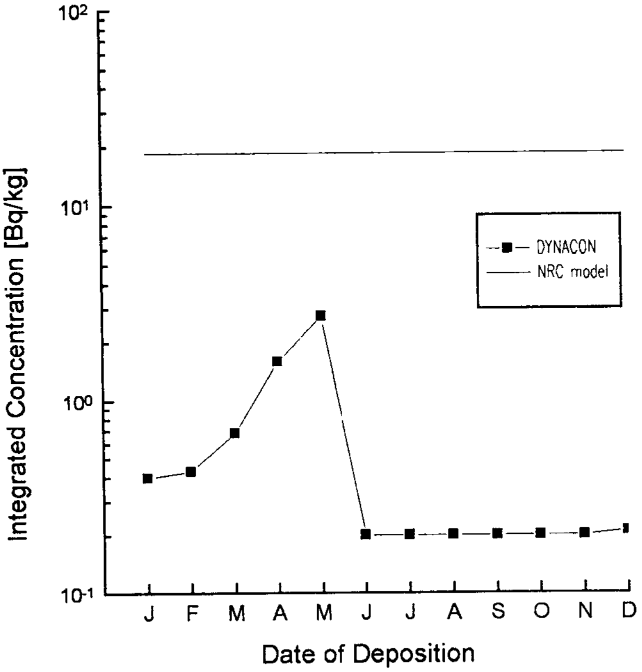

Fig. 2. The radionuclide concentrations in grain calculated from DYNACON and NRC model for Sr-90

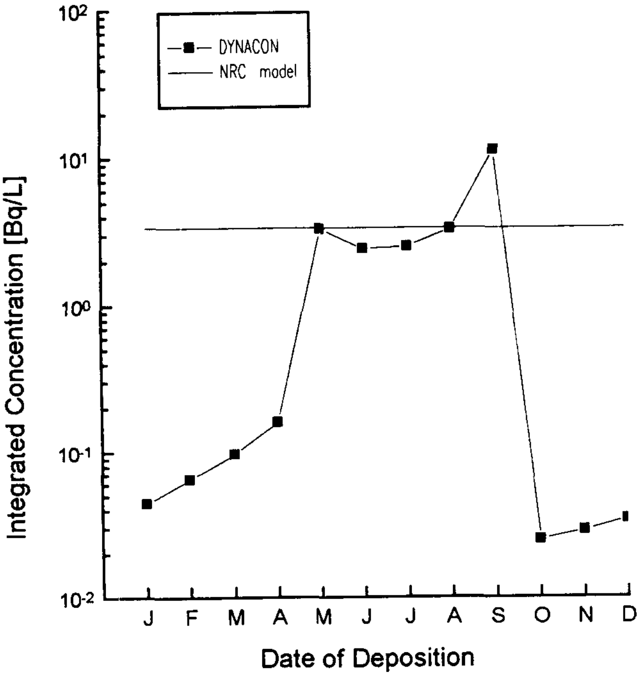

Fig. 3. The radionuclide concentrations in milk calculated from DYNACON and NRC model for Cs-137

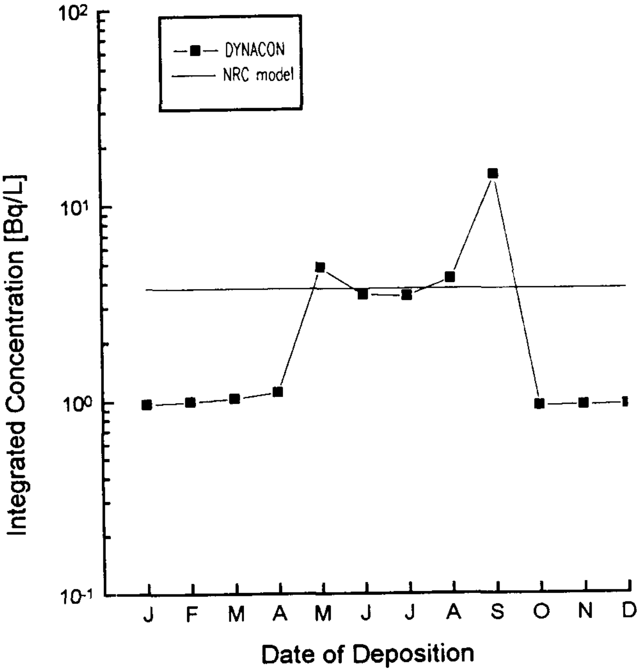

Fig. 4. The radionuclide concentrations in milk calculated from DYNACON and NRC model for Sr-90