Development of foodchain model for estimating radionuclide concentration in marine organisms following nuclear accident

Sora Kim, Byung-Il Min, Kihyun Park, Jiyoon Kim, Kyung-Suk Suh*

Nuclear Environmental Safety Research Division, Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea

Introduction

Developing technology for estimating the long-term behavior of radionuclides in the environment is essential to assess the long-term impacts of accidental releases on humans and environment. There have been cases of ocean contamination by radioactive materials released by nuclear accidents such as Chernobyl and Fukushima Nuclear Power Plant (NPP) accidents. In the long-term, it is important to evaluate the impact of the accidental radioactive contamination of the marine environment.

A foodchain model named LARIAS (Land and Aquatic Radionuclide transport and Ingestion dose Assessment System) is under development for estimating radionuclide transfer through the terrestrial and aquatic foodchain and ingestion doses in Korea following a nuclear accident. The terrestrial and freshwater (lake and river) foodchain models [1-2] have already been developed as a part of LARIAS. Currently, a marine foodchain model was developed to evaluate radionuclide concentrations in marine organisms and the exposure dose due to ingestion.

Model description

Outline of model

The model is based on a dynamic compartment model and developed to reflect Korean dietary habits. It calculates the radionuclide transfer through the marine foodchain and ingestion doses following accidental releases of radionuclides into the ocean. The model considers four groups of marine organisms as follows: phytoplankton, zooplankton, prey fish, and predatory fish.

The radionuclide concentrations of seawater over time are used as source-term data. As shown in Figure 1, the foodchain model contains six compartments: water, sediment, and four marine organism groups.

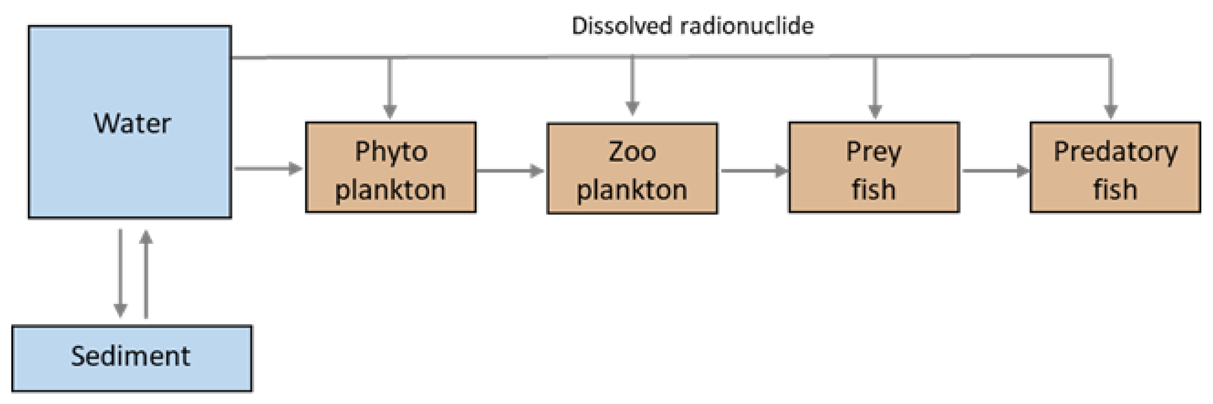


Fig. 1. Schematic outline of dynamic compartment model for marine foodchain

Basic equations of model

Equation (1) ~ (4) represent the change of radionuclide concentration in four compartments over time. The radionuclide concentration in seawater was configured to be entered for the entire evaluation period in units of a day. The radioactivity transfer for compartments is dynamically modeled by a first-order differential equation using rate constant. Radioactive decay is considered in all compartments.

Phytoplankton (C_{phy}):

$$\frac{dC_{phy}}{dt} = (K_{w0}R_{w_{up0}})C_{wat} - (\lambda_{bio0} + \lambda_{rad})C_{phy} \quad (1)$$

Zooplankton (C_{zoo}):

$$\frac{dC_{zoo}}{dt} = (K_{w1}R_{w_{up1}})C_{wat} + (K_{f1}R_{f_{up1}})(C_{phy}\frac{dwf_{zoo}}{dwf_{phy}}) - (\lambda_{bio1} + \lambda_{rad})C_{zoo} \quad (2)$$

Prey fish (C_{prey}):

$$\frac{dC_{prey}}{dt} = (K_{w2}R_{w_{up2}})C_{wat} + (K_{f2}R_{f_{up2}})(C_{zoo}\frac{dwf_{prey}}{dwf_{zoo}}) - (\lambda_{bio2} + \lambda_{rad})C_{prey} \quad (3)$$

Predatory fish (C_{pred}):

$$\frac{dC_{pred}}{dt} = (K_{w3}R_{w_{up3}})C_{wat} + (K_{f3}R_{f_{up3}})(C_{prey}\frac{dwf_{pred}}{dwf_{prey}}) - (\lambda_{bio3} + \lambda_{rad})C_{pred} \quad (4)$$

C: radionuclide concentration in each compartment (Bq/kg)

K_W: ratio of radionuclide absorbed from ingested water to each organism group (no-dimension); (0 ~ 3 for phytoplankton, zooplankton, prey fish, and predatory fish)

R_W: water uptake rate of each organism group (m^3/kg·d)

K_f: ratio of radionuclide absorbed from ingested food to each organism group (no-dimension)

R_f: food uptake rate of each organism group (kg/kg·d)

λ_{bio}: biological loss rate of each organism group (d^{-1})

λ_{rad}: radioactive decay constant (d^{-1})

dwf: dry weight fraction of organism (no-dimension)

Input parameters

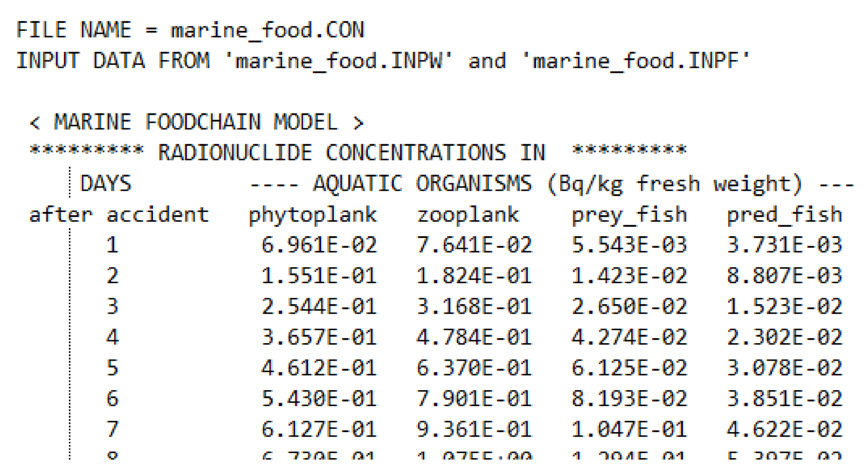
Input parameters on marine organism groups were referred to Maderich et al. (2014) [3]. Korean-specific dietary habit data for marine food were used the average value of food supply per person per day for 2010-2018 in 2018 Food balance sheet of Korea Rural Economic Institute (KREI) [4]. Ingestion dose coefficients for adults were taken from International Commission on Radiological Protection (ICRP) Publication 72 (ICRP, 1996) [5].

Code System

Our code system was written in C language. The fourth-order Runge-Kutta method was applied to the numerical integration of ordinary differential equations. The code is composed of files as shown in Table I. Figure 2 shows the example of output file (CON file).

Table I: Input and output files

	Files	Contents
Input	INPF file	Data related to marine foodchain
	INPW file	Data related to calculation period and radionuclide concentration in sea water
Output	CON file	Results of radionuclide concentration in marine organism groups
	OUT file	Results of exposure dose from ingestion of marine food



```
FILE NAME = marine_food.CON
INPUT DATA FROM 'marine_food.INPW' and 'marine_food.INPF'

 < MARINE FOODCHAIN MODEL >
 ********* RADIONUCLIDE CONCENTRATIONS IN  *********
    DAYS         ---- AQUATIC ORGANISMS (Bq/kg fresh weight) ---
 after accident   phytoplank   zooplank    prey_fish   pred_fish
       1           6.961E-02   7.641E-02   5.543E-03   3.731E-03
       2           1.551E-01   1.824E-01   1.423E-02   8.807E-03
       3           2.544E-01   3.168E-01   2.650E-02   1.523E-02
       4           3.657E-01   4.784E-01   4.274E-02   2.302E-02
       5           4.612E-01   6.370E-01   6.125E-02   3.078E-02
       6           5.430E-01   7.901E-01   8.193E-02   3.851E-02
       7           6.127E-01   9.361E-01   1.047E-01   4.622E-02
```

Fig. 2. Example of output file (CON file)

Conclusions

The marine foodchain model was recently developed to evaluate radionuclide transfer through the marine organisms and the resulting ingestion doses under the Korean dietary habit following accidental releases. We will conduct comparative analysis studies with observation data and the calculation results of other models as further research. The developed model will be used as a tool to calculate contaminated levels of marine organisms and ingestion doses for an accidental releases.

References

[1] S.R. Kim, B.I. Min, K.H. Park, B.M. Yang, J.Y. Kim, K.S. Suh, Evaluation of radionuclide concentration in agricultural food produced in Fukushima prefecture following Fukushima accident using a terrestrial food chain model. Journal of Radioanalytical and Nuclear Chemistry. 316, 1091–1098 (2018).

[2] S.R. Kim, K.S. Suh, B.I. Min, K.H. Park, B.M. Yang, J.Y. Kim, Development of freshwater foodchain model for estimating radionuclide concentration in aquatic products following nuclear accident, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 22-24, (2019).

[3] V. Maderich, R. Bezhenar. R. Heling, G. de With, K.T. Jung, J.G. Myoung, Y.-K. Cho, F. Qiao, L. Robertson, Regional long-term model of radioactivity dispersion and fate in the Northwestern Pacific and adjacent seas: application to the Fukushima Dai-ichi accident, Journal of Environmental Radioactivity 131, 4-18 (2014).

[4] Korea Rural Economic Institute, 2018 Food balance sheet, (2019).

[5] International Commission on Radiological Protection, Age-dependent doses to members of the public from intake of radionuclides: part 5. Compilation of ingestion and inhalation dose coefficients. ICRP Publication 72. ICRP, Pergamon Press, Oxford (1996).

KAERI 한국원자력연구원 Korea Atomic Energy Research Institute

ACKNOWLEGEMENT

This work was supported by the National Research Foundation of Korea (NRF) and funded by the Korean government (MSIP) (MSIP: NRF-2017M2A8A4015253, NRF-2020M2C9A1061641).