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Radiation Dose Assessment Model for Marine Biota (K-BIOTA-DYN-M)

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1. Introduction

A dose assessment of non-human biota is used to investigate if an ecosystem is safe from the radiation risk of radioactivity released into the environment by an accident or during normal operation of a nuclear facility. For the case of an emergency exposure situation such as a nuclear accident, the dynamic model is suitable for considering the temporal change in the activity concentration of an environmental medium. In this study, a dynamic compartment model based on the food chain of marine biota, which can be used with easily obtainable ecological parameters, is presented to predict the activity concentration and dose rate of marine biota as a result of a nuclear. The model was applied to investigate a long-term effect of the Fukushima accident on the marine biota by using ^{131}I, ^{134}Cs, and ^{137}Cs activity concentrations of seawater measured for up to about 2.5years after the accident in the port of FDNPS, which was known to be the most severely contaminated.

2. Methods

2.1 Model

The K-BOTA-DYN-M is a dynamic compartment model to assess the activity concentration and whole body dose rate of marine biota when the seawater activity concentration varies with time, likely for the early phase after an accident. The model consists of seven marine biota compartments including phytoplankton, zooplankton, prey fish, benthic fish, crustacean, mollusk, and macroalgae, and one sediment compartment (Fig 1). Phytoplankton is assumed to be instantaneously in equilibrium with seawater because their amount exists exorbitantly, and thus the activity concentration of phytoplankton is estimated using the equilibrium concentration ratio (CR). The other biota intake the radioactivity from both water and diet, and simultaneously lose the radioactivity through the biological elimination and radioactivity decay. Details of the mode are given elsewhere [1]

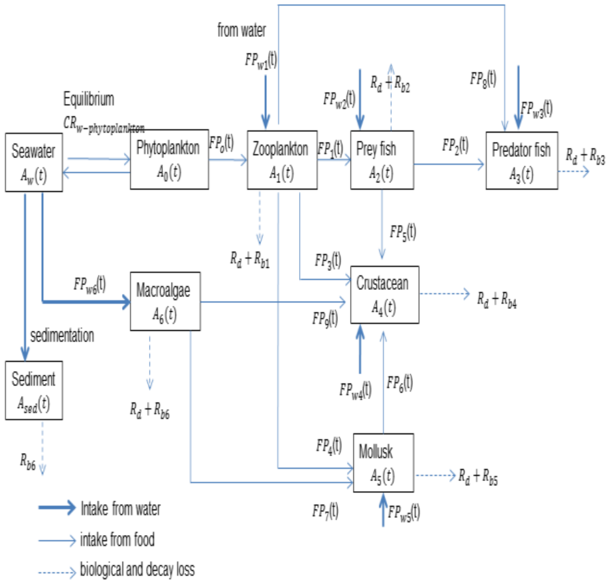

Fig. 1. Conceptual diagram of K-BIOTA-DYN-M

2.2 Sedimentation process

The activity concentration of sediment (A_{sed})(Bq/kg dry) is estimated by the first order kinetic model for the sedimentation.

$$\frac{dA_{sed}}{dt} = k_{sed}\frac{d_w}{d_{sed}\rho_p}\left(A_w - \frac{A_{sed}}{K_d}\right) - R_d A_{sed} \quad (1)$$

where k_{sed} (d^{-1}) is the sedimentation rate constant, d_w (m) is the seawater depth, d_{sed} (m) is the sediment depth, ρ_p (kg dry/l) is the sediment density, and K_d (l/kg dry) is the equilibrium distribution coefficient of radionuclide between seawater and sediment.

3. Application

3.1 Seawater activity concentration

For a long-term prediction, the activity concentration of ^{131}I, ^{134}Cs, and ^{137}Cs in seawater sampled for up to about 2.5 years after the accident on March 11, 2011 at two locations in the port of FDNPS were taken from a publicly open web site [2], and are plotted in Fig 2. The sampling locations of seawater are at 30m north of the Unit 5-6 discharge channel of FDNPS (S1), and at

330m south of the Unit 1&2 discharge channel of FDNPS (S2).

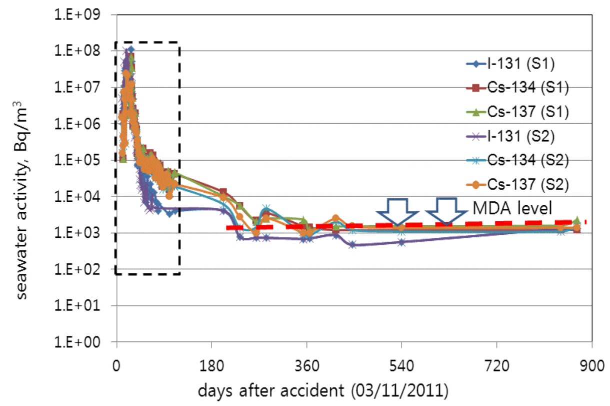

Fig. 2. Observed seawater activity concentration

3.2 Sediment activity concentration

Fig 3 shows the predicted sediment activity concentrations and their comparison with the observed sediment activity concentrations for cesium. The present kinetic model for the sedimentation predicted the observed data well, when the value of the sedimentation rate constant (k_{sed}) is about 1.E-5d^{-1}, which leads to the lumped parameter ($\frac{k_{sed} d_w}{d_{sed} \rho_p}$) value of 1.7E-3 lkg^{-1}d^{-1}

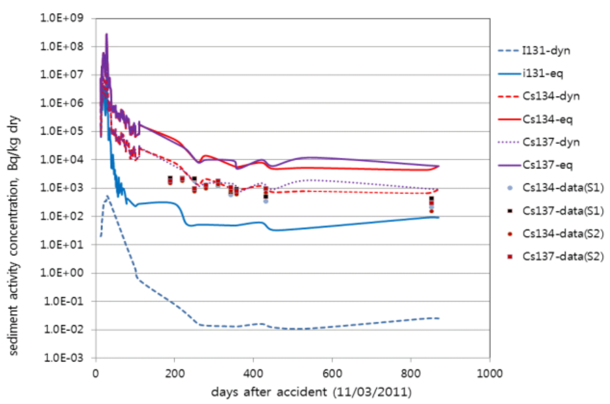

Fig. 3. Predicted sediment activity concentrations and their comparison with the observed one

3.3 Biota activity concentration

Fig 4 shows the calculated activity concentration profiles of biota for Station 1. The highest biota activity concentration of ^{131}I reached about 1.0E8 Bq/kg for phytoplankton, and the highest biota concentration of ^{134}Cs or ^{137}Cs reached 4.1E6 Bq/kg for zooplankton. The predicted activity concentration profile for phytoplankton agreed with the trend of the seawater activity profile exactly based on an equilibrium assumption. The activity concentration profile for zooplankton is influenced by the uptake rate of radioactivity from seawater as well as diet (phytoplankton)

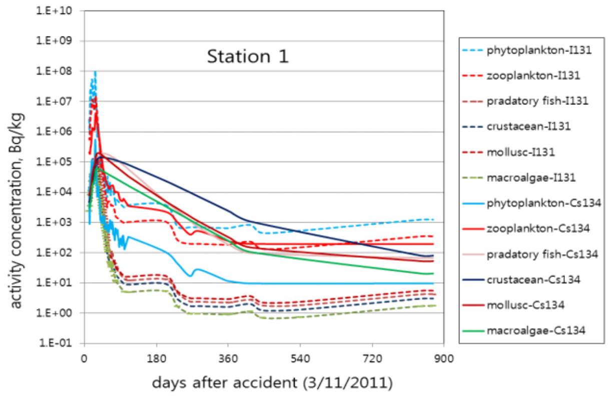

Fig. 4. Predicted biota activity concentration

3.4 Whole body dose rate

Fig 5 shows the predicted whole body total dose rate profile after the accident for biota in the port of FDNPS. The total dose rate is the sum of internal and external dose rate. The highest total dose rate was obtained around the peak of the seawater activity concentration, and reached about 1.E6 μGy/d for all biota. The total dose rate were temporary above the UNSCEAR's bench mark level [3] to protect aquatic biota from ionizing radiation, but the high exposure remained within two months. The high exposure might give some radiation effect in the individual biota, but would give unlikely any detrimental effect on the biota of the population level due to the short exposure time.

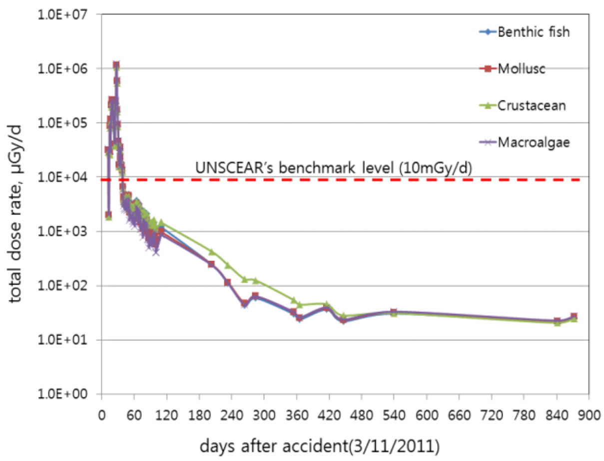

Fig. 5. Predicted whole body dose rate of biota

4. Conclusion

A dynamic compartment model was presented to assess the activity concentration and whole body dose rate of marine biota, and was tested through the prediction of the activity concentration and dose rate of the marine biota using the seawater activities of ^{131}I, ^{134}Cs, and ^{137}Cs measured after the accident at two locations in the port of the Fukushima Daiichi Nuclear Power Station (FDNPS), as a result the Fukushima nuclear accident that occurred on March 11, 2011.

The prediction results showed the radiological effect on the population of the marine biota as a consequence of the accident was insignificant. This result is also valid for biota in a less contaminated offshore because the present assessment was made for the most highly contaminated area such as marine ecosystem in the port of FDNPS. Conclusively, the present dynamic model can be usefully applied to estimate the activity concentration and whole body dose rate of the marine biota as the consequence of a nuclear accident,

Acknowledgement

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[3] UNSCEAR, 2008. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, *UNSCEAR 2008 Report to the General Assembly with Scientific Annexes, Volume II Scientific Annexes E: Effects of ionizing radiation on non-human biota*.