Dependency of soil activity concentration on soil -biota concentration ratio of radionuclides for earthworm

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1. Introduction

The transfer of radionuclides to wildlife (non-human biota) is normally quantified using an equilibrium concentration ratio (CR_{eq}), defined as the radionuclide activity concentration in the whole organism (fresh weight) divided by that in the media (dry weight for soil) [1,2].

The present study describes the effect of soil radionuclide activity concentration on the transfer of ^{137}Cs, ^{85}Sr and ^{65}Zn to a functionally important wildlife group, annelids, using a commonly studied experimental worm (*E.andrei*). Time-dependent whole body concentration ratios of ^{137}Cs, ^{85}Sr and ^{65}Zn for the earthworm were experimentally measured for artificially contaminated soils with three different activity concentrations for each radionuclide which were considerably higher than normal background levels. Two parameters of a first order kinetic model, the equilibrium concentration ratio (CR_{eq}) and the effective loss rate constant (k), were estimated by comparison of experimental CR results with the model prediction.

2. Materials and method

2.1 Model

A first–order kinetic equation is often used to predict the time-variation of radionuclide activity concentrations in biota [3,4].

$$C_b(t) = C_{b,eq}(1 - e^{-kt}) \qquad (1)$$

where $C_b(t)$ is the radionuclide activity concentration in biota at time t, $C_{b,eq}$ is the equilibrium radionuclide activity concentration in biota, and k is the effective loss rate of radionuclide from the biota. If the soil radionuclide activity concentration is constant (which is generally true since the soil radionuclide total content will not be significantly reduced by the uptake of radionuclide in earthworms considering the difference in density between soil and organism), the time-dependent concentration ratio $CR(t)$ can be expressed by

$$CR(t) = CR_{eq}(1 - e^{-kt}) \qquad (2)$$

where CR_{eq} is the equilibrium concentration ratio.

2.2 Experimental procedures

The experimental procedure for the CR measurement of the earthworms is shown in Fig 1. Soil was sampled from a field near the Gyeongju low and intermediate level radioactive waste repository in the Republic of Korea. The sampled soil was dried after passing through a 0.5cm sieve. Source of three radionuclides, ^{137}Cs, ^{85}Sr, and ^{65}Zn, were added to 0.4 kg of the uncontaminated dried soil. The artificially contaminated soil was then well mixed together with 19.6 kg of uncontaminated dried soil and 4 kg of dried manure (to provide food for the worms) using a V-type soil mixer to ensure a uniform distribution of radionuclides in the soil. Water (9 kg) was added to the contaminated soil to ensure adequate and similar levels of moisture of soil during the experiment. The three different soil activity concentrations used in the experiments are summarized in Table 1. The time-dependent CR values were calculated by the ratio of the measured earthworm activity (Bq/kg wet) to the measured soil activity (Bq/kg dry).

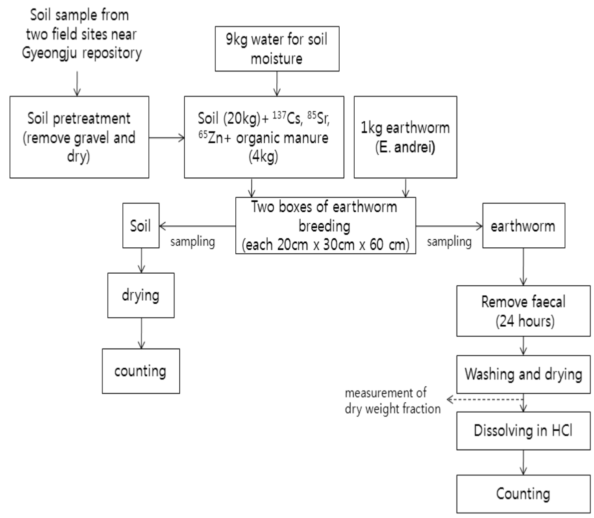

Fig 1 Experimental procedure for CR measurement of earthworm

Table 1 Soil activity concentrations used in the experiments (Bq/kg dw)

EXP. No	Radionuclide activity concentration in soil (Bq/kg dw)		
.	^{137}Cs	^{85}Sr	^{65}Zn
EXP-C1	8.23E3	8.32E3	8.21E2
EXP-C2	6.07E4	6.65E4	6.58E3
EXP-C3	3.84E5	3.84E5	3.84E4

3. Result

3.1 Transfer parameters

Two transfer parameters, CR_{eq} and k, of the first-order kinetic equation (Eq (1)) were obtained using the Marquardt least square algorithm. The calculated parameter values are summarized in Table 2. The biological half-life ($t_{1/2}$) for ^{137}Cs in the present study ranged from 4.3 to 7.7 days depending on the soil activities studied, which were within the range of the biological half-life (4 days to 1 month) of ^{137}Cs in invertebrates reported by Digregorio et al. [5]. The biological half-life of ^{85}Sr ranged from 3.3 to 9.36 days and those of ^{65}Zn ranged from 3.85 to 11.36 days. Whicker and Schultz [4] reported that the biological half-life of ^{85}Sr and ^{90}Sr in animals varied widely from 17 hours for insects to 593 days for laboratory mice.

Table 2 Parameter values of the first-order kinetic model

R/N	EXP. No.	$T_{1/2}$ (d)	CR_{eq} (Bq/kg fresh per Bq/kg dry)
^{137}Cs	C1	4.95	4.1E-3
	C2	4.3	3.0E-3
	C3	7.7	3.9E-4
^{85}Sr	C1	3.3	2.94E-2
	C2	6.9	2.2E-2
	C3	9.36	1.39E-3
^{65}Zn	C1	5.3	5.0E-2
	C2	3.85	3.16E-3
	C3	11.36	1.39E-3

* $T_{1/2}$ (biological half-life) = $0.693/k$

3.2 Effect of soil activity on CR_{eq}

To investigate the effect of soil activity concentration on the equilibrium concentration ratio (CR_{eq}) quantitatively, an empirical equation of log-linear form that is often used to relate the bioaccumulation to soil concentration was fitted to the data (Fig 2.)

At equilibrium, the activity concentration of ^{137}Cs and ^{85}Sr in earthworm was highest for EXP-C2 with the intermediate level soil activity concentration, whilst the activity concentration of ^{65}Zn was highest for the most contaminated EXP-C3. However, the trend was not statistically insignificant based on P-values. Overall, the effect of soil activity concentration on the CR_{eq} was more influenced by the amount of soil activity itself than the amount of the uptake of radionuclide in earthworm.

4. Conclusion

The present parameter values for the earthworm are the first reported results obtained for high soil radionuclide activity concentrations, and are expected to be useful to assess the radiation dose to earthworm which lives in a highly contaminated soil environment resulting from a nuclear accident. However, there was a high uncertainty in the values as they were derived with a few experimental data. Therefore, additional studies for various different species and soil properties are needed to improve the general applicability of the transfer parameters, and to provide the kinetic data useful for dynamic models.

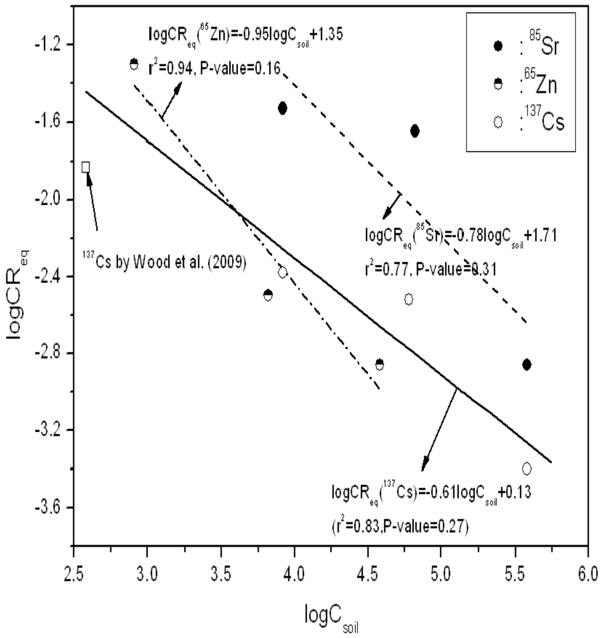

Fig 2 Empirical relationship of CR_{eq} with soil activity

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