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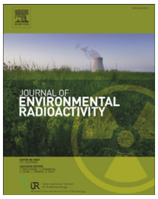

Effects of soil water content on the external exposure of fauna to radioactive isotopes

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ABSTRACT

Within a recent model intercomparison about radiological risk assessment for contaminated wetlands, the influence of soil saturation conditions on external dose rates was evidenced. This issue joined concerns of assessors regarding the choice of the soil moisture value to input in radiological assessment tools such as the ERICA Tool. Does it really influence the assessment results and how? This question was investigated under IAEA's Modelling and Data for Radiological Impacts Assessments (MODARIA) programme via 42 scenarios for which the soil water content varied from 0 (dry soil) to 100% (saturated soil), in combination with other parameters that may influence the values of the external dose conversion coefficients (DCCs) calculated for terrestrial organisms exposed in soil. A set of α, β, and γ emitters was selected in order to cover the range of possible emission energies. The values of their external DCCs varied generally within a factor 1 to 1.5 with the soil water content, excepted for β emitters that appeared more sensitive (DCCs within a factor of about 3). This may be of importance for some specific cases or for upper tiers of radiological assessments, when refinement is required. But for the general purpose of screening assessment of radiological impact on fauna and flora, current approaches regarding the soil water content are relevant.

1. Introduction

Assessing the impact of exposure of fauna and flora to ionizing radiation requires its quantification, taking into account the interactions between energy (i.e. radiation) and matter (.i.e. living organisms), on the basis of the description and modelling of the afferent physical processes. Such processes are controlled by the nature of particles, the geometric relationship between media and receptors, as well as the composition of any crossed matter, both in terms of elements and radionuclides.

Considering the variability of the water content in matter, especially soils and sediments, their activity concentration is usually expressed with regard to their dry weight, to obtain standardised and reproducible results. But the realistic assessment of fauna and flora exposure to ionizing radiation requires considering them alive that is to say to run dosimetric calculations accounting for water content of any exposure source. For soil, it may be user-defined as done in some operational tools dedicated to environmental radiation protection, like the ERICA Tool (Brown et al., 2008). In the absence of relevant data, assessors may assume a range of default values that directly impact external dose rates, as illustrated for wetland ecosystems (Stark et al., 2015).

Taking advantage of the MODARIA (Modelling and Data for Radiological Impacts Assessments) programme (IAEA, 2012–2015; see: http://www-ns.iaea.org/projects/modaria/), the issue of the dosimetric impact of soil moisture was investigated in order to establish how influent this parameter may be on external dose rates experienced by organisms.

The EDEN (Elementary Dose Evaluation for Naturel environment) dosimetric tool (Beaugelin-Seiller et al., 2006) allows for the deeper exploration of such questions (Vives I Battle et al., 2007, 2011) and has already been used to examine the effect of the heterogeneity of radioactive contamination in soil and sediment on fauna external exposure (Beaugelin-Seiller, 2014). It was then also used in the framework of the MODARIA Working Group 8 ("Biota modelling: further development of transfer and exposure models and application to scenarios") to test the effect of the soil water content on the values of external dose conversion coefficients (DCC) calculated for terrestrial organisms living in soil.

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2. Materials and methods

The usual and consensual approach to calculate the external dose rate $DR_{ext}(I,O)$ received by an organism O exposed to the radionuclide I consists basically in applying the following equation:

$$DR_{ext}(I,O) = DCC_{ext}(I,O)\cdot C_{media}(I)$$

where DCC_{ext} is the dose conversion coefficient allowing to convert an activity concentration (C_{media}; Bq kg^{-1} or Bq L^{-1}) into a dose rate (Gy/unit of time).

Most of the approaches used in environmental radiation protection (Copplestone et al., 2002; US-DOE, 2002; ICRP, 2008; Ulanovski and Pröhl, 2008) rely on tabulated DCCs. At the opposite, EDEN allows calculating specific DCC to any organism, for any radionuclide and any exposure scenario, by running Monte-Carlo simulations. All the required data are user-defined with the exception of nuclear data, which are taken from the JEFF (Joint Evaluated Fission and Fusion File) database (OCDE-NEA, 1997). The first step of any calculation with EDEN produces "basic" DCCs which correspond to a limited number of energy values representative of the range of usual emissions for each kind of radiation (10, 9, and 11 energies for α, β, and γ radiation, respectively). DCCs for other energy values present in the spectrum of a given radionuclide are then obtained using interpolation techniques. Basic DCCs are calculated for each source medium with a dedicated Monte Carlo tool, by creating and tracking an adjusted number of particles. Detailed method is exposed elsewhere (Beaugelin-Seiller et al., 2006). Briefly, particles are sampled uniformly within each source volume where each particle emitted is created with an input energy and a randomly sampled direction. Every time a particle hits the organism on its path, special counters tally the corresponding energy deposition. The tracking of α particles is based on the continuous slowing down approximation (CSDA); the energy loss along the course is determined by integrating the stopping power of each medium crossed. β particles are described as mono-directional electron beams transported in a straight line; the energy loss is based on results predetermined by calculating the energy deposited within an adapted cylinder centred around the beam with the MCNP code (Briesmeister, 2000). Photon path is considered as mainly influenced by the photo-electric effect at low energies and Compton scattering at average and high energies, according to the range of energies of interest and the elemental composition of living matter. Accounting for the probability of interaction of each γ particle with the organism, the deposited energy is assessed applying in parallel three classical approaches (collision, chord flux and virtual flux). At the end, one single result is retained, on the basis of the lowest statistical uncertainty.

Two soils were considered, each having the same elementary dry composition, but different porosity. To be realistic, the porosity was taken equal to 30 and 50%, which is the upper bound of actual values for soils. For both soils, moisture was varied from 0 (dry soil) to 100% (saturated soil), by steps of 5%. The soil composition to consider for DCCs calculation was determined combining dry mass composition, porosity and moisture. The soil matrix was geometrically described as a homogeneous semi-infinite 1-m-thick layer of various densities, density being the input data in EDEN that allows taking into account the soil water content. According to the soil characteristics (Table 1), its density varies from 1.3 to 2.2. Considering factors that may influence DCC values, it was decided to vary also the size of organisms. For this theoretical exercise, three spherical organisms were defined (0.1, 1 and 10 cm diameter), the composition of which was taken from FASSET animal data (Taranenko et al., 2004). Each of them was located in the middle of the soil layer. Lastly, calculations were performed for a set of

Table 1
Variation of soil composition and density according to its porosity and its water content.

Element (% in mass)	Water content (% of void volume)																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Porosity: 30%																					
H	2.10	2.16	2.23	2.29	2.35	2.41	2.47	2.52	2.58	2.64	2.69	2.75	2.80	2.85	2.90	2.95	3.01	3.05	3.10	3.15	3.20
C	1.60	1.59	1.57	1.56	1.55	1.54	1.53	1.51	1.50	1.49	1.48	1.47	1.46	1.45	1.44	1.43	1.42	1.41	1.40	1.39	1.38
O	57.70	57.96	58.21	58.47	58.71	58.96	59.19	59.43	59.66	59.89	60.12	60.34	60.56	60.77	60.98	61.19	61.40	61.60	61.80	62.00	62.20
Al	5.00	4.96	4.92	4.88	4.84	4.81	4.77	4.73	4.70	4.66	4.63	4.59	4.56	4.52	4.49	4.46	4.43	4.40	4.36	4.33	4.30
Si	27.10	26.88	26.67	26.46	26.25	26.05	25.85	25.65	25.45	25.26	25.07	24.89	24.70	24.52	24.34	24.17	24.00	23.82	23.66	23.49	23.33
K	1.30	1.29	1.28	1.27	1.26	1.25	1.24	1.23	1.22	1.21	1.20	1.19	1.19	1.18	1.17	1.16	1.15	1.14	1.13	1.13	1.12
Ca	4.10	4.07	4.03	4.00	3.97	3.94	3.91	3.88	3.85	3.82	3.79	3.77	3.74	3.71	3.68	3.66	3.63	3.60	3.58	3.55	3.53
Fe	1.10	1.09	1.08	1.07	1.07	1.06	1.05	1.04	1.03	1.03	1.02	1.01	1.00	1.00	0.99	0.98	0.97	0.97	0.96	0.95	0.95
Density (10^2 g cm^{-3})	1.86	1.87	1.89	1.90	1.92	1.93	1.95	1.96	1.98	1.99	2.00	2.02	2.04	2.05	2.07	2.08	2.10	2.11	2.13	2.14	2.16
Porosity: 50%																					
H	2.10	2.25	2.39	2.52	2.65	2.78	2.90	3.02	3.14	3.25	3.35	3.46	3.56	3.66	3.75	3.84	3.93	4.02	4.10	4.18	4.26
C	1.60	1.57	1.54	1.51	1.49	1.46	1.44	1.41	1.39	1.37	1.35	1.33	1.30	1.28	1.27	1.25	1.23	1.21	1.19	1.18	1.16
O	57.70	58.30	58.87	59.43	59.97	60.48	60.98	61.47	61.94	62.39	62.83	63.25	63.66	64.06	64.45	64.83	65.19	65.54	65.89	66.22	66.55
Al	5.00	4.91	4.82	4.73	4.65	4.57	4.49	4.42	4.34	4.27	4.21	4.14	4.08	4.02	3.96	3.90	3.84	3.79	3.73	3.68	3.63
Si	27.10	26.60	26.11	25.65	25.20	24.76	24.34	23.94	23.55	23.17	22.80	22.44	22.10	21.76	21.44	21.12	20.82	20.52	20.23	19.95	19.68
K	1.30	1.28	1.25	1.23	1.21	1.19	1.17	1.15	1.13	1.11	1.09	1.08	1.06	1.04	1.03	1.01	1.00	0.98	0.97	0.96	0.94
Ca	4.10	4.02	3.95	3.88	3.81	3.75	3.68	3.62	3.56	3.50	3.45	3.40	3.34	3.29	3.24	3.20	3.15	3.10	3.06	3.02	2.98
Fe	1.10	1.08	1.06	1.04	1.02	1.01	0.99	0.97	0.96	0.94	0.93	0.91	0.90	0.88	0.87	0.86	0.84	0.83	0.82	0.81	0.80
Density (10^2 g cm^{-3})	1.33	1.35	1.38	1.40	1.43	1.45	1.48	1.50	1.53	1.55	1.58	1.60	1.63	1.65	1.68	1.70	1.73	1.75	1.78	1.80	1.83