2024 International Nuclear Atlantic Conference – INAC 2024
Escola de Guerra Naval, Rio de Janeiro, RJ, May 6 - 10, 2024

ISBN: 978-65-594-1256-3

Comparison of ERICA Tool versions 1.3 and 2.0 in an environmental scenario using NORM residue

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1. Introduction

Several models for dose assessment of non-human biota to ionizing radiations were developed and constantly improved to implement the current philosophy, developing radiological models, frameworks and approaches for non-human biota protection [1,2,3]. International Commission on Radiological Protection (IRCP) recommends derived reference levels in the dose rate range from 0.1 mGy d^{-1} to 100 mGy d^{-1} [2]. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) recommends reference levels for the dose rate of 400 μGy h^{-1} (10 mGy d^{-1}) for terrestrial plants and aquatic organisms, for terrestrial animals dose rate of less than 40 μGy h^{-1} (1 mGy d^{-1}) to the most exposed individual in a population [4].

The ERICA Tool was developed by European Union to assess the effects of radionuclides in the environment and to support decision making [1]. This software operates in three different tiers and provides estimated absorbed dose rate (internal and external) to reference organisms from different ecosystems and performs risk characterization based on activity concentration in the environment and in biota whole body.

The main objective of the paper was to estimate absorbed dose rate in terrestrial biota in an environmental scenario using Naturally Occurring Radioactive Material (NORM) residue for comparison of results obtained in versions 1.3 and 2.0 of ERICA Tool. For this study in the environmental scenario used the phosphogypsum (PG), soil amended with PG and soil without PG. PG is classified as a NORM residue of the phosphate fertilizer industry which is stored in stacks; one possible use is the application as a soil conditioner for the various benefits to agriculture [5] and its use also contributes to reducing the risk in biota, when compared with the practice of deposition in stacks [6].

2. Methodology

The estimated absorbed dose rates to the biota in the environmental scenario were calculated using ERICA Tool versions 1.3 and 2.0. The estimated absorbed dose rate was run using Tier 2. The default values of the ERICA Tool for both versions were used in the estimated absorbed dose rate: dose conversion factors, radioecology parameters, occupancy factors, radiation weighting factors (α: 10, β: 3 and γ: 1), exposure configuration and reference organism geometries. Detailed explanation in relation to the default parameters used in the ERICA Tool could be found in the literature and in the help manual of the tool available in the software [1,7,8,9]. ERICA Tool version 2.0 has been updated with new features, changes and corrections: new dosimetry (implementing ICRP Publication 136 and dose contribution from short-lived progeny in a decay chain), inclusion of radon and thoron, updated (CRs, Kds and EMCLs) and various functional enhancements [9].The reference organisms used in the ERICA Tool for the terrestrial biota were: amphibian, annelid, arthropod-detritivorous, bird, flying insects, grasses & herbs, lichen & bryophytes, mammal-large, mammal-small-burrowing, mollusk-gastropod, reptile, shrub and tree.

Nisti et al. [10] determined the activity concentrations of natural radionuclides (^{238}U, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{232}Th and ^{228}Ra) in typical Brazilian soils, only PG and soils amended with PG used in the input data in the ERICA Tool for both versions. More detailed descriptions of the environmental scenario used in this study are available in the references used [10].

3. Results and Discussion

The results with the highest activity concentration values (^{238}U, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{232}Th and ^{228}Ra) were used in the ERICA Tool for estimated absorbed dose rate, thus considering the results more restrictive in environmental scenario. The ERICA Tool version 2.0 automatically included the radionuclides ^{210}Bi, ^{218}At, ^{218}Po, ^{214}Bi, ^{214}Pb, ^{214}Po and ^{228}Ac; however, the contribution of these radionuclides to the estimated total absorbed dose rate was less than 0.5%. The estimated absorbed dose rate (external, internal) for terrestrial biota in the PG, soils amended with PG and soils using ERICA Tool for both versions are presented in Table I.

Table I: Estimated Absorbed Dose Rate (μGy h^{-1}) for terrestrial biota using ERICA Tool 1.3 and 2.0.

	ERICA Tool 1.3 Terrestrial biota (μGy h^{-1})		ERICA Tool 2.0 Terrestrial biota (μGy h^{-1})	
Sample	External[(a)]	Internal[(a)]	External[(a)]	Internal[(a)]
PG	7.51 10^{-2} - 3.82 10^{-1}	1.28 - 58.6	1.01 10^{-1} - 3.95 10^{-1}	1.60 – 75.0
Soil with PG	1.20 10^{-2} - 6.10 10^{-2}	1.68 10^{-1} - 8.54	1.67 10^{-2} - 6.56 10^{-2}	2.36 10^{-1} – 11.9
Soil	1.18 10^{-2} - 6.01 10^{-2}	1.57 10^{-1} - 8.12	1.65 10^{-2} - 6.45 10^{-2}	2.18 10^{-1} – 10.8

[(a)] range value (minimum - maximum)

Results of estimated total absorbed dose rate obtained by ERICA Tool 1.3 and 2.0 for reference organisms in the terrestrial biota are presented in Table II.

Table II: Estimated total absorbed dose rate obtained by ERICA Tool 1.3 and 2.0.

Organism	PG (μGy h^{-1})		Soil with PG (μGy h^{-1})		Soil (μGy h^{-1})	
	1.3	2.0	1.3	2.0	1.3	2.0
amphibian	3.24	11.1	4.34 10^{-1}	1.61	4.14 10^{-1}	1.56
annelid	2.31	13.5	3.54 10^{-1}	2.04	3.45 10^{-1}	1.93
arthropod-detritivorous	2.28	15.1	3.25 10^{-1}	2.36	3.16 10^{-1}	2.19
bird	1.79	2.26	2.41 10^{-1}	3.35 10^{-1}	2.35 10^{-1}	3.20 10^{-1}
flying insects	2.05	3.57	2.88 10^{-1}	5.18 10^{-1}	2.79 10^{-1}	4.96 10^{-1}
grasses & herbs	11.2	12.4	1.66	1.99	1.60	1.88
lichen & bryophytes	58.7	75.1	8.56	11.9	8.14	10.9
mammal-large	2.85	5.42	3.75 10^{-1}	7.80 10^{-1}	3.58 10^{-1}	7.52 10^{-1}
mammal-small-burrowing	3.08	5.67	4.13 10^{-1}	8.21 10^{-1}	3.95 10^{-1}	7.93 10^{-1}
mollusc-gastropod	2.22	2.27	3.34 10^{-1}	3.72 10^{-1}	3.26 10^{-1}	3.45 10^{-1}
reptile	3.49	11.1	4.64 10^{-1}	1.62	4.41 10^{-1}	1.57
shrub	17.3	21. 9	2.35	3.25	2.26	3.09
Tree	1.39	1.72	1.86 10^{-1}	2.56 10^{-1}	1.75 10^{-1}	2.37 10^{-1}

The estimated rates of absorbed dose per internal dose presented the highest doses in both versions. Estimated absorbed dose rate (internal and external) were higher using ERICA Tool 2.0, with the exception of the estimated external absorbed dose rate for flying insects, lichen & bryophytes and mollusc-gastropod for the PG, soil and soil with PG.

Table III presents the results of the ratio of the estimated absorbed dose rate (external and internal) between the versions for reference organisms used in the ERICA Tool in the terrestrial biota. The ratio was calculated using of the estimated absorbed dose rate (external and internal) obtained by ERICA Tool version 2.0 divided by version 1.3.

Table III: Ratio between the versions of the ERICA Tool for reference organisms in the terrestrial biota.

Organism	PG		Soil with PG		Soil	
	External[(a)]	Internal[(a)]	External[(a)]	Internal[(a)]	External[(a)]	Internal[(a)]
amphibian	1.04	3.72	1.08	4.11	1.08	4.21
annelid	1.04	6.79	1.07	6.70	1.07	6.51
arthropod-detritivorous	1.04	7.75	1.07	8.66	1.07	8.28
bird	1.02	1.28	1.07	1.42	1.06	1.39
flying insects	0.90	1.76	0.94	1.81	0.94	1.79
grasses & herbs	1.04	1.11	1.07	1.19	1.07	1.16
lichen & bryophytes	0.83	1.28	0.87	1.39	0.87	1.33
mammal-large	1.34	1.91	1.40	2.10	1.40	2.12
mammal-small-burrowing	1.04	1.95	1.08	2.13	1.07	2.16
mollusc-gastropod	0.94	1.01	0.98	1.10	0.98	1.04
reptile	1.04	3.42	1.08	3.81	1.08	3.91
shrub	1.02	1.27	1.06	1.38	1.06	1.37
tree	1.04	1.18	1.08	1.32	1.08	1.31

[(a)] Ratio = ERICA Tool version 2.0 / ERICA Tool version 1.3

Greatest differences in the estimated absorbed dose rate between ERICA Tool versions, for the estimated external absorbed dose rate were the lichen & bryophytes and mammal-large, for estimated internal absorbed dose rate for arthropod-detritivorous, annelid, amphibian and reptile.

The two most relevant radionuclides and the contribution percentage are presented in Table IV.

Table IV: Radionuclides and the contribution percentage in the estimated absorbed dose rate.

Environmental Scenario	ERICA Tool 1.3		ERICA Tool 2.0	
	1º Rn *(%)*	2º Rn *(%)*	1º Rn *(%)*	2º Rn *(%)*
	External absorbed dose rate			
PG	^{226}Ra *(69.9%)*	^{228}Ra *(30.0%)*	^{226}Ra *(65.3%)*	^{228}Ra *(33.0%)*
Soil with PG	^{226}Ra *(58.0%)*	^{228}Ra *(41.9%)*	^{226}Ra *(52.1%)*	^{228}Ra *(44.4%)*
Soil	^{226}Ra *(57.4%)*	^{228}Ra *(42.6%)*	^{226}Ra *(51.6%)*	^{228}Ra *(45.1%)*
	Internal absorbed dose rate			
PG	^{226}Ra *(60.1%)*	^{210}Po *(36.4%)*	^{226}Ra *(53.9%)*	^{210}Po *(20.4%)*
Soil with PG	^{226}Ra *(56.0%)*	^{210}Po *(31.1%)*	^{226}Ra *(46.6%)*	^{210}Po *(16.1%)*
Soil	^{226}Ra *(57.1%)*	^{210}Po *(29.4%)*	^{226}Ra *(48.6%)*	^{210}Po *(15.6%)*
	Total absorbed dose rate			
PG	^{226}Ra *(60.4%)*	^{210}Po *(35.5%)*	^{226}Ra *(54.1%)*	^{210}Po *(20.1%)*
Soil with PG	^{226}Ra *(56.1%)*	^{210}Po *(30.2%)*	^{226}Ra *(46.7%)*	^{210}Po *(15.8%)*
Soil	^{226}Ra *(57.1%)*	^{210}Po *(28.5%)*	^{226}Ra *(48.7%)*	^{210}Po *(15.3%)*

The radionuclides that contributed most to the estimated external absorved dose rate were ^{226}Ra and ^{228}Ra, estimated internal absorbed dose rate were ^{226}Ra and ^{210}Po and resulting in estimated total absorved dose rate were ^{226}Ra and ^{210}Po for both versions of the ERICA Tool.
In Tables III and IV the radionuclides ^{210}Bi, ^{218}At, ^{218}Po, ^{214}Bi, ^{214}Pb, ^{214}Po and ^{228}Ac were not considered.

4. Conclusions

The two versions of ERICA Tool used in this paper presented excellent performance and similar interface between versions. ERICA Tool version 2.0 has been updated with new features, changes and corrections.
Estimated absorbed dose rates were higher using ERICA Tool 2.0, with exception of the estimated external dose rates for the flying insects, lichen & bryophytes and mollusc-gastropod. The results of estimated absorbed dose rates were similar for the soil conditioned with PG and the soil between each version.
All the estimated absorbed dose rates in the organisms analyzed in this paper were below the UNSCEAR recommends reference levels for both versions of the ERICA Tool.
The biota assessment contributes for environmental protection and as such is considered one of the Sustainable Development Goals of United Nations.

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