

Response to Doctoral (PhD) Dissertation Review Questions

Author:

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Thesis title:

Survey of Naturally Occurring Radionuclides in Soils, Water, and Rice from Artisanal and Small-Scale Gold Mining Affected Areas in Ghana

Reviewer:

Dr Krisztián Radó

(Site manager)

I would like to sincerely thank Dr Krisztián Radó for his conscientious work and valued time in reviewing my thesis, and for his appreciation of my work. I would like to give the following answers to his numbered questions.

- 1. What is the difference between the estimation of outdoor and indoor gamma dose exposure, and how is this reflected in the calculation and interpretation of radium equivalent activity (Ra_{eq})**

The outdoor and indoor gamma dose estimations differ mainly in source distribution, environmental geometry, and occupancy. The outdoor gamma dose exposure originates primarily from ^{226}Ra , ^{232}Th , and ^{40}K in soils and it is assessed in an open environment where the gamma radiation is more dispersed, less occupancy and resulting in a relatively lower dose rate:

$$D_{out}(n\text{Gy}/h) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K$$

In contrast, indoor gamma dose exposure is largely influenced by activities concentration of same radionuclides but this time in building materials and in a confined geometry, leading to higher gamma dose rates, and further amplified by higher occupancy. The indoor gamma dose is commonly estimated by applying a correction factor to the outdoor gamma dose as provided by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 2000 report:

$$D_{in}(n\text{Gy}/h) = 1.4 \times D_{out}$$

To assess the external annual effective dose, the occupancy (OF) and dose conversion factor (CF) (0.7 Sv/Gy) at 8760 hours per year are applied:

$$E = D(n\text{Gy}/h) \times OF \times CF(\text{Sv}/\text{Gy})$$

$$E(m\text{Sv}/y) = D(n\text{Gy}/h) \times OF \times 0.7(\text{Sv}/\text{Gy}) \times 8760(\text{h}/y)$$

where $OF = 0.2$ (outdoor) and 0.8 (indoor).

The Radium equivalent activity (Ra_{eq}), however, is a single index used to represent the combined activity of these same radionuclides:

$$Ra_{eq}(\text{Bq/kg}) = A_{Ra} + 1.43A_{Th} + 0.077A_K$$

Although Ra_{eq} standardizes radionuclides content, it does not differentiate between indoor and outdoor exposure conditions. It should be noted that the Ra_{eq} was developed specifically for building materials. Therefore, its interpretation is context dependent. For example, the same Ra_{eq} value is less significant in outdoor exposure conditions due to dispersion and lower occupancy, but more critical in indoor exposure conditions where exposure is prolonged, confined and higher occupancy. Hence, the recommended limit of 370 Bq/kg is primarily applied to building materials to control indoor radiological risk to ensure that indoor annual effective dose does not exceed 1 mSv.

2. How does the radiological impact of artisanal and illegal mining compare to the environmental and health risks posed by heavy metals (e.g., Hg, Cd, As, Cu) and organic contaminants (e.g., fuel spills, cyanide) associated with these activities?

The radiological impact of artisanal and illegal mining to environment and human health is generally lower, more chronic and it presents a probabilistic (stochastic) long-term health risk compared to the environmental and health risks from heavy metals and organic contaminants which are highly toxic, mobile, and bioaccumulative, and result in acute, deterministic, and dominant risk to human health and the environment in artisanal and illegal mining areas. Consequently, although radiological monitoring is essential for long-term safety, chemical and organic toxicity may pose a more urgent and severe clinical and ecological challenge in these mining areas.

I thank Dr Krisztián Radó once again for reviewing my thesis and humbly request for the acceptance of my answers.

Veszprém, 2026 May 8


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