RESPONSE LETTER TO REVIEWER'S QUESTIONS ON PHD THESIS

Thesis Title:	**Application of the European Basic Safety Standards Directive in Underground Mines: A Comprehensive Radioecology Study in a Hungarian Manganese Mine**
Author:	**Amin Shahrokhi**
Reviewer:	**Dr. Norbert Kavasi, PhD**

Dear Dr. Norbert Kavasi,

I would like to take this opportunity to thank you for the effort and expertise that you contribute to reviewing my Ph.D. thesis.

The discussion below responds directly to specific questions made by Dr. Norbert Kavasi. The reviewer's questions are in bold and italicized. The author's answers are in normal font style.

Thank you so much regarding your comments, I do agree with your comments and I will try avoiding same mistakes on my future scientific activities.

I hope the responses are convincing and answer your questions correctly.

1. ***Please explain the contribution of radon to the average exposure of the population. Is it around 50% or more?***

   Based on the changes in estimating the dose from inhaling radon after introducing a new dose coefficient values by the ICRP, in case of general population, the dose from inhaled radon compared to the UNSCEAR (2008) value (~1.3 $mSv \cdot y^{-1}$) increased by a factor of 2 as ~2.5 $mSv \cdot y^{-1}$ (using the nominal risk coefficient from ICRP Publication 115, and ICRP publication 103) and this value recently changed to ~3 $mSv \cdot y^{-1}$ based on the new dose conversion convention (ICRP publication 117); but the new estimation values has not been updated by UNSCEAR or other organization (e.g. WHO, IAEA, etc.) and in the literature the old value (~1.3 $mSv \cdot y^{-1}$ by UNSCEAR, 2008) is used because there is no reference for the new value. Therefore, scientifically the contribution of radon to the average exposure of the population increased by a factor of approximately 2 and with contribution higher than 50% (around 63%), but in literature still old value is used and no updated applied to this value up to now, in this case the contribution is less than 50% (around 42%).

2. ***Table 9. Please explain, how it is possible that the radon emanated (110.3 kBq) from the Pylon 2000A radon source is higher than the source Ra-226 activity (105.7 kBq)?***

   Unfortunately, in the table 9. I had typos and I meant to write 105 kBq. The presented value in thesis (110310.7 Bq) is a mistake and corrected value is 105 kBq.

3. *What is the relevance of K-40 measurement to radon study?*

From radon aspect no direct link but the main aim of the study was to characterise the source of the radon and to better characterising of the rock types the K-40 data might be useful. In the other hand, it might be useful for further studies can be a reference which deals with other radiological measurement than radon survey. Additionally, it can give an overview of estimation of dose from the mine wall to the readers (the author was not estimated the gamma dose from mine wall, but using the measured values in this study, the approximately gamma dose can be estimated).

4. ***The Ra-226, Th-232, and K-40 were determined in 32 rock samples. However, in Fig 32 much less points presented for the distribution of Ra-226 and Th-232. Please explain why.***

Figure 32 shows the normal distribution of Ra-226 and Th-232 among the rock samples (32 rock samples from 6 stone type); as the concentration of these two materials between the samples from the same stone type mainly was similar, the calculated values were so close to each other and in some cases overlapping each other, due to this in the graph it seems less point but in fact some points are overlapped.

5. ***Considering the presented results in Fig 31 and 32 the distribution of K-40 is different from Ra-226 and Th-232. Please explain why.***

As the rock types are sedimentary, this variation between the K-40 and other radionuclides (Ra-226 and Th-232) due to the geological origin of the rocks. It may also have related to your question: the high variance of naturally occurring radioactive materials in the nature is due to the chemical characteristics of radionuclides, e.g. the high migration properties and the good solubility, etc.

6. ***What is the explanation of the significant Ra-226 enrichment (one magnitude!) comparing to U-238 in carbonate ore samples?***

Regarding your question I recheck my calculation and I found that during the conversion of U from ppm to $Bq \cdot kg^{-1}$, I had a typo in adding conversion factor to the excel formula. Therefore, here I am reporting the corrected values what I recalculated using correct conversion factor. After correction, there is not significant variation as in carbonate ore samples the concentration of U-238 was reported as 7-21 $Bq \cdot kg^{-1}$ (with an average of 13 $Bq \cdot kg^{-1}$), and Ra-226 in two samples measured as 15 and 18 $Bq \cdot kg^{-1}$.

Following Table 8. And Table 17. are represented corrected values after modification on conversion factor.

The significant variation between U-238 and Ra-226 in some case is due to disequilibrium what is common in uranium decay series, as example U-238 can be selectively leached relative to U-234; U-234 can be selectively leached relative to U-238; Th-230 and Ra-226 can be selectively removed from the decay chain.

Table 1- The average values of element composition of the Úrkút manganese

	Mn (wt%)	Fe (wt%)	V (μg/g)	Co (μg/g)	Ni (μg/g)	Cr (μg/g)	Th (Bq·kg^{-1})	U (Bq·kg^{-1})	Ce (μg/g)	Nd (μg/g)
Grey Mn-carbonate	20	6	61	266	45	27	8	21	228	56
Black shale	3	6	151	414	105	68	32	35	191	53
Brown Mn-carbonate	28	1	20	454	75	0	8	7	133	29
Brown-grey Mn-carbonate	10	9	80	138	41	39	16	10	128	36
Beige Mn-carbonate	1	6	122	29	45	68	20	15	79	27
Brown-black Mn-carbonate	24	13	61	301	63	15	12	18	162	33
Green Mn-carbonate	16	7	51	155	20		4	7	122	31
Cherty limestone (Mullock)	-	-	-	17	71	-	24	14	41	24
Marlstone (Mullock)	-	-	-	6	79	-	8	5	32	16
Greenish grey calcareous marl (Mullock)	0	3	77	80	35	55	45	25	90	34
Limestone (Mullock)	0	1	39	18	102	20	20	7	33	21

Table 2- Comparison of the Ra-226 and U-238 concentration among rock samples

Rock Type	U-238 (Bq kg^{-1})	Ra-226 (Bq·kg^{-1})
Carbonate Ore	7-21 (13)	15 & 18 (16)
Black shale	35	9-18 (13)
limestone	7-14 (10)	2-6 (3)
Marlstone	5 & 25 (15)	3-6 (4)

7. ***The Th-232 (Th-228) concentration was similar or higher than the Ra-226 in many rock samples. Probably thoron was also released during the explosion of ore. Please explain the thoron influence on the radon measurement results.***

Yes, almost in half amount of radon concentration thoron was measured; to avoid the influence of the thoron on radon measurement, due to the very low half-life of thoron the measured values after second measurement cycle (10 minutes) were considered; likewise, there was a 5-minute interruption to let thoron decay.

Thoron had a significant influence on radon measurements and dose estimation (as it was discussed widely and there are several publications du to this fact for the same mine e.g. Kovács, T. et al., 2008[1]; Kavasi, N. et al., 2009[2]), but the author had tried to eliminate the influence of this factor as low as possible using specific devices such as EQF3220 and Pylon WLx. Normally, this was really difficult due to the short half-life, short travel distance, etc.

(1) *2008; 6 p; SAR; Buenos Aires (Argentina); IRPA 12: 12. International congress of the International Radiation Protection Association (IRPA): Strengthening radiation protection worldwide; Buenos Aires (Argentina); 19-24 Oct 2008; Oral presentation; 11 refs., 1 fig., 4 tabs.*

(2) *Kávási, N., Somlai, J., Vigh, T., Tokonami, S., Ishikawa, T., Sorimachi, A., & Kovacs, T. (2009). Difficulties in the dose estimate of workers originated from radon and radon progeny in a manganese mine. Radiation Measurements, 44(3), 300-305.*

8. ***Radon concentration results of two Iranian manganese mines (Robat-Karim and Venarch-Qom) can be found in the literature. The lowest radon concentrations (10-84 Bq/m^3) was reported from the Venarch-Qom manganese mine while the Ra-226 concentration in the ore samples from this mine was one magnitude higher than in the samples from the Urkut manganese mine. What is the explanation of higher radon level in the Urkut manganese mine if the Ra-226 is lower than in other mines?***

I can give five theoretical answers for this variations between radon concentration in the mines:

(A) Possibility of errors during experiments. The obtained results from my study came along with the results reported in several previous studies that carried out by different researchers for the same mine.

(B) Geological features and regional climate conditions. For example, regarding my knowledge, the Venarch-Qom mine is located in a dry climate area with very low precipitation (with yearly average of ~135mm) while the average of annual evaporation rate is estimated to be about 300 mm, but Úrkút manganese mine is located in a wet area with very high precipitation (average ~560mm per year) and low evaporation; or the high variation between outside and inside air temperature in the Venarch-Qom mine (the average minimum temperature at the coldest month of the year is -5.16 and the average maximum of the warmest month is 42.5 degrees, and the maximum absolute temperature of the air is 49 degrees in the months of July and August, and the minimum absolute temperature of the air is -24 degrees in February), while in case of Úrkút mine location this deviation is much lower (the average minimum temperature at the coldest month of the year is 0 and the average maximum of the warmest month is 21 degrees), therefore as usually the air temperature inside the mine is constant, this difference between inside and outside air temperature significantly can influence on the natural air ventilation from inside to outside resulting reduction on radon concentration significantly. All environmentally parameters can influence on radon exhalation from the mine wall or ground.

(C) Good combination of the force ventilation and the outdoor radon level. If the outdoor radon level is near to zero and the air ventilation is high, it might be possible to reach the mentioned low level indoor radon concentration in Venarch-Qom manganese mine, but in this case the equilibrium factors should be different then reported value of 0.4.

(D) In the manganese mine the main route of entry radon is the exhaled radon from the surrounding rocks. From the mentioned papers by the reviewer regarding radon concentration in Venarch-Qom mine, I was not able to estimate the radon exhalation rate of the rocks. Theoretically if the radon exhalation rate is near to zero (just like in the granite surface) maybe the surrounding rocks contribution is low. And as its very

dry area, the contribution of dissolve radon in water is very low as it might not so much water exist in the Venarch-Qom mine area.

9. ***Table 22. Please explain why the working time of miners has uncertainty.***

   The uncertainty includes the time when was spending during working hours but not inside the mine such as breaking time, and due to the task distribution, they were not working every day in the underground places.

10. ***Please explain why A5 point had the highest water radon concentration.***

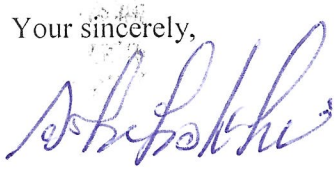
    Generally, the overall dissolved radon concentration in the mine waters is quite low (for example the average dissolved radon concentration in the tap water of Veszprem city is about 10 $Bq \cdot L^{-1}$); that so, the levels of the radon in the mine waters is near to the limit of detection.
    In case of the A5, the dissolved radon concentration only seems to be high (relatively high) comparing with the other samples radon concentration. The higher radon concentration in the sample A5 is due to the long contact time with the air and the water was not disturbed (no strong stream the radon is not desorbed, so it was possible to reach a relatively high level), likewise, its due to the origin of the water.

I hope I've been able to answer your questions well.

Many thanks for your consideration.

2018. Dec. 03, Veszprém

Your sincerely,



Amin Shahrokhi