Estimates of Effective Doses among Czech Uranium Miners

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Abstract. Czech uranium mining started on industrial base in the 1890s. It is estimated that the total production has been 110 000 t of uranium and the uranium industry has employed nearly 100 000 underground workers. Radiation doses in uranium mines include contribution form inhalation of radon and uranium dust and from external gamma radiation. The presentation includes an estimation of radiation doses, which is based on measurements of physical and chemical characteristics of the mining aerosol conducted recently in the mine. The main parameters were: size, chemical solubility in lung fluid, and amount of Rn gas emanating from uranium particles. The mean size of particles in terms of AMAD was in the range 5-9 μm. Study of kinetics of dissolution of uranium collected on filters from personal dosimeters ALGADE estimated rapidly dissolved fraction of 0.142 and 0.177 for U-238 and U-234, respectively. Fraction of Rn gas emanating from uranium particles was estimated by measuring activity ratios of radon progeny and Ra-226. This fraction, which determines how the gross long lived alpha activity is distributed into radionuclides of the uranium series, were in the range 32% - 63% with the mean of 43%. Based on these parameters, committed effective doses from long lived radionuclides in uranium dust were calculated using the IMBA software. In conditions at mine Rozna in 2000-2009, the mean annual effective doses are 1.9 mSv from long lived radionuclides, 4.1 mSv from radon and its progeny (using conversion 1WLM=10mSv) and 2.2 mSv from external gamma radiation.

Key Words: uranium mines, effective dose, long lived radionuclides

Introduction

Radiogenic risk in uranium mines is usually linked to radon exposure, particularly in earlier periods of mining, when ventilation in mines was limited. At present, radon levels are 1-2 orders of magnitude lower. Therefore, exposures to other radiation components – external gamma and long lived radionclides in mining aerosol are of increased importance.

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The aim of this report is to estimate size distribution of aerosol particles containing uranium and its decay products in uranium mine Rožná I in dependence on conditions in the mine and mill.

Methods

The estimation of physical parameters of mine aerosol was based on samplings and measurements in mine Rozna I, where the ore is mined from the depth up to 1200m. Five and six stage cascade impactors were repeatedly placed at three different sites where higher dust content was expected – at stopes, at crushing plants, and at the end of the chute where carts are loaded by the ore. Gamma spectrometric analyses were performed using HPGe detectors.

The radiation dose from the mine aerosol depends on several physical and chemical parameters. The physical ones include isotopic composition, including proportion of radon activity escaping from particles, which determines how the gross alpha activity is distributed into radionuclides of the uranium series. Estimates of this proportions in terms of activities of Rn deacy products (Bi-214, Pb-214) and Ra-226 were based on gamma spectrometry as above. The particle size in terms of activity median aerodynamic diameter (AMAD) for each working site were estimated assuming log-normal distribution of activities corresponding to stages of cascade impactors (Hinds 1999), including geometric standard deviations (GSD).

Chemical parameters of particles, particularly the solubility of particles in lung fluid, were estimated by own measurements for U-234 and U-238 (Beckova and Malatova 2008) and parameters for other radionuclides were taken from (Duport et al. 1991).

For conversion of unit intakes into effective doses, we used software IMBA (Integrated Modules for Bioassay Analysis), which implements the biokinetic and dosimetric models currently recommended by the International Commission on Radiological Protection (ICRP) and enables the users to specify their own parameter values to the customized internal dose calculations (IMBA 2005).

Results

Samplings in mines resulted in a total of 14 data sets. The character of activity distribution obtained from these samplings is similar. The highest fraction of activities is in the two last categories (4.2-10.2 and >10.2 μm) and lowest fraction in category 0.39-0.69 μm. Surprisingly, the activity in the very low category (<0.39 μm) is higher then in next categories suggesting bi-modal distribution. For these reasons, analyses were conducted ignoring the first category (representing about 20% of activities) and parameters (AMAD and GSD) were estimated from such limited data. Particle size for different working sites in terms of AMAD were in the range 2.0- 9.2 μm with the mean of 7.3 μm and GSD were in the range 2.1-6.5 with the mean 3.2. These results generally correspond to data in workplaces (Dorian and Bailey 1995).

The fraction of escaped radon in different samplings varied from 32% to 63%. The mean value was 43%. Based of this observation, the isotopic composition of U-238 series can is summarized in Table 1. The weights in this table indicate fractions of alpha radionuclides, both long lived (LL) and short lived (SL) in the gross alpha activity.

Table 1. Isotopic composition and numbers of alpha emitters assuming 43% radon escape for U-238 and U-235 decay series

	Emitter type [a]	weight
U-238	LL	1
U-234	LL	1
Th-230	LL	1
Ra-226	LL	1
Rn-222	SL	0.57
Po-218	SL	0.57
Po-214	SL	0.57
Po-210	LL	0.57
Total		6.28
U-235	LL	0.0526
Pa-231	LL	0.0526
Th-227	LL	0.0526
Ra-223	LL	0.0526
Rn-219	SL	0.0526
Po-215	SL	0.0526
Bi-211	SL	0.0526
Total		0.3682

[a] Emitter type: long lived (LL), short lived (SL)
[b] Assuming fraction $^{235}U/^{238}U$= 0.0526 and 43% Rn escape, ie. n=6.65 alpha emitters

Effective doses from unit intake of radionuclides were calculated for long lived radionuclides. These calculations were performed using the IMBA software (IMBA 2005) with user defined absorption parameters (Table 2) similarly as in (Marsh et al. 2011). Results of these calculations in terms of conversion coefficients are given in Table 3 containing calculations for different particle sizes (AMAD < 0.4 μm and AMAD= 5, 10, and 7 μm). The resulting conversion of 3.4 mSv/kBq corresponding to AMAD=7 μm was used to illustrate mean annual effective doses at mine Rozna in the period 2000-2009, which is 1.9 mSv. For comparison, the mean effective annual dose from radon and its decay products is 4.1 mSv using the latest recommendation of ICRP on radon (ICRP 2010) and the mean annual doses from external radiaton is 2.2 mSv.

Table 2. Absorption parameters of long lived radionuclides.

Nuclide	f_r [a]	s_r (d^{-1}) [b]	s_s (d^{-1}) [c]	f_1 [d]
^{224}Ra, ^{226}Ra, ^{228}Ra	0.11	7.32	0.000412	0.2
^{210}Pb	0.26	3.91	0.00101	0.2
^{228}Th, ^{230}Th, ^{232}Th	0.14	4.56	0.000683	0.0005
^{234}U,^{235}U,^{238}U	0.22	0.78	0.00144	0.2
^{231}Pa	0.18	4.1	0.000886	0.0005
^{227}Ac	0.18	4.1	0.000886	0.0005
^{210}Po	0.18	4.1	0.000886	0.1

[a] Rapid fraction
[b] Solubility of rapid component
[c] Solubility of slow component
[d] Fraction of activity absorbed in blood from intestines

Table 3. Estimates of conversion coefficients (mSv/kBq) for different long lived radionuclides and particle size (AMAD) assuming 43% radon escape and resulting conversion for U-238 and U-235 series

AMAD	<0.4 μm	5 μm	10 μm	7 μm	5 μm [a]	10 μm [a]	7 μm [a]
U-238	5.84	3.09	1.87	2.50	3.72	2.75	3.25
U-234	6.79	3.98	2.41	3.23	4.64	3.38	4.04
Th-230	8.78	4.96	3.06	4.04	5.83	4.34	5.09
Ra-226	10.6	6.18	3.92	5.09	7.18	5.38	6.31
Po-210	5.15	3.32	1.80	2.60	3.78	2.56	3.20
Pb-210	0.76	1.10	0.94	1.02	1.03	0.90	0.97
U-235	6.19	3.41	2.07	2.76	4.05	2.98	3.53
Pa-231	10.3	5.82	3.56	4.73	6.84	5.03	5.96
Ac-227	36.2	24.5	15.0	19.9	27.1	19.5	23.5
weighted sum [b]	38.09	22.46	13.88	18.33	26.07	19.20	22.76
resulting conversion	5.8	3.4	2.1	2.8	3.9	2.9	3.4

[a] Correction for 20% fraction of fine particles (<0.4 μm)
[b] Assuming fraction $^{235}U/^{238}U$= 0.0526 and 43% Rn escape, ie. n=6.61 alpha emitters

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References

[1] Hinds WC (1999) Aerosol Technology: properties, behavior and measurement of airborne particles. John Wiley & Sons, Inc.

[2] Bečková V, Malátová I (2008) Dissolution behaviour of ^{238}U, ^{234}U and ^{230}Th deposited on filters from personal dosemeters. Radiation Protection Dosimetry 129:469-472.

[3] Duport P, Robertson R, Ho K Horvath F (1991) Flow-through dissolution of uranium-thorium ore dust, uranium concentrate, uranium dioxide, and thorium alloy in simulated lung fluid. Radiat. Prot. Dosim. 38:121-133.

[4] Dorrian MD, Bailey MR (1995) Particle size distribution of radioactive aerosols measured in workplaces. Radiation Protection Dosimetry 60:119-133.

[5] Marsh JW , Blanchardon E, Gregoratto D, Hofmann W, Karcher K, Nosske D, Tomasek L (2011) Dosimetric calculations for uranium miners for epidemiological studies. Radiation Protection Dosimetry, doi:10.1093/rpd/ncr310

[6] IMBA (2005) User Manual for IMBA Professional Plus (Version 4.0), © HPA, 2005 (http://www.imbaprofessional.com/about/description).

[7] International Commission on Radiological Protection (2010) Lung cancer risk from radon and progeny and statement on Radon. ICRP Publ 115, Ann ICRP 40(1).