HIROSAKI UNIVERSITY

Radiation Emergency Medicine 2015 Vol.4, No.2 53–57

REM
Radiation Emergency Medicine

Note

Radiation Exposure Problems of Tourist Cave Workers Originating from Radon in Relation to the New IAEA BSS and ICRP Recommendations

János Somlai[1], Anita Csordás[1], Zoltán Sas[1], Annamária Kopek[2] and Tibor Kovács[1]*

[1]*Institute of Radiochemistry and Radioecology, University of Pannonia, H-8200 Veszprém, Egyetem Street 10. Hungary*
[2]*Balaton-felvidéki National Park Directorate, H-8229 Csopak, Kossuth Street 16.*

Received 6 March 2015; revised 23 April 2015; accepted 27 April 2015

The regulation of radiation exposure originating from radon has become strict during the past years; in 2014 the reference level was given to be 300 Bq/m^3 in case of dwellings and other buildings with high occupancy factor by International Basic Safety Standards (IAEA BSS) – released by IAEA – or the maximum allowable value in non-radiation conditions (radiation workers)[1)]. We had previously been surveying the changes of radon concentration in the tourist cave's air for 8 years, and had measured the radiation exposure of those working there for 11 years. The 8-year average of radon concentration was 7430 Bq/m^3. Before the renovation works at the end of 2011 (removing previous coal slag filling) it was 8630 Bq/m^3, while during the years 2012-2014 it was 5430 Bq/m^3, however, it still considerably exceeds the current reference level of 1000 Bq/m^3 (and that planned for the future as 300 Bq/m^3). The workers' radiation exposure has been surveyed individually using track detectors during the past 11 years. The average number of workers was 12 per year and the average radiation exposure was 10.6 mSv/year which resulted in a committed effective dose of 18.55 mSv/year calculated using the new recommendation. During the 11 years the annual effective dose exceeded 20 mSv/year in 6 cases.

Applying the new dose conversion factor the actual radiation exposure exceeded the 20 mSv/year value in 44 cases where the average radiation exposure was 28.9 (20.4-53.0) mSv/year.

Key words: Radon, Radiation workers, Tourist cave, International Basic Safety Standard (IAEA BSS)

1. Introduction

Based on the newest surveys the WHO found that radon is the second cause for lung cancer following cigarette smoking; 3-14% of the lung tuberculosis is caused by radon and its decay products (depending on the average radon concentration of the different countries)[2)].

In order to reduce (restrict) the risk of radiation exposure originating from radon concentration in the air space of residential buildings and workplaces ICRP conceptualized its recommendations in its Publication 65 in the year 1993[3)]. Based on these they recommended the activity levels to be set for 200-600 Bq/m^3 for residential buildings and 500-1500 Bq/m^3 for workplaces in the different countries. Based on these in case of 2000 hours/year working hours and an equilibrium factor of 0.4 results in a radon concentration of 1 Bq/m^3 and a committed effective dose of $6.23 \cdot 10^{-3}$ mSv/year. Therefore, depending on the national regulations those working in the given

*Tibor Kovács: Institute of Radiochemistry and Radioecology, University of Pannonia, H-8200 Veszprém, Egyetem Street 10. Hungary
E-mail: kt@almos.uni-pannon.hu

workplaces could receive a radiation dose of 3.1-9.3 mSv/year from radon without the given workplace having been considered a workplace danger zone.

Intervals recommended by ICRP are hardly justifiable, therefore ICRP 103 (2007) made a clearer recommendation for the activity level of (600 Bq/m^3 in residential buildings) and 1500 Bq/m^3 in workplaces[4]. In the case of radiation workers e.g. workers of nuclear power plants, uranium ore miners, uranium processing industry etc. the limit should be expressed as an effective dose of 20 mSv per year, averaged over defined 5 year periods (100 mSv in 5 years)[4]. Based on the more and more numerous and exact epidemiological surveys, however, researchers established risk factors higher than values estimated before. Therefore, WHO[2] maximized the recommendation limit in residential buildings as 300 Bq/m^3, in workplaces as 1000 Bq/m^3. In 2009 ICRP also published a statement stating that they found the restriction reasonable and recommended a value to be introduced identical to the recommendation of WHO. In 2010 the ICRP 115 publication was published which, based on the processing of new scientific results stated that the probability of the formation of cancer is higher than that estimated before[5]. The Commission now recommends a new nominal risk coefficient: $14 \cdot 10^{-5}$ per mJh/m^3, instead of the Publication 65 value of $8.0 \cdot 10^{-5}$ per mJh/m^3 which means an increment of 1.75 times. (It can be seen that in case of the previous radon level of 1500 Bq/m^3 the workers' radiation exposure could reach the value 16 mSv/year when the workplace was not considered a workplace with radiation danger.)

In 2014 the Official Journal of the European Union, L13, Volume 57 17 January 2014 Legislation the „Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/EURATOM, 90/641/EURATOM, 96/29/EURATOM, 97/43/EURATOM and 2003/122/EURATOM" communication was published, based on which „Member States shall establish national reference levels for indoor radon concentrations in workplaces[6]. The reference level for the annual average activity concentration in air shall not be higher than 300 Bq/m^3, unless it is warranted by national prevailing circumstances.

Underground workplaces, mainly mines, caves are considered workplaces with potential radon danger, therefore radon concentration is important to be measured in these places[7-16].

In Hungary the regulation on workplace radon concentration has been introduced since 2003. The reference level is 1000 Bq/m^3 causing a radiation exposure of ~ 6 mSv/year. In case of a value exceeding this level the radon level must be reduced. In case the annual average radon concentration cannot be reduced below this level it should be considered a workplace with radiation danger and the workers must continuously be checked using dosimeters[17].

Radon measurement has been going on since 2003 in the tourist cave inspected by us. Results before 2007 were given account of in a previous paper of ours[18-20]. During our inspections the radon concentration in the cave was identified together with the workers' radiation exposure originating from radon. The value of radiation exposure originating from radon was also examined based on the new recommendation.

2. Method and calculation

2.1. Radon concentration measurements, and personal dosimetry in the cave

The monthly average radon concentration and the radiation exposure of those working in the cave was measured using a passive method. CR-39 type TASTRAK nuclear track-etch detectors were used[19]. Detectors were placed in NRPB and later in RADUET holders[21]. Detectors were changed monthly. During working hours the detectors were attached to the workers' clothes and after the working hours they stored in a room with low, controlled radon concentration. Taking the value measured in the store-room and the working hours into consideration the values of the workers' detectors were corrected. After the exposition the track detectors were etched in 6M NaOH solution for 2 hours, then in later years for 3 hours, and the track intensity was identified. The detectors in the different holders were calibrated in a calibration chamber (produced and calibrated by Genitron Instruments GmbH) employing a PYLON RN 2000A calibration standard source.

2.2. Calculation of the committed effective dose

Assuming the 0.4 equilibrium factor used in literature and in the Hungarian regulation knowing the measured radon concentration (C_{Rn}) a committed effective dose was calculated using the following relationship:

$$E = C_{Rn} \cdot 0.4 \cdot t \cdot K \qquad (1)$$

Where:

E is the committed effective dose (mSv), C_{Rn} is the average radon concentration (Bq/m^3), 0.4 is the equilibrium factor, t is the time (2000 h), and K is the dose conversion factor.

So far the IAEA BSS No. 115 recommendation issued by IAEA in 1996[22] was taken into account when identifying K which was applying the calculation method recommended by the ICRP publication No. 65[5]. In case of 2000 hours and an equilibrium factor of 0.4 a radon concentration of 1 Bq/m^3 at a workplace results in a committed effective dose of $6.23 \cdot 10^{-3}$ mSv/year.

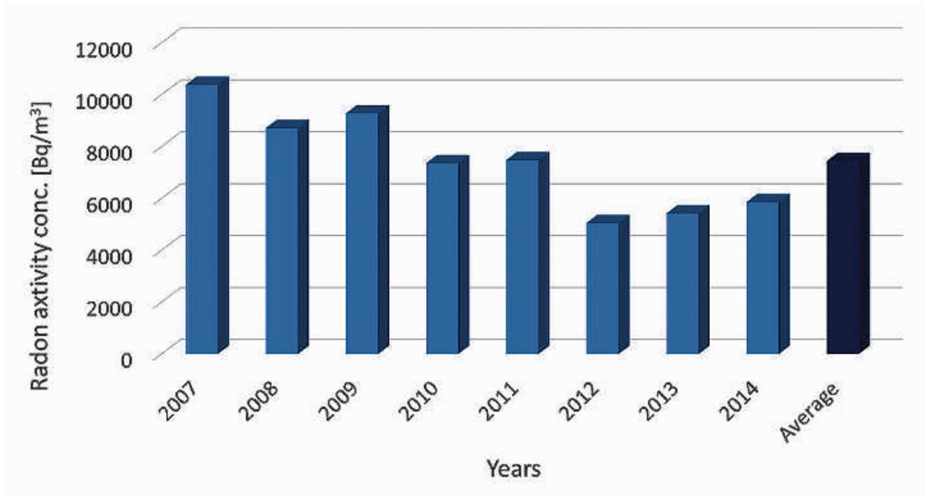

Fig. 1. Annual average radon concentration in the cave (years 2007–2014).

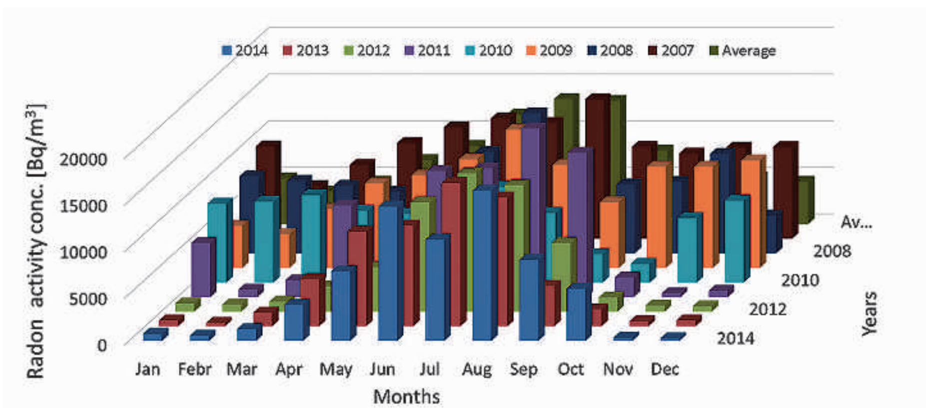

Fig. 2. Monthly changes in radon concentration in the cave in the years 2007–2014.

Based on the new statement of ICRP[5] radon risk is much greater (1.75 times the conversion factor used until now) therefore also the actual radiation exposure of the workers – estimated on the basis of recent recommendations.

3. Results and Discussion

3.1. Radon in the cave

Figure 1 shows the annual average changes of radon concentration in the years 2007–2014.

The average of the radon concentration values in the cave for 8 years was 7430 Bq/m³. As it is shown the annual average of radon concentration in each year has considerably exceeded the limit 1000 Bq/m³ (action level) given in the Hungarian regulation. It is hard to find a way to reduce radon concentration in the cave. Applying forced ventilation the climate, flora and fauna of the cave would be changed which is not advisable. By the end of the year 2011 the filling at the bottom of the cave paths was changed as coal slag had previously been used for this which had a Ra-226 concentration between 500-1300 Bq/kg. The change of the monthly average radon concentration (and the effect of the renovation) is shown in Figure 2.

The figure clearly shows that after changing the cave's subsoil filling the cave behaves like a typical foot cave that is during the winter months radon concentration is low while in summer months it is high. Before the intervention it was the highest during the summer months, but even during the winter months high concentration values were measured. This may be a reason for the average value of 8630 Bq/m³ measured during 2007-2011 and 5430 Bq/m³ measured in 2012-2014. However, these are considerably higher than 1000 Bq/m³ and the action level 300 Bq/m³ mentioned in the new recommendation. Therefore, this workplace is in the category of workplaces with radiation danger. Since the cave has a touristic purpose restricting the entry is not possible. The cave is relatively small (72 m land

Table 1. Data concerning the radiation exposure of workers in the cave

Year	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004
Months	84	78	59	74	77	72	73	61	53	56	54
Employers	14	13	11	12	12	12	13	9	14	9	10
Collective dose (p·mSv)	119	120	105	125	99	131	126	123	138	104	150
Average dose (mSv/year)	8.5	9.2	9.5	10.4	8.2	10.9	9.7	13.6	9.9	11.6	15.0
Maximum dose (mSv/year)	13.3	13.4	14.7	21.6	13.9	22.0	18.8	24.4	18.6	19.6	30.3
Maximum dose (mSv/year)	13.3	13.4	14.7	21.6	13.9	22.0	18.8	24.4	18.6	19.6	30.3
Persons >20 mSv/year	0	0	0	1	0	1	0	1	0	0	3
Average dose > 20 mSv/year				21.6		22.0		24.4			26.5
New calculation methods											
Average dose (mSv/year)	14.9	16.1	16.6	18.2	14.4	19.1	17.0	23.8	17.3	20.3	26.3
Maximum dose (mSv/year)	23.3	23.5	25.7	37.8	24.3	38.5	32.9	42.7	32.6	34.3	53.0
Persons >20 mSv/year	2	2	5	3	4	6	4	5	4	4	5
Average dose >20 mSv/year	21.9	24.1	22.6	32.9	22.4	26.7	30	34.7	27.7	29.1	40.0

and 180 m water surface for boats) so the visitors spend approximately half an hour in the cave. Calculating the 8-year average radon concentration (7430 Bq/m^3) the expected radiation exposure of visitors is 11.6 μSv (and 20.3 μSv with the new recommendation) which is totally acceptable in case of radon and means a negligible risk considering radiation exposure.

3.2. Workers' radiation exposure

Table 1 summarizes the results and data calculated based on the currently valid recommendations, and the data calculated using the new dose conversion factor. Only those workers were taken into consideration for the summary who had worked in the cave for at least 2 months during the given year.

The number of months worked by all the workers in the different years are shown together with the number of personnel, collective dose (person mSv), the average radiation exposure of the workers (mSv/year), the maximum committed effective dose (mSv/year) in the given year, the number of those workers whose radiation exposure exceeded 20 mSv/year in the given year, and the average radiation exposure of these workers.

The average radiation exposure calculated using the new dose conversion factor, the maximum dose and the number and average radiation exposure of those people whose annual committed effective dose exceeded the value 20 mSv/year.

The data clearly show that the workers' radiation exposure has been considerable during the past years, especially if calculated using the new dose conversion value. When taking the previous dose conversion values into account – except for the initial year of 2004 (3 people) – it only happened 3 times during the 10 years that somebody's radiation exposure exceeded the value 20 mSv/year, (total number of people: 6, average 24, 6 (21.6-30.3) mSv/year) which could be compensated by taking into account the dose limit having been valid before (100 mSv/5 years). However, when using the new dose conversion factor each year 2-6 people, a total of 44 people exceeded the dose limit. Their average radiation exposure was 28.9 (20.4–53.0) mSv. The question arises how the radiation exposure of the past years should be taken into account when the new regulation comes into effect. Based on the new scientific results these people have received a radiation exposure exceeding the dose limit during the past years. On what basis should the radiation exposure of the past 5 years be taken into account? In case the limit is taken strictly and we want to protect the workers then those experienced workers whose new and assumingly the actual radiation exposure values have exceeded 100 mSv/5 years during the past period should be dismissed.

Limits concerning radiation exposure can only be complied with in the future if during the summer months when radon concentration is high the possible largest number of workers should be hired and permanent workers should be given their leave or employ them in other locations. However, this may reduce the level of service as each new employee should be trained as tour guides. Occasional employment lasting for only a few months is unattractive causing further worries for the employer.

4. Summary

The annual average radon concentration in the cave inspected has been rather high during the past 8 years (7430 Bq/m^3), although it has been managed to be reduced during the past 3 years to an average value of 5430 Bq/m^3. Still, it considerably exceeds the 1000 Bq/m^3

action level value currently valid in Hungary and also the value 300 Bq/m^3 on workplaces given in the new EURATOM recommendation. The cave should be considered a workplace with radiation danger and the radiation exposure originating from radon of those working there needs to be continuously measured.

Inspections so far have shown that by careful work arrangement and involving occasional employees during the summer months can help achieve keeping the radiation exposure of those permanently working there under the dose limit 20 mSv/year (actually 100 mSv/5 years). Taking the new dose conversion factor into account the radiation exposure have exceeded the value 20 mSv/year (average 28.9 mSv/year) by 44 people during the past 11 years making the employer face a new challenge, and the question arises whether the people having received > 20 mSv/year radiation exposure before can be further employed or not.

Acknowledgements

The present study was supported by the Hungarian State and the European Union projects Grant No. TÁMOP-4.2.2.A-11/1/KONV-2012-0071.

References

1. IAEA (2014) Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. ISBN 978-92-0-135310-8. International Atomic Energy Agency, Vienna.
2. WHO., 2009. A public health perspective, WHO handbook on indoor radon. World Health Organization, Switzerland.
3. ICRP, 1993. Protection Against Radon-222 at Home and at Work. ICRP Publication 65. Ann. ICRP 23(2).
4. ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37(2-4).
5. ICRP, 2010. Lung Cancer Risk from Radon and Progeny and Statement on Radon. ICRP Publication 115, Ann. ICRP 40(1).
6. COUNCIL DIRECTIVE 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/EURATOM, 90/641/EURATOM, 96/29/EURATOM, 97/43/EURATOM and 2003/122/EURATOM.
7. Bahtijari M, et al. (2008) Exposure to radon in the Gadime Cave, Kosovo, J Env Radioact, 99(2):343–348.
8. Fijałkowska-Lichwa L et al. (2014) Short-term radon activity concentration changes along the Underground Educational Tourist Route in the Old Uranium Mine in Kletno (Sudety Mts., SW Poland), J Environ Radioact 135:25–35.
9. Panigrahi DC, et al. (2014) Assessment of inhalation exposure potential of broken uranium ore piles in low-grade uranium mine. J Radioanal Nucl Chem. 302:433–439.
10. Kavasi N, et al (2011) Dose estimation and radon action level problems due to nanosize radon progeny aerosols in underground manganese ore mine. J Environ Radioact, 102(9):806–812.
11. Hakl J, et al. (1997) Radon transport phenomena studied in Karst caves-international experiences on radon levels and exposures, Radiat Meas, 28(1):675–684Gregorič A, et al (2011) Dependence of radon levels in Postojna Cave on outside air temperature, Nat Hazard Eearth Sys, 11(5):1523–1528.
12. Skubacz K, et al. (2011) Occupational radiation risk caused by NORM in coal mining industry Radioprot 46(6):S669–S674.
13. Quindós Poncela L, et al (2004), Radon exposure in uranium mining industry vs. exposure in tourist caves, Radiat Prot Dosim, 111:41–44.
14. Vaupotič J, et al. (2001) Methodology of radon monitoring and dose estimates in Postojna Cave, Slovenia, Health Phys, 80:142–147.
15. Lario J, et al. (2005) Radon continuous monitoring in Altamira Cave (northern Spain) to assess user's annual effective dose. J Environ Radioact, 80(2):161–74.
16. Doyi I, (2013) Assessment of occupational radiation exposure in underground artisanal gold mines in Tongo, Upper East Region of Ghana. J Environ Radioact, 126:77–82.
17. Kávási N, et al. (2003) Occupational and patient doses in the therapeutic cave, Tapolca (Hungary) Radiat Prot Dosim, 106:263–266.
18. Somlai J, et al. (2009) Radiation dose of workers originating from radon in the show Cave of Tapolca. Journal of Radioanalytical and Nuclear Chemistry, 279:219–225.
19. Somlai J, et al. (2010) Annual average radon concentration in the show caves of Hungary J Radioanal Nucl Chem, J Radioanal Nucl Chem, 303:885–890.
20. Kávási N, et al. (2010) Estimation of effective doses to cavers based on radon measurements carried out in seven caves of the Bakony Mountains in Hungary, Radiat Meas, 45(9):1068–1071.
21. Sorimachi A, et al. (2012) Performance test of passive radon–thoron discriminative detectors on environmental parameters Radiat Meas 47(6):438–442.
22. IAEA (1996) International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources Safety Series, No. 115, International Atomic Energy Agency, Vienna.