THE JOURNAL OF PREVENTIVE MEDICINE
2002; 10 (2): 46-51

INFLUENCE OF VENTILATION AND AEROSOL SIZE ON THE ANNUAL EFFECTIVE DOSE RECEIVED BY REFERENCE WORKERS IN URANIUM MINES

Vlad C. Tomulescu[1], Raluca Gheorghe[2], Olga Iacob[3]

1.University of Bucureşti, the Physics Faculty; 2. Institute of Public Health, Bucureşti; 3. Institute of Public Health, Iaşi

Abstract. A high level of radon daughters concentration has a tremendous impact on the effective dose received by the workers. This paper presents the annual effective doses received by different Reference Workers performing different type of activity in uranium mines. The effect of mitigation is presented as a comparison of the annual dose levels for equilibrium and for non-equilibrium conditions between radon and its short-lived decay daughters.
Key words: radon daughters, Reference Worker, annual effective dose

Rezumat. Concentrația ridicată a descendenților de viață scurtă ai radonului în minele uranifere are o influență importantă asupra dozei efective anuale primite de muncitori. Prezenta lucrare are drept scop calcularea dozelor efective anuale primite de Muncitorul de Referință în funcție de tipul respirației în cursul efectuării diferitor activități intr-o mina de uraniu. Sunt comparate dozele efective anuale in condiții de ne-echilibru si de echilibru secular între radon si descendenții acestuia.
Cuvinte cheie: descendenți ai radonului, „muncitor de referință", doză efectivă anuală

INTRODUCTION

The atmosphere of a mine can be characterized mainly by the following physical parameters: temperature, relative humidity and particle size distribution of aerosols, volume concentration of radon, age of ventilation air and volume concentration of the radon decay products. In the air of the uranium mine, the concentration of ^{222}Rn and its daughter products depends on the richness of the ore and its composition, its physical and geological structure and the techniques of mining and ventilation. Human practices, type of extraction, transport or maintenance is also influencing the activity concentration. The radioactivity in a mine atmosphere stems from emanation from the ore bodies, the mine walls and mine waters. Radon gas, soluble in water, can be transported by underground water over long distances and released when the pressure over the water is reduced. At a temperature of 20^0 C, when an equilibrium state is reached, radon will be present in water at 0.23 times the concentration it has in the air in contact with.

METHOD

The radioactive contamination in mine arises from the ^{222}Rn gas, its unattached daughter products, or daughter products attached to dust particles. The radioelements potentially hazardous to the miners are ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po. The most important contribution to the organ dose and thus to the effective dose belongs not to the parental radon, but to its decay daughters (RnD). The particle size of an aerosol, usually found in a mine (which attachment is significant as an inhalation hazard), is 0.14 μm (AMAD).

Aerosol measurements in mines, indoors and inside human respiratory tract have shown a range between 0.05 and 0.5 μm, but rarely bigger hygroscopic aerosols can be also found. From the radiation protection point of view, great importance is related to the fraction of free ions and those attached to particles, because the free ions, being smaller in size, are mainly deposited on the bronchial epithelium. The fraction of unattached (free) ions, though with important contribution to the dose, was determined by several methods and considered small (about 15%), as compared to the fraction of the attached ones. Relative humidity also modifies the conditions of attachment of free fraction to aerosols by changing the total number of condensation nuclei; a high level of humidity (often close to 100% in underground mines) reduces the proportion of the free fraction (1). For calculation purposes, the paper is considering all radon daughters attached to aerosols. For a better evaluation, the data were computed for aerosols ranging from 0.01 to 10 μm.

The amount of ^{222}Rn present in the mine atmosphere depends on the rate of emanation into the mine, the rate of removal by ventilation, and the build-up of radioactive decay daughter products. The immediate daughters of radon gas have short half-lives and thus will rapidly build up in an atmosphere containing radon, though freshly emanated radon is free of them. Equilibrium is reached in about three hours. Ventilation greatly affects the equilibrium condition, and therefore it is rare, even in poorly ventilated mines, to find equilibrium conditions. As an example, if we take 0.1 air change / minute (assuming perfect mixing), the ^{222}Rn : ^{218}Po : ^{214}Pb : ^{214}Bi : ^{214}Po ratios are estimated to be about 1 : 0.71 : 0.14 : 0.04 : 0.04, respectively (2), which relates to an equilibrium factor of 0.16. The paper presents a comparison between the annual effective doses in both cases, when secular equilibrium is reached, and when that above-mentioned equilibrium ratio between radon and its daughters is established.

For annual dose calculations, the ModeLung software was used (3). ModeLung is the software based on Human Respiratory Tract Model (4) and on the data available in the International Commission on Radiological Protection, Publication no. 66 (5). It calculates organ equivalent doses and, when applying the appropriate organ weighting factors, the daily, monthly or annual effective doses.

The four subjects analyzed in this work are the Reference Workers, as it follows:

1) normal nose breather performing usual work;
2) normal nose breather performing heavy work;
3) habitual mouth breather performing usual work;
4) habitual mouth breather performing heavy work.

All data were computed taking into account the risk organ's weight and subjects' respiration rate (1.2 m^3/h for usual work and 1.7 m^3/h for heavy work).

The tissue weighting factors (w_T) are important for calculation of effective dose from the organ dose equivalents. They are a measure of organ radio sensitivity related to all body. The weighting factor for naso-pharynx (N-P) region is not specified in the recommendations of the International Commission on Radiological Protection (ICRP), because of the low number of extra-thoracic cancers observed, so it should be included in the list of remainder tissues (a total value of 0.05). But it is as well stated that if one of the remainder tissues receives an equivalent dose in excess of the highest dose in any of the 12 organs or tissues for which w_T was specified, that organ should receive a weighting factor of half the remainder, i.e. 0.025. The other half is used for the rest of remainder tissues. The deposition of radioactive material being most important in the N-P region, as entrance way to the respiratory tract, the organ dose equivalent will be the highest for the extra-thoracic tissue (6). This enables us to use the value of 0.025 for the N-P tissue-weighting factor and 0.025 to blood, as material provider for the rest of remainder organs. The lung-weighting factor is 0.12, and according to the "regional lung dose concept" it should be separated (7). An apportionment of 0.08 has to be assigned to the tracheo-bronchial (T-B) region and 0.04 for the pulmonary (P) region. The lung lymph nodes will have a corresponding weighting factor of 0.00012. For the gastro-intestinal tract (G-I) we propose the weighting factor of the stomach, i.e. 0.12.

The material intake by inhalation is calculated with the following formula:

$$I = C \times R \times t$$

Where:
I - the intake of activity (kBq);
C - radon concentration (kBq/m^3);
R - respiration rate (m^3/h);
t - duration of working in environment (h);

1kBq/m^3 radon was taken into calculation for activity concentration in mine. The annual effective dose was computed from the hourly effective dose (t = 1h), by multiplying it with 2,000 h (40 working hours per week; 50 weeks per year), in order to compare it with the annual limit of effective dose (20 mSv).

RESULTS AND DISCUSSION

From figure 1 it can be noticed first that for equilibrium condition between radon and its daughters, the annual effective dose due to RnD is almost double, but in all cases, the minimal exposure is for 0.2 µm aerosols. In equilibrium condition (which is a theoretical situation), the mouth breather receives the highest annual effective dose when a heavy work is performed in large aerosols environment (larger than 1.2 μm).

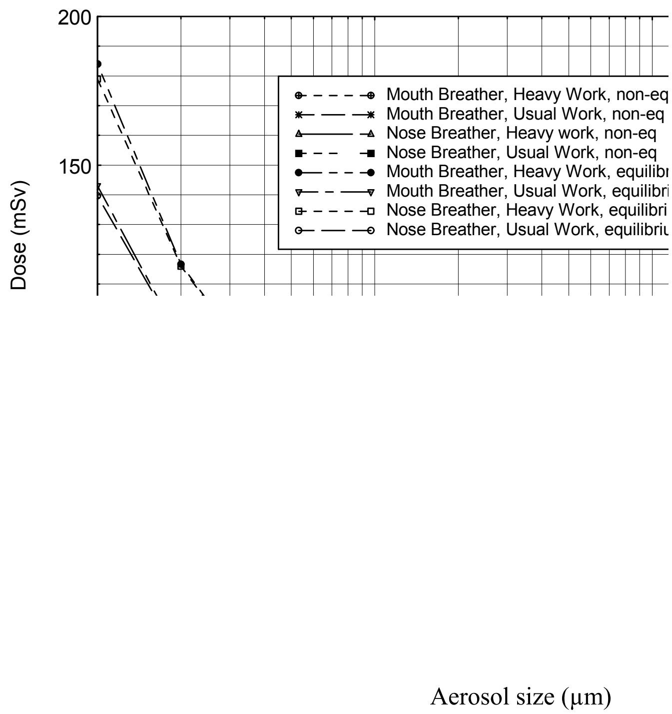

Fig. 1. Annual Effective Doses for the Reference Worker performing labor activity

In the range of 0.05 ÷ 1.2 μm aerosols, all nose breathers receive a higher effective dose than the mouth breathers performing same work.

All Reference Workers from an environment with 1kBq/m^3 concentration of radon and where the equilibrium is reached receive a dose above the Annual Limit of 20 mSv.

In the case of non-equilibrium (as defined above), the Reference Workers receive an annual effective dose below the limit for aerosols in the range of:

- 0.06 ÷ 0.7 μm, for the nose breather performing heavy work;
- 0.06 ÷ 0.9 μm, for the mouth breather performing heavy work;
- 0.04 ÷ 1.6 μm, for the nose breather performing usual work;
- 0.04 ÷ 1.4 μm, for the mouth breather performing usual work.

In figure 2 is presented the annual effective doses as a function of the equilibrium factor F (obtained for the nose breather Reference Worker performing usual work, in 1kBq/m^3 radon concentration). Obviously, the dose is increasing continuously as the environment condition is approaching to the secular equilibrium.

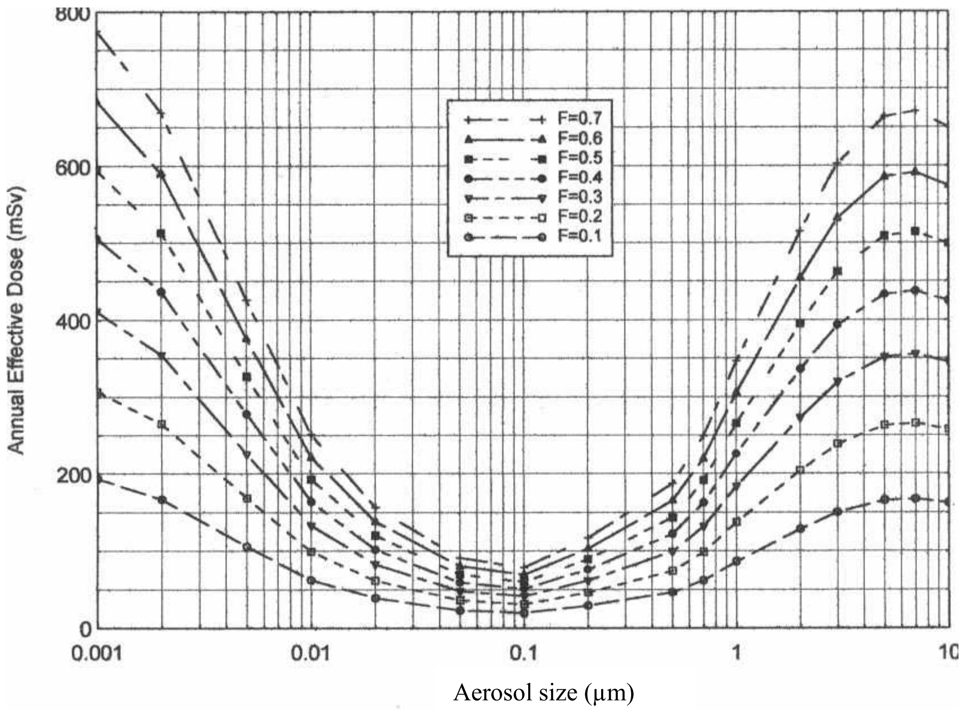

Fig.2. Annual Effective Dose as function of Equilibrium Factor

CONCLUSION

An intense ventilation of 1 air change / minute in uranium mines can decrease the annual dose level with about 50%.

In such settled non-equilibrium condition, the work performed in radon concentration of 1 kBq/m^3 and aerosol range 0.06 ÷ 0.7 μm is not assuming effective doses above the annual limit of effective dose (20 mSv).

REFERENCES

1. S.A. Durrani, R. Ilic: *Radon Dosimetry and Monitoring in Mines*, Radon Measurements by Etched Track Detectors, Applications in Radiation Protection and the Environment, World Scientific, 1997.
2. xxx Technical Reports Series, Publication No.142: *Inhalation Risks from Radioactive Contaminants*, IAEA Vienna, 1984.

3. V. Tomulescu: *Biomathematical Models for Radon Daughters Inhalation*. The ModeLung software, presentation at the Second International Colloquium on Mathematics in Engineering and Numerical Physics; 2002, April, 22-27, Bucharest Polytechnic Institute.
4. M.R. Bailey: *The New ICRP Model for the Respiratory Tract*, Radiation Protection Dosimetry, 1994, 53 (1-4): 107-114.
5. xxx International Commission On Radiological Protection, Publication No.66: *Human Respiratory Tract Model for Radiological Protection*, Pergamon Press, 1993.
6. V. Tomulescu: *Internal Dose Assessment for Workers Inhaling Radon Daughters as function of Aerosol Size*, In: Journal of Preventive Medicine, 2002, 10 (1): 55-64.
7. xxx International Commission On Radiological Protection, Publication No.32: *Limits for Inhalation of Radon Daughters by Workers*, Pergamon Press, 1981.
8. Monique Roy, Catherine Courtay: *Daily Activities and Breathing parameters for use in the Respiratory Tract Dosimetry*, Radiation Protection Dosimetry, 1991, 35 (3): 179-186 .
9. L. Koblinger, W. Hofmann: *Analysis of Human Lung Morphometric Data for Stochastic Aerosol Deposition Calculations*, Physics in Medicine & Biology, 1998, 30: 541-556.
10. O. Castren: *Strategies to Reduce Exposure to Indoor Radon*, Radiation Protection Dosimetry, 1988, 24 (1-4): 487-490.
11. J. Porstendorfer: *Influence of Physical Parameters on Doses from Radon Exposures*, 5th International Conference on High Levels of natural Radiation and Radon Areas, International Congress Series *1225*, 2002, p.149-160.
12. Renate Winkler-Heil, W. Hofmann: *Comparison of Modeling Concepts for Radon Progeny Lung Dosimetry*, 5th International Conference on High Levels of natural Radiation and Radon Areas, International Congress Series *1225*, 2002, p. 169-177.
13. W. Jacobi, K. Eisfeld: *Dose to Tissues and Effective Dose Equivalent by Inhalation of Radon-222, Radon-220 and their Short-Lived Decay Daughters*, Gesellschaft fur Strahlen- und Umweltforschung mbH, GSF-Report *S-626*, 1980.