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INTERNAL DOSES AS FUNCTION OF AEROSOL SIZE FOR THE REFERENCE WORKER INHALING RADON DAUGHTERS

V.Tomulescu

University of Bucharest, Faculty of Physics

Abstract. The paper presents an assessment of internal doses received by workers in Uranium mining, due to inhalation of radon daughters. Four Reference Worker subjects have been taken: normal nose breathers performing usual work, or heavy work, and habitual mouth augmenter involved in heavy or usual work. The total activity duration is 6 hours, i.e. one working day. The equilibrium between radon and its decay products was considered at 1 kBq/m^3 mean concentration of Radon activity in air. The paper takes into account the contribution to internal dose of all short live radon daughters, all being considered attached to aerosols. The aerosol size is ranging from 0.0006 μm to 20 μm.
The work shows radiation doses on several internal organs and tissues and the effective dose, as function of aerosol size. Results were computed with ModeLung software, based on ICRP Publication 66 data
Key words*: *reference worker, inhalation, radon daughters, aerosol size, organ dose, effective dose

Rezumat. Lucrarea îşi propune o evaluare a dozelor echivalente primite de muncitori din mineritul uranifer in urma inhalării de descendenți ai radonului. S-au luat în studiu patru cazuri aplicate Muncitorului de Referință: cu respirație normală pe nas, efectuând o activitate uzuală sau muncă fizică intensă şi cu respirație pe gură implicați în munca uzuală sau intensă. Perioada de activitate este de 6 ore, adică o zi de munca. S-a considerat cazul echilibrului secular stabilit între radon si produşii săi de filiație, la o concentrație medie de activitate a radonului in aer de 1 kBq/m^3. Lucrarea ia in calcul contribuția tuturor descendenților de viață scurtă ai radonului, aceştia fiind considerați ca fiind în totalitate ataşați de aerosoli. Domeniul de dimensiuni ale aerosolilor inhalați în mineritul uranifer este de 0.0006-20 μm. Lucrarea prezintă doza echivalentă calculată pentru câteva țesuturi si organe interne, în funcție de dimensiunea aerosolului. Rezultatele au fost obținute cu ajutorul programului de calcul ModeLung, pe baza datelor furnizate de ICRP Publication 66.
Cuvinte cheie: Muncitor de Referință, inhalare, descendenți radon, dimensiune aerosol, doza echivalentă

INTRODUCTION

The main source of radiation of workers in Uranium mines is represented by the radon gas and its daughters (RnD) attached to aerosols. For radiation protection purposes, one should calculate the radiation level for workers performing activity in contaminating environment. The radioactivity concentration in air, aerosol size, duration and type of labor in environment, and subject's physical and physiological data should be taken into account (1-5). Since the radon

daughters are alpha emitters, their main target is the respiratory tract with its organs and tissues (2,3).
The purpose of this study was to assess the equivalent doses that may be received by workers due to inhaled radon progeny in uranium mining.

METHOD

The subject chosen for this study is the Reference Worker, with all its anatomical data as considered in International Commission on Radiological Protection, Publication no. 66 (1). We discussed the 4 cases of a Reference Worker as it follows: normal nose breather performing usual labor (respiration rate 1.2 m^3/h); habitual mouth breather performing usual labor (respiration rate 1.2 m^3/h); normal nasal augmenter performing heavy work (respiration rate 1.7 m^3/h); habitual mouth breather performing heavy work (breathing rate 1.7 m^3/h). The subjects are involved during 6 hours in their specific type of activity, so the final results represent the dose values after one working day of exposure.
The organs at risk considered are:

- the extrathoracic region containing the nasal passage, the pharynx and the larynx; labeled Naso-Pharynx (N-P);
- the trachea, bronchial and bronchiolar regions, up to the terminal bronchioles; labeled the Tracheo-Bronchial region (T-B);
- the alveolar interstitial tissue, containing the respiratory bronchioles, the alveolar ducts and the alveoli; labeled Pulmonary region (P);
- the respiratory lymph nodes; labeled Lymph Nodes region (LN);
- the body fluids, represented by blood and plasma; labeled Body Fluids region (BF);
- the gastro-intestines; labeled Gastro-Intestinal duct (G-I).

It was considered a mean concentration of Radon activity in air: 1 kBq/m^3, in equilibrium with its decay daughters. The final results represent the contribution of all radon daughters. This paper takes into account only the atoms (RnD) attached to aerosols. The aerosol size is ranging from 0.0006 μm to 20 μm, and represents the Activity Median Thermodynamic Diameter (AMTD) (up to 0.1 μm) and Activity Median Aerodynamic Diameter (AMAD) (up from 1 μm).
The results were obtained with ModeLung software (V.2.2) (6). ModeLung is a computer program, modeling the physical and physiological processes during and after radionuclide inhalation, when using the data base available in the International Commission on Radiological Protection, Publication no. 66 (2) and the recommendations from Technical Reports Series, Publication no. 142, “Inhalation Risks from Radioactive Contaminants” (7). The organ doses should be seen as parts of the effective dose. They are calculated from the organ dose equivalents, when applying the tissue weighting factors.

RESULTS

Doses to the N-P region

The Fig. 1 presents the dose distribution on the N-P region as function of aerosol size, on a logarithmic scale. It can be observed that the organ dose is higher as the aerosol is smaller. The organ doses present a maximum for 7 μm aerosols for normal nose breathers, and a maximum at 15-20 μm for habitual mouth breathers. The organ doses are minimum at 0.1 aerosols, for all subject cases.

It can be noticed that the doses are higher for nose breathers than for mouth breathers, which is a normal fact since the naso-pharynx is more exposed in the case of nasal respiration.

The dose values are higher for subjects performing heavy work, because of a higher activity intake.

The small dose difference for large aerosols is justified by the anatomical difference of nose and mouth airways, the mouth breathers' respiration ducts being larger than the nasal ducts, so the penetrability of aerosols in the pharynx is increased by mouth intake, while the anterior nose is tremendously stopping the large aerosols.

Doses to the T-B region

Fig. 2 is presenting the doses to the T-B region as function of aerosol size. The higher doses are received by the mouth breather performing heavy work, and are maximum for 0.003 μm aerosols. Same aerosol size offers maximum doses to the other subjects.

There is a minimum dose for 0.3 ÷ 0.5 μm aerosols, in all cases.

The organ dose curves show a second maximum for 3 ÷ 5 μm aerosols in all cases.

It should be pointed out that here is no significant difference between doses in similar cases for small aerosols (up to 1 μm). The dose difference between mouth breathers and nose breathers is increasing for aerosols up from 1 μm (higher for mouth) because of the larger dimension of mouth airways. The difference is continuously decreasing again for aerosols larger than 5 μm because of general aerosol stopping in upper N-P.

Doses to pulmonary region

In Fig. 3 it can be seen the distribution of organ doses to the pulmonary active region, as function of aerosol size. For all cases, the doses to the pulmonary region are higher for aerosols of 0.01÷0.02 μm.

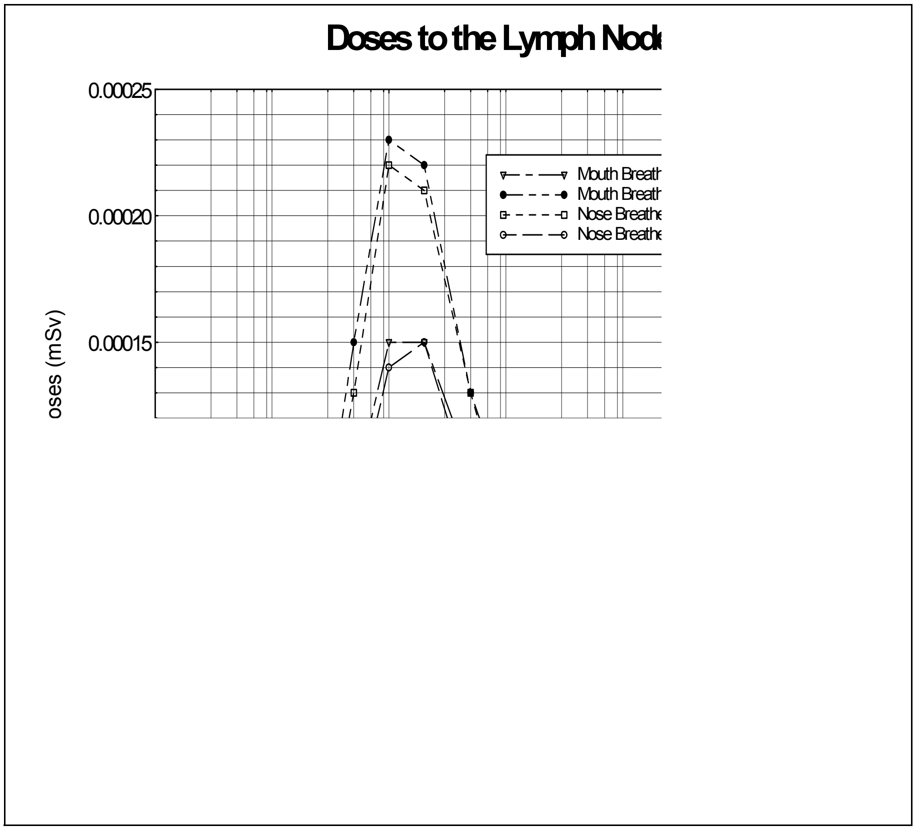
In the case of mouth breather, it can be as well observed a maximum at 2÷3 μm. This one has a possible correspondence to the maximum of doses to T-B region – positioned at 3 μm (same case of mouth breather). The correspondence is explained by the fact that the lung model currently used in ModeLung takes into account the nuclides transportation (with two rates) from the P region to the T-B region. Probably, the same influence can be observed for any other subject, in case of a higher intake by inhalation.

For extremely small or extremely large aerosols, the doses to pulmonary region are minimum, probably because of deposition processes to the upper levels of the respiratory tract. For medium sized aerosols, the mainly process is the clearance, keeping the material on site, with a tremendous impact on the organ dose. The particles attached to medium and to large aerosols (mainly inhaled by mouth) are slower transported from the alveoli – suggested by the second maximum at about 2 μm.

Doses to Pulmonary regi

Doses to the lymph nodes

The dose distribution on the Lymph nodes is similar to the one in the Pulmonary region, since the alveolar region is its main and only provider of radioactive material. Because of the other processes of deposition, transportation and clearance in pulmonary region, the doses to the lymphatic system are 10% smaller. Consequently, the doses show a similar distribution with respect to all processes in the alveoli (Fig. 4).



The organ doses for subjects involved in heavy work are obviously higher than the ones of reference workers involved in usual work. There is always a sensible difference, with a plus for the habitual mouth breather.

Doses to the body fluids

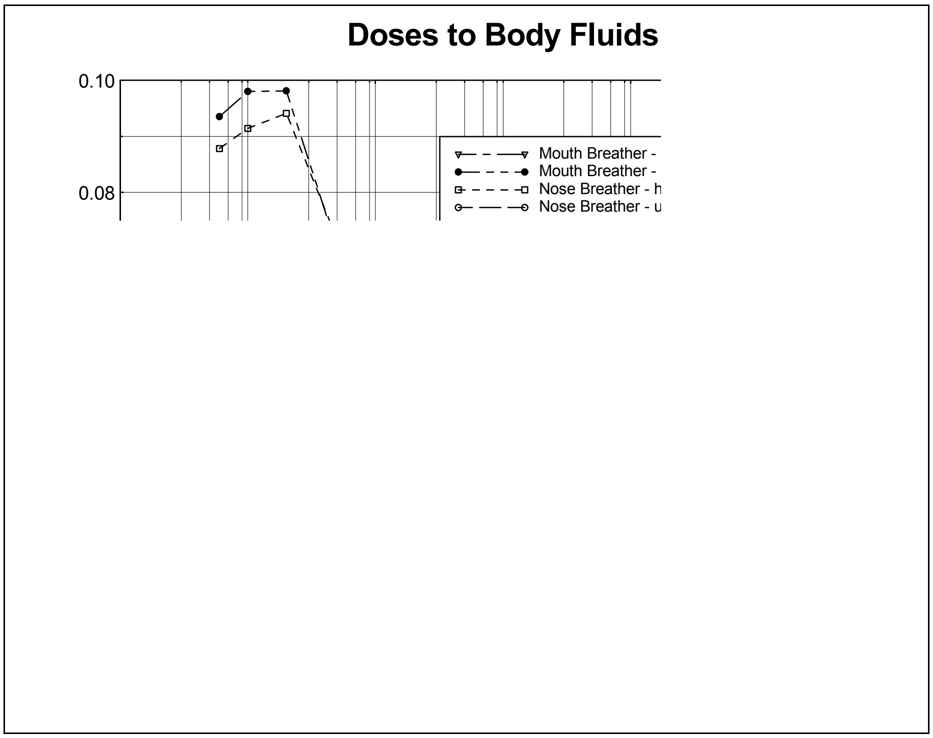
The dose distribution to the body fluids can be seen in Fig. 5.

A first observation is that the dose distributions are very similar to the ones of doses to the N-P region, with a minimum at about 0.1 µm aerosols.

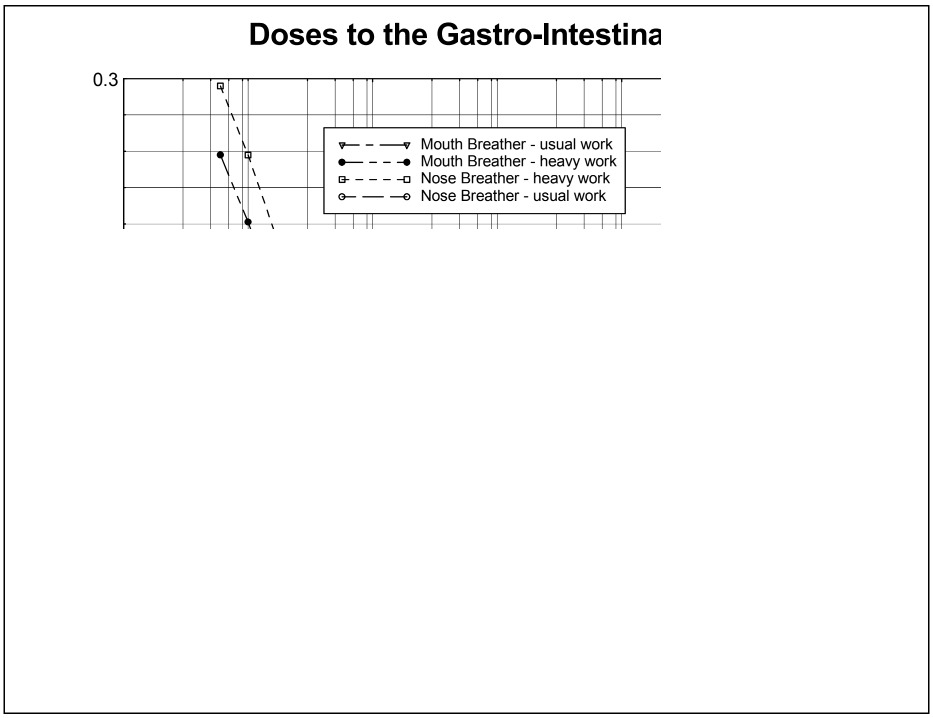
For large aerosols, there is a sensibly higher dose for the nose breather. This can be explained by the contribution of material transported from the N-P region. Starting with values of 10 µm, the difference is quite negligible, because of competition of transported material from N-P (more for nose breather) and the one transported from T-B, P and LN – more deposited material in the case of mouth breather.

For extremely small aerosols, there is a plus of dose for the mouth breather, which comes from the material transported from the T-B region. Unfortunately there is no available data, but probably, for smaller aerosol size, the curves may join together

because of increasing contribution of material transported from Naso-Pharynx .
The last observation which can be made is that obviously, the higher respiration rate, the higher dose. That means the heavy worker always receives a higher dose to body fluids.

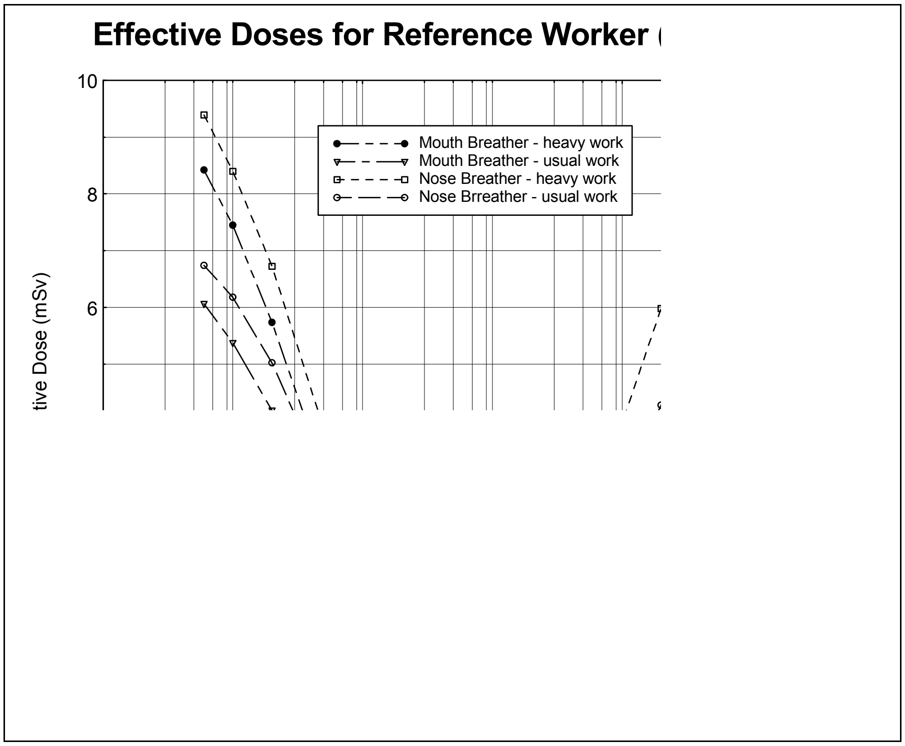


Doses to the gastro-intestinal tract
In Fig. 6, it can be seen the distribution of doses to the gastro-intestinal tract as function of aerosol size. The G-I tract is fed with transported material from only N-P and T-B regions. As the deposition to the N-P is higher than the deposition to the T-B, the shape of the curves for G-I is very similar to the one seen in Fig. 1 for the N-P region.
Consequently, the dose values are higher for the normal nose breather than for habitual mouth breather.
The doses show a general minimum at 0.1 µm aerosols, and increase with the decrease of aerosol size. A maximum is observed for 7 µm aerosols (in case of nose breathers) and for 15-20 µm aerosols (in case of mouth breathers).
Obviously, the subject involved in heavy work, receives higher doses.



Effective doses

The effective doses were computed for all 4 subjects by addition of all organ doses respectively. It was consequently obtained the Fig. 7, presenting the distribution of effective doses to the Reference Worker. Because the highest dose is always received by the N-P region, for the effective dose it was obtained an expectable similar distribution to this region in relation to aerosol size.



CONCLUSIONS

1. The most important conclusion it can be pointed out is that the minimum effective dose received by any subject is for 0.1 µm aerosols.
2. It can generally be stated as well, that the smaller aerosol, the higher effective dose. Fortunately, the RnD attachment to aerosols has a low probability on the range of low AMTD.
3. The normal nose breather is subject to higher doses to the naso-pharingeal region, and the gastro-intestinal tract.
4. The mouth breather receives higher doses to the tracheo-bronchial system.
5. No matter the respiration way, the alveoli, the lymph nodes and the body fluids are almost equally exposed to radiation in both cases – nose and mouth breather.
6. In any case, the dose level to the naso-pharynx is always the highest, and 10 times higher than the one to the tracheo-bronchial system, which is the second organ at risk.
7. For aerosols up to 0.1 µm, no matter the respiration way, the heavy workers are more exposed to radiation, so the respiration rate has

a tremendous impact to the effective dose.

8. For aerosol size ranging from 0.1 to 7 μm, no matter the breathing rate, the nose breather receives higher effective doses than any other subject exposed for the same duration, while performing any type of activity.

REFERENCES

1. Dixon D.W. – *Hazard assessment of work with ones containing elevated levels of natural radioactivity*. NRPB-R 143, 1984.
2. International Commission On Radiological Protection, Publication No.66, "*Human Respiratory Tract Model for Radiological Protection*", Ann. of ICRP 1994, v. 24, 1-3.
3. Int. Com. on Rad. Prot. Pub. No. 68- *Dose coefficients for intake of radionuclides by workers*. Am. of ICRP (1995), v. 24, 4.
4. Documents of NRPB – *Standards for intakes of radionuclides*. 1998, v. 9, 4, p. 29.
5. Kendall G.M., Muirhead C.R., MacGibbon B.H. and al – *First analysis of the National Registry for radiation workers. Occupational exposure to ionizing radiation and mortality.* NRPB-R 251, 1992, p. 102
6. V.Tomulescu – "*Biomathematical Models for Radon Daughters Inhalation. The ModeLung software*" – personal communication: Second International Colloquium on Mathematics in Engineering and Numerical Physics, 2002, April, 22-27, Bucharest Polytechnic Institute.
7. Technical Reports Series, Publication No. 142, "*Inhalation Risks from Radioactive Contaminants*".