EFFECTIVE DOSES AS A FUNCTION OF AGE AND GENDER FOLLOWING AN INDOOR INTAKE OF RADON DAUGHTERS

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Abstract. The paper presents an assessment of effective doses received by different categories of population because of Radon daughters inhaled when performing indoor activity. The results show the distribution of the effective doses as function of aerosol size, for different types of activity. The effective doses were computed by the aid of the original ModeLung software, based on the compartment model of the respiratory tract.

Key words: compartment model, Radon daughters, aerosol, effective dose.

INTRODUCTION

Radon and its decay products are the main source of irradiation by natural ways for population. The main contribution to the dose belongs not to the inhaled Radon gas but to its short lived decay daughters (Po-218, Bi-214, Pb-214, and Po-214), which are α (Po-218, Po-214) and β (Bi-214, Pb-214) emitters, attached to aerosols. Calculation of radiation doses due to Radon and its daughters received by different categories of population is of great importance. The intake relates to the radioactive material that is deposited and consequently absorbed in the different tissues or organs. Age, gender and type of activity determine the respiration rate. The tissue masses are involved in organ doses calculations, depending also on age and gender. Therefore, when applying a tissue weighting factor and summarizing on all organs, one can calculate the effective dose for a particular subject, performing a specific activity in the contaminating environment. The ModeLung software is computing doses due to α and β radiation generated by all Radon daughters.

METHOD

The ModeLung software is an original computer program, based on the human respiratory tract model [1]. It was developed at the Elementary Particle

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Physics Department within the Faculty of Physics of the University of Bucharest. A complete compartment model should include the main organs or tissues that get first into contact with the material of intake, as well as the connective organs or tissues where the material is transported to, represented by compartments. The pathways (arrows) or sub-compartments (pools), which are describing the transit or deposition of material, suggest all physiological phenomena.

As a first step into determining the target organs one should design a compartment model to fit onto the anatomical structures (Fig.1). The main compartments are the following ones:

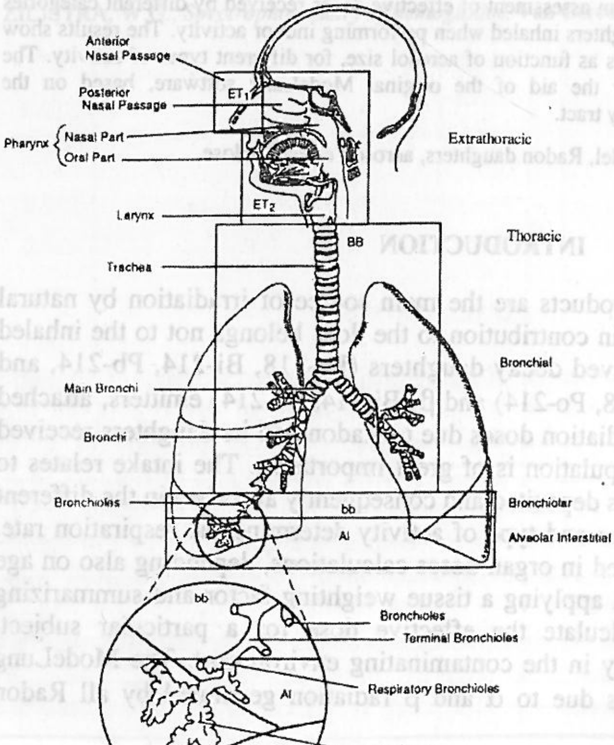

Fig. 1. – The human respiratory system [1].

- the extrathoracic region (ET) – labeled as well the naso-pharynx region (N-P), comprising the anterior nose (ET1), and the posterior nasal passages, the larynx, pharynx and mouth (ET2);
- the tracheo-bronchial region (T-B), containing the trachea and the bronchi from which the deposited material is cleared by ciliary action (BB), and the bronchiolar region (bb), consisting of the bronchioles and terminal bronchioles;

- the alveolar-interstitial region (AI) – labeled as well pulmonary region (P) – consisting of the respiratory bronchioles (bronchioles with some alveoli supposed, generation 16th to 18th), the alveolar ducts and sacs with their alveoli, and the interstitial connective tissue;
- the lymph nodes (LN).

All regions contain lymphatic tissue or components of it. Fluid accumulated in the interstitial connective tissue is collected in lymph capillaries, from which it flows in one direction into the lymph vessels, and passes through one to several lymph nodes. The lymph nodes of the extrathoracic regions are considered of low interest for dosimetry purposes. The lymph nodes of the thoracic regions, which are morphologically located in the bronchial region (BB), drain this region as well as the bronchiolar (bb) and alveolar-interstitial (AI) regions.

The gases (as Radon) and the vapors that are inhaled by the humans suffer a process of uptake into the body fluids. The inhaled solid materials as the Radon daughters attached to the aerosols are first deposited in the main regions of the respiratory tract – the N-P, the T-B and the P regions. From there, one amount of material is transported to different regions, and the rest of material is absorbed into blood and body fluids.

The compartment model for dosimetry purposes is shown in Figure 2. The connective compartments considered of main interest for this study are:

- blood and body fluids (BF);
- gastro-intestinal tract (G-I).

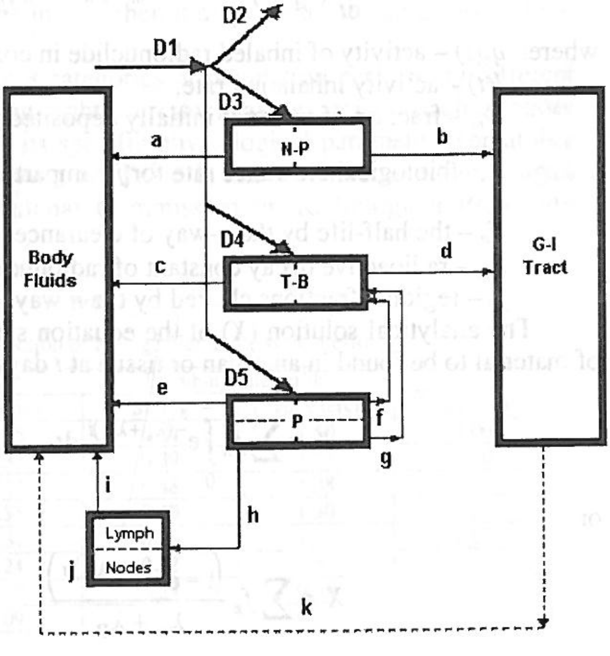

Fig. 2. – The compartment model (adapted from [2]).

The letters “a” to “j” corresponding to one sub-compartment indicate the different clearance and translocation pathways, as it follows:

a. rapid absorption of material deposited into the naso-pharynx directly into the systemic blood;

b. activity clearance by ciliary mucus transport from the naso-pharynx to the gastro-intestinal tract;

c. rapid absorption of activity deposited in the tracheo-bronchial compartment into the systemic circulation;

d. rapid ciliary mucus transport from the T-B compartment to the G-I;

e. direct translocation of the activity from the pulmonary region to the blood;

f. rapid clearance phase from the lung to the G-I via the tracheo-bronchial tree; it depends on alveolar phagocytosis and muco-ciliary movement;

g. like f, except that it is much slower and depends on the nature of the activity deposited;

h. slow removal of activity from the lung compartment *via* the pulmonary lymph, depending on phagocytic activity and lymph drainage;

i. represents a secondary pathway in which activity is cleared by the lymph in process (h) and is introduced into the blood; this process depends on the dissolution of the particles and probably on the turnover of lymphocytes;

j. the process by which activity in the G-I tract from process b, d, f, and g can find its way into the blood stream; it is not taken into account in this study.

According to these considerations, one should set a system of differential equations:

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(q_n(t)\right)=I(t)\cdot D_m\cdot f_n-\lambda_n q_n(t)-\lambda_{\mathrm{R}} q_n \qquad (1)$$

where: $q_n(t)$ – activity of inhaled radionuclide in compartment n; (n = a ÷ j)

$I(t)$ – activity inhalation rate;

D_m – fraction of material initially deposited in the n organ;

λ_n – biological clearance rate for j compartment; $\lambda_n=\frac{\ln 2}{T_n}$;

T_n – the half-life by the n-way of clearance.

λ_{R} – radioactive decay constant of radionuclide;

f_n – regional fractions cleared by the n way.

The analytical solution (X) of the equation system gives the resident amount of material to be found in an organ or tissue at t days after a unitary intake:

$$X=\sum f_n\int_0^\infty \mathrm{e}^{-(\lambda_n+\lambda_{\mathrm{R}})t}\,\mathrm{d}t \qquad (\mu\mathrm{Ci}\cdot\mathrm{d}) \qquad (2)$$

or

$$X=\sum f_n\frac{\left(1-\mathrm{e}^{-(\lambda_n+\lambda_{\mathrm{R}})\cdot t}\right)}{\lambda_n+\lambda_{\mathrm{R}}} \qquad (\mu\mathrm{Ci}\cdot\mathrm{d}) \qquad (3)$$

If neglecting the exponential:

$$X = \sum \frac{f_n}{\lambda_n + \lambda_R} \quad (\mu\text{Ci} \cdot \text{d}) \tag{4}$$

λ_R, f_n and λ_n are defined as above for $n = \text{a} \div \text{j}$.

The organ equivalent dose is calculated for each organ at risk/compartment, according to its weight and burden.

$$DE_n = \frac{51}{M_n} \sum_j \sum_i \left[X_j \cdot p_i \cdot E_i \cdot (QF)_{in} \cdot (AF)_{ijn} \right] \cdot I \tag{5}$$

where: DE_n – the equivalent dose on organ / tissue *"n"* (mSv)

M_n – the organ weight (g);

X_j – resident quantity in organ / tissue *"j"* (µCi·d);

E_i – radiation energy (α or β) of particle *"i"* (MeV);

51 – transformation factor (g·rad/MeV) x disintegration/µCi·d;

$(QF)_{in}$ – quality factor of *"i"* radiation emitted in organ *"k"*;

$(AF)_{ijn}$ – absorbed fraction of energy in organ *"n"* when a particle of *"i"* type is getting disintegrated in organ *"j"*;

p_i – probability of disintegration for the *"i"* particle;

I – intake (kBq) = (radioactive concentration in air) × (respiration rate) × (exposure time).

Starting from the last formula and after selecting the environmental conditions, the ModeLung software computes the radioactive material deposition to each compartment according to the intake, then it displays the organ doses and the effective doses.

The study takes into account 8 categories of population performing different activities (as sleeping, resting/sitting, light exercise, heavy exercise). Each category is introduced in the database with its specific physiological parameters (breathing rate according to one physical activity; see Table 1) and its anatomical data (organ weight), according to the International Commission on Radiological Protection recommendations [1, 3].

Table 1

Breathing rate as a function of age, gender and physical effort

Category of population	Breathing rate (m^3/h)			
	Sleeping	Sitting	Light exercise	Heavy work
Adult, male	0.45	0.54	1.50	3.00
Adult, female	0.32	0.39	1.25	2.70
15 years old, male	0.42	0.48	1.38	2.92
15 years old, female	0.35	0.40	1.30	2.57
10 years old	0.31	0.38	1.12	2.03
5 years old	0.24	0.32	0.57	–
1 year old	0.15	0.22	0.35	–
3 months old	0.09	–	0.19	–

All categories are considered normal nose breathers, living during 8 hours in a Radon environment with a mean concentration of activity of 150 Bq/m^3 (Rn).

The non-equilibrium condition between the parental Radon and its short-lived decay daughters is defined by the following ratio of concentrations [2]:

Rn-222 : Po-218 : Pb-214 : Bi-214 : Po-214 = 1 : 0.71 : 0.14 : 0.04 : 0.04

which is considered stable during all 8 hours of activity. Those values correspond to an equilibrium factor between Radon and its daughters of about 0.16.

All Radon daughters are considered attached to aerosols.

The aerosol size is ranging from 0.001 to 10 μm.

The tissue weighting factors are important for calculation of effective dose from the organ dose equivalents. They are a measure of organ radiosensitivity related to all body. The weighting factor for naso-pharynx region is not specified in the recommendations of the International Commission on Radiological Protection (ICRP), because of the low number of ET cancers observed, so it should be included in the list of remainder tissues (a total value of 0.05). But it is as well recommended that for some radionuclide, if one of the remainder tissues receives a higher dose than any organ for which w_T have a specified value, 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, the organ dose equivalent will be the highest for the extrathoracic tissues [4]. This enables us to use the value of 0.025 for the N-P tissue weighting factor and 0.025 to blood, as remainder organ. The lung weighting factor is 0.12, and is separated into 0.08 for the T-B region and 0.04 for the P region. The lung lymph nodes will have a corresponding weighting factor of 0.00012. The gastro-intestinal tract will have the weighting factor of the stomach, i.e. 0.12. The effective dose levels were computed with the ModeLung software [5], for different aerosol sizes.

RESULTS

1) A first observation that can be made is that, when the level of physical effort is higher, the effective doses are higher. Thus, when performing heavy work, there is a 4 times higher dose level than when sleeping, 3 times higher than the one for sitting, and double than the dose received by the categories engaged in a light exercise. That is obvious, since the internal irradiation is higher when the amount of intake is larger.

2) Another important aspect is that no matter the physical effort, age or gender, for 0.1 μm aerosols, the dose is minimum. That fortunately corresponds to the case of most common aerosol size indoor.

3) For the sleeping case (Fig. 3), it is noticed that the 1 year old child is the most exposed category to Radon daughters, no matter the aerosol size. For the 3 months old infant, the situation is following from very close. There is also a noticeable high level of exposure for the 5 years old child and a little bit lower for the 10 years one. The adults and the teenagers have very similar dose levels, but the adult female receives the minimum dose.

4) For the sitting situation (Fig. 4), there is a very similar distribution of the dose levels, with a maximum of exposure for the 1 year old child, followed by the 5 years old and 10 years old. The less exposed are the adults and teenagers.

5) For the categories involved in light exercise (Fig. 5), the most exposed are the 1 year and 10 years old subjects. The others receive very similar doses, with a minimum for the 5 years old child.

6) In the case of heavy work (Fig. 6), the less exposed is the adult male, but the values for the adult female and the 15 years old female are not much higher. The most exposed is the 15 years old male. The 10 years old child receives an average effective dose.

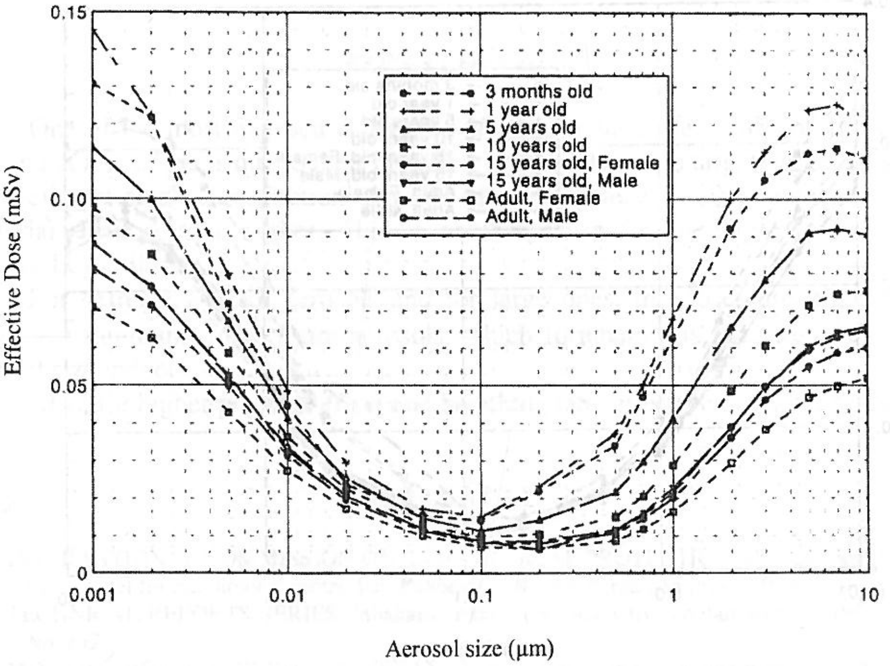

Fig. 3. – Effective doses as a function of age and gender during sleeping.

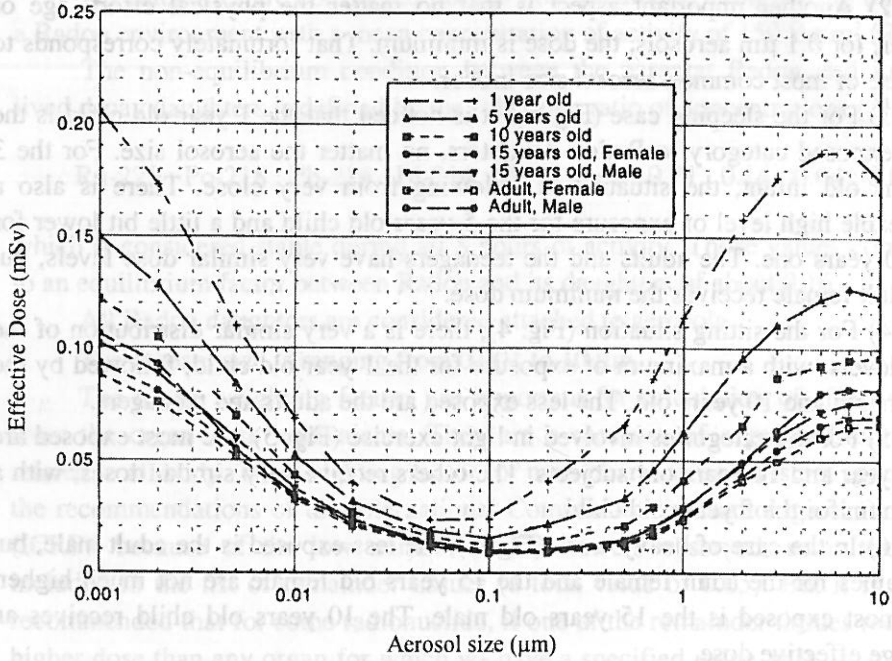

Fig. 4. – Effective doses as a function of age and gender during sitting.

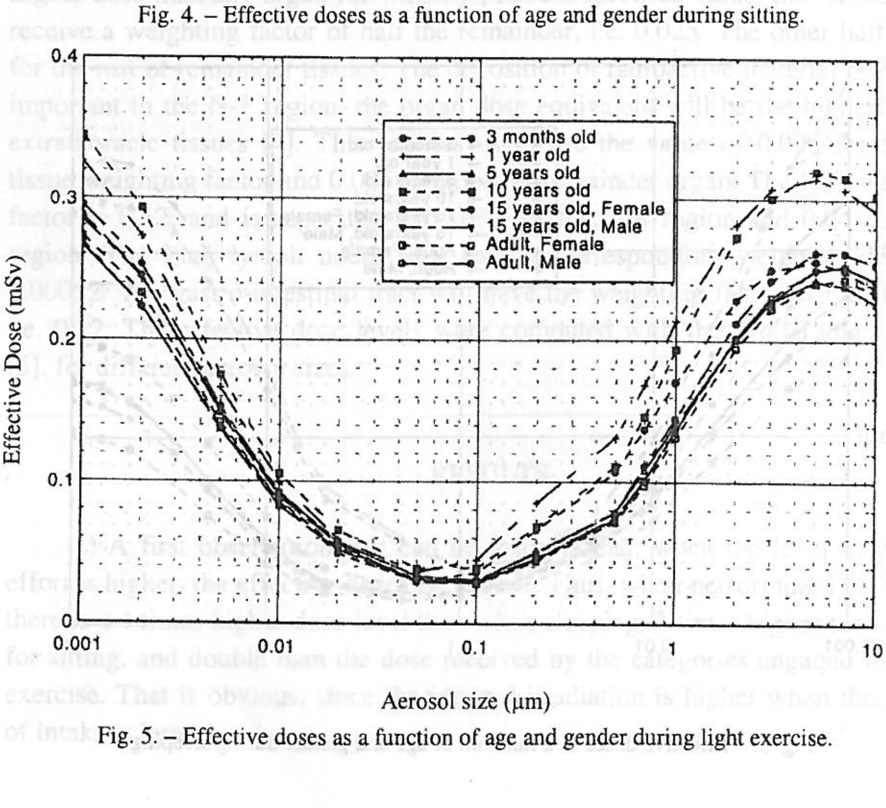

Fig. 5. – Effective doses as a function of age and gender during light exercise.

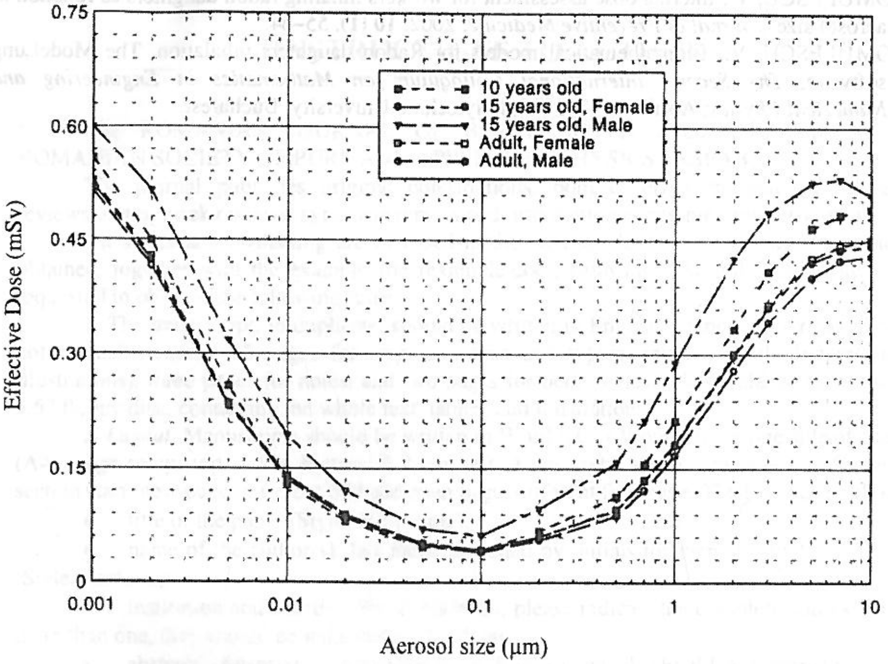

Fig. 6. – Effective doses as a function of age and gender during heavy work.

CONCLUSIONS

One of the most exposed categories of population is the youth (of 10 years old and below). This is due to their breathing rate in relation to target organ weight. As well, for smaller respiration airways (the youngster's case), the radioactive material deposition is higher. This is another cause for the high dose levels received by children.

For extremely small aerosols and for large ones, the doses are high. The doses are minimum for 0.1 μm aerosols, which fortunately is the most frequent aerosol size indoors.

Also, for higher physical effort and breathing rate, effective doses are higher.

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