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DOSES IN HUMAN ORGANS DUE TO ALPHA, BETA AND GAMMA RADIATIONS EMITTED BY THORON PROGENY IN THE LUNG

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This work consists of two parts. In the first part, the doses in the human lung per unit exposure to thoron progeny, the dose conversion factor (DCF), was calculated. Dependence of the DCF on various environmental and subject-related parameters was investigated. The model used in these calculations was based on ICRP 66 recommendations. In the second part, the human lungs were considered as the source of beta and gamma radiation which target the other organs of the human body. The DCF to other organs was obtained as 20 μSv WLM^{-1}, which is larger than the DCF for radon progeny, which was 13 μSv WLM^{-1}. This is a consequence of the longer half-life of the relevant thoron progeny than that of the radon progeny. It is interesting to note that after the lungs, where the radiation source is actually located, muscle tissue receives the largest dose.

INTRODUCTION

Thoron, ^{220}Rn, is a radon isotope which decays by emission of an alpha particle with energy of 6.29 MeV, with a half-life of 55 s. Like radon, thoron due to its chemical inertness can migrate from soil into the atmosphere. In dwellings and closed spaces with poor ventilation accumulation of thoron and its progeny is possible, depending on the strength of the source[(1)]. The decay products consist of a variety of nuclides and each of them may be attached to aerosols of varying sizes. The unattached fraction typically comprises only around 2 % of the total activity.

Many dosimetric studies were carried out in order to determine the level of human exposure from inhaled radon, thoron and their progenies. These studies considered doses from short-lived progeny which emit alpha particles. However, other types of radiation, beta and gamma, are also present and contribute to the total dose, not only to the lung. ^{212}Pb and ^{212}Bi are short-lived thoron progeny, which decay by emitting beta particles accompanied by gamma radiation. The contribution of beta and gamma radiation from nuclides deposited in the lungs is not only to the lungs but to all other organs of the human body.

METHODOLOGY

In order to determine the dose per unit exposure, which is usually called the dose conversion factor (DCF), it is necessary to transform the dose per particle of radiation into the dose per unit exposure. To do that, the equilibrium activities of nuclides in the lungs per unit exposure are required. These data were obtained using the program LUNGDOSE, which was developed earlier for ^{222}Rn and described in a previous publication[(2)], and hence that a detailed description will not be given here. In this program, the concepts introduced in ICRP 66 publication[(3)] were adopted. Since the decay schemes and alpha energies are different in the ^{222}Rn and ^{220}Rn series, the program LUNGDOSE was modified to take into account these differences. Modifications in the LUNGDOSE program performed in order to calculate the DCF for thoron progeny have already been described[(4)].

The input parameters for the program LUNGDOSE have been changed within reasonable ranges with different steps in different cases, whereas the other parameters have been kept at their best estimates, as is shown in Table 1(a). DCFs were calculated for each of these sampled combinations and results are presented below.

In the second part of the work, all parameters were taken on their best estimates, which correspond to the adult Caucasian male, as given in Table 1(a). On the basis of these parameters, equilibrium activities of thoron progeny were calculated in regions of the respiratory tract and are presented in Table 2. Activities are calculated per unit exposure (WL), which corresponds to 275 Bq m^{-3} for thoron in a secular equilibrium with progenies.

For ^{212}Pb, the total activity in all regions (BB, bb and AI) is 7.05 Bq WL^{-1} and for ^{212}Bi is 9.36 Bq WL^{-1}. These activities are quite small in comparison with the radon progeny ^{214}Pb and ^{214}Bi, which are 406.8 and 578.4 Bq WL^{-1}, respectively (also obtained with the LUNGDOSE program[(2)]).

Using data for activities, A_n, yields, Y_R^n, of radiation and the mean absorbed dose per particle of radiation, $\overline{D_{T,R}^n}$, obtained from simulation, absorbed doses, $D_{T,R}^n$, per WLM for different types of

Table 1. (a) Input parameters for the model of human respiratory tract, their best estimates and ranges[9] and DCF-L. (b) The total gamma and beta equivalent dose from ^{212}Pb and ^{212}Bi per WLM for different organs, DCF-O.

Parameter	Best estimate	Parameter value range	DCF-L range	DCF-O nSv WLM^{-1}	Male	Female
(a)				(b)		
Unattached aerosol size (AMTD)	0.9 nm	0.5–3.5 nm	5.26–5.91	Lung	1.68×10^{5}	1.65×10^{5}
Nucleation aerosol size (AMAD)	50 nm	10–100 nm	9.32–4.72	Skin	5.1	4.0
Accumulation aerosol size (AMAD)	250 nm	100–400 nm	8.55–4.74	Liver	33	50
Coarse aerosol size (AMAD)	1.5 μm	1.0–4.0 μm	5.42–5.51	Stomach	1.7	2.3
Transfer to blood	600 min	100–1000 min	1.17–5.56	Bladder	0.03	0.05
Unattached shape factor	1	1–1.9	5.46–5.46	Testes/ovaries	0.011	0.1
Nucleation shape factor	1.1	1–1.9	5.46–5.46	Oesophagus	2.7	3.4
Accumulation shape factor	1.1	1–1.9	5.46–5.43	Colon	0.3	0.36
Coarse shape factor	1.1	1–1.9	5.46–5.43	Thyroid	0.2	0.52
Unattached hygroscopic growth factor	1	1–2	5.46–5.43	Bone surface	8.4	6.1
Nucleation hygroscopic growth factor	1.5	1–3	5.58–5.77	Bone marrow	15	8.8
Accumulation hygroscopic growth factor	1.1	1–1.9	5.56–5.51	Brain	0.38	0.48
Coarse hygroscopic growth factor	1.5	1–4	5.41–5.44	Breasts		5.1
Ventilation λ_v	0.55 h^{-1}	0.2–2 h^{-1}	4.17–5.10	Remainder	3.90×10^{3}	3.97×10^{3}
Aerosol attachment λ_v	50 h^{-1}	5–500 h^{-1}	5.99–4.28			
Unattached plateout λ_d^u	20 h^{-1}	5–110 h^{-1}	4.47–4.47			
Attached plateout λ_d^a	0.2 h^{-1}	0.05–1.1 h^{-1}	4.47–4.47			
Unattached fraction	0.02	0.0019–0.1565	4.28–6.00			

Table 2. Equilibrium activities of thoron progeny in (Bq WL^{-1}) in various regions of HRT.

	^{212}Pb	^{212}Bi
BB	3.15	4.36
Bb	2.61	3.47
AI	1.29	1.53

radiation R (β or γ) and nuclide n (^{212}Pb or ^{212}Bi) in the main organs of the human body and the remainder tissue T were obtained:

$$D^n_{T,R} = \overline{D^n_{T,R}} \cdot A_n \cdot Y^n_R. \quad (1)$$

Further, the equivalent dose H_T in some organ T was obtained as

$$H_T = \sum_n \sum_{R=\beta,\gamma} w_R D^n_{T,R}, \quad (2)$$

where w_R is the radiation weighting factor whose values for β^- and γ radiation are equal to 1. Summation per nuclide n was done to include contributions from both ^{212}Pb and ^{212}Bi.

After obtaining the equivalent dose for the organs and remainder tissue for both males and females, the effective dose was calculated as

$$E = w_{\text{breasts}} H_{\text{breasts}} + \sum_T w_T \frac{H_{T,\text{m}} + H_{T,\text{f}}}{2}, \quad (3)$$

with $H_{T,\text{m}}$ as the equivalent dose for the male and $H_{T,\text{f}}$ for the female phantom; w_T are tissue weighting factors taken from the new ICRP 103 recommendations[5].

In order to determine doses in organs of the human body due to sources of radiation placed in the lungs, a mathematical model of the human body known as the Oak Ridge National Laboratory (ORNL) phantom[6] was used together with Monte Carlo Neutron Particle (MCNP transport) software[7], which enables simulation of radiation transport and interaction with matter in arbitrary geometries.

RESULTS AND DISCUSSION

DCF as a function of input parameters

The DCF-L (L is for lung) for thoron progeny depends on the blood transfer rate. This dependence is shown in Figure 1. As expected, the DCF increases with the half-life of transfer to blood from 1 to about 6 mSv WLM^{-1}. Slower transport from lung to blood means a longer retention time in the lungs, which causes a larger lung dose.

The unattached aerosol size, expressed as AMTD, was varied from 0 to 3.5 nm. As shown in Figure 2, the DCF increases slightly from 5.3 up to 5.9 mSv WLM^{-1}.

Similar calculations were performed by varying the size of nucleation mode (from 20 to 100 nm) Figure 3, accumulation mode (from 100 up to 400

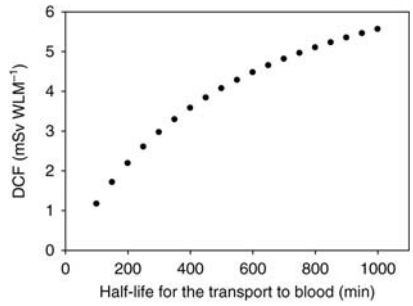

Figure 1. Dependence of DCF-L half-life of on transfer to blood.

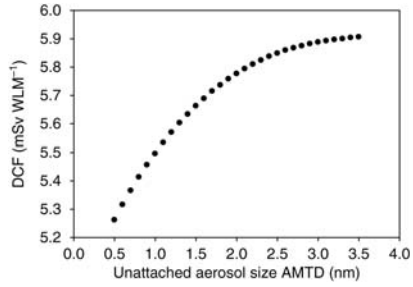

Figure 2. Dependence of DCF-L on unattached aerosol size.

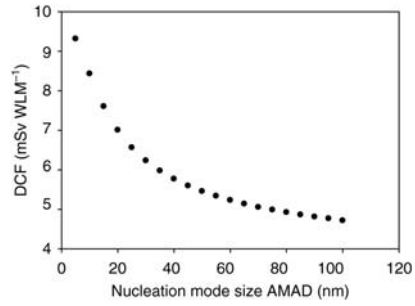

Figure 3. Dependence of DCF-L on nucleation mode size.

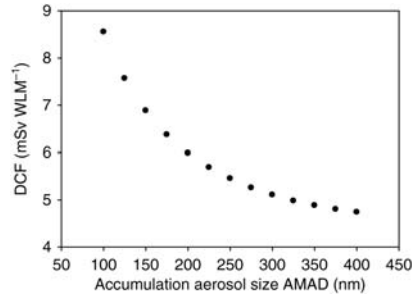

Figure 4. Dependence of DCF-L on accumulation mode size.

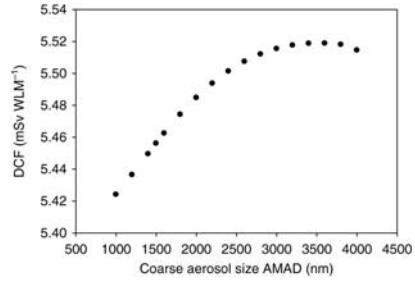

Figure 5. Dependence of DCF-L on coarse mode size.

nm) Figure 4 and coarse mode (from 1000 nm up to 4000 nm), Figure 5.

Dependence of DCF to the shape factor was also calculated and presented in Figure 6, where can be seen that DCF is almost independent on the shape factor of nucleation and unattached modes, while it slowly decreases with the shape factor of coarse and accumulation modes.

Dependence of the DCF on the hygroscopic growth factor is shown in Figure 7. The DCF varys with the hygroscopic factor, but the dependence is different for various modes. Dependence is most pronounced for the nucleation mode, where it increases from 5.4 up to almost 5.8 mSv WLM^{-1}.

Finally in Figure 8 dependence of the DCF on the unattached fraction is presented. Linear dependence is found, and the equation of fit line is presented in the legend of the figure.

If all parameters were kept at their best estimates, a DCF of ~4.5 mSv WLM^{-1} would be obtained.

Doses in other organs due to the beta and gamma radiation emitted by thoron progeny in the lung

Doses in all the main organs and remainder tissue of the human body from beta and gamma progeny are calculated as described above and shown in Table 1(b). It can be seen from Table 1(b) that the absorbed dose is the largest in the lung, which is expected, since the source is in the lung itself. It is interesting to note that the dose in the remainder tissue is larger than doses in all main organs. According to ICRP 103 Publication[5], the tissue weighting factor for the remainder tissues (0.12) applies to the arithmetic mean dose of the 13 organs and tissues for each sex. These organs are: adrenals, extra thoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (for male), small intestine, spleen, thymus and uterus/cervix (for female). After detailed investigation of doses in these organs, it is concluded that the largest contribution to dose the in the remainder tissue is to muscle. The absorbed dose from beta particles in muscle is 3.49, 4.01, 31.58 and 35.69 (μGy WLM^{-1}) for

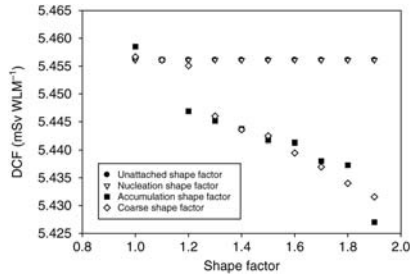

Figure 6. DCF as a function of shape factor.

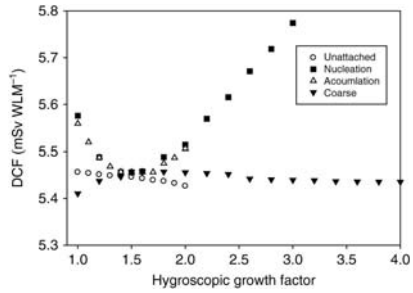

Figure 7. DCF-L as a function of the hygroscopic growth factor.

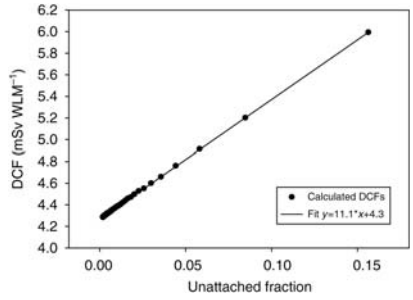

Figure 8. DCF-L as a function of unattached fraction.

^{212}Pb male, ^{212}Pb female, ^{212}Bi male and ^{212}Bi female, respectively. Muscles were regarded as the soft tissue of the body minus the skeletal system and all the organs identified in the phantom. The large dose in this tissue can be explained by the fact that muscle tissue surrounds lungs and is directly exposed to radiation.

The effective dose, calculated using Equation (3), is 20.45 μSv WLM^{-1}.

CONCLUSION

The DCF value for best estimates agrees with the results from the literature. Parameter variation in this work induces DCF variation from 1 to 6 mSv WLM^{-1}, Table 1(a).

Table 1(b) summarises doses in all main organs and the remainder of tissue due to the radiation source being located in the lungs DCF-O (O is for organs). The effective dose was found to be 20.45 μSv WLM^{-1}. This value is quite large when compared with the effective dose from beta and gamma emitting radon progeny ^{214}Pb and ^{214}Bi which is 13.4 μSv WLM^{-1}[8]. At a first glance this could look strange, since activities of radon progenies are quite larger than those from thoron. For beta-emitting radon progeny, the total activity in the lung is 958.2 Bq WL^{-1}, whereas for thoron it is 16.41 Bq WL^{-1}. This discrepancy can be overcome when regarding spectrums of radon and thoron progeny[8]. The thoron progenies ^{212}Pb and ^{212}Bi emit beta and gamma particles with higher energy than radon progeny and deliver higher doses, which when calculated per unit exposure result in a greater DCF.

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Serbian Ministry of Science and Environment Protection who supported this work through the project grant No 141023.

REFERENCES

1. Steinhausler, F. *Environmental ^{220}Rn*. A review. Environ. Int. **22**(1), S1111–S1123 (1996).
2. Nikezic, D. and Yu, K. N. *Microdosimetric calculations of absorption fraction and the resulting dose conversion factor for radon progeny*. Radiat. Environ. Biophys. **40**, 207–211 (2001).
3. ICRP 66, Human Respiratory Model for Radiological Protection. *A Report of a Task Group the International Commission on Radiological Protection*. ICRP Publication 66 (Oxford: Pergamon Press) (1994).
4. Nikezic, D. and Stevanovic, N. *Room model with three modal distributions of attached 220Rn progeny and dose conversion factor*. Radiat. Prot. Dosim. **123**, 95–102 (2007).
5. ICRP 103. Quantities used in Radiological Protection. Vol. **37,** Anex B (Oxford: Pergamon Press) pp. 247–322 (2007).
6. Eckerman, K. F., Cristy, M. and Ryman, J. C. *The ORNL mathematical phantom series*. Available on http://ordose.ornl.gov/ (last accessed on 26 April 2010) (1996).
7. Briesmeister, J. F. Ed. MCNP—A General Monte Carlo N-Particle Transport Code, Version 4B, LA-12625-M (New Mexico, Los Alamos: Los Alamos National Laboratory) (1997).
8. Markovic, V. M., Krstic, D. and Nikezic, D. *Gamma and beta doses in human organs due o radon progeny in human lung*. Radiat. Prot. Dosim. **135**(3), 197–202 (2009).
9. Marsh, J.W. and Birchall, A. *Sensitivity analysis of the weighted equivalent lung dose per unit exposure from radon progeny*. Radiat. Prot. Dosim. **87**, 167–178 (2000).