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Comparison of Radon (^{222}Rn) and Thoron (^{220}Rn) Gamma Dosimetry in the Environment Using the ORNL Mathematical Phantom

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ABSTRACT

Background: The potential hazards of exposure to radiation from radon have been of great concern worldwide, as it is associated with an increased risk of lung cancer. Radon (^{222}Rn) and its progeny are the main sources of radioactivity in the environment. The half-life of ^{222}Rn (3.82 days) is long enough for it to diffuse into and build up in homes. ^{220}Rn or thoron from the ^{232}Th series, and ^{219}Rn—a decay product of ^{235}U—have very short half-lives (55.6 and 3.96 sec, respectively) and are of minor significance compared to ^{222}Rn in the ^{238}U series. However, these sources, like thoron, are important in uranium mines. Radon and thoron progeny decay by emitting β particles accompanied by γ radiation. Although γ rays are comparatively less damaging to the respiratory system than α and β particles, it is the principal deposited energy in other organs.

Methods: Comparison of radon and thoron γ radiation dosimetry was performed using a modified Oak Ridge national laboratory (ORNL) adult mathematical phantom and the Monte Carlo N-particle transport code (MCNP).

Results: The results showed that the highest amount of the absorbed dose was in the lung followed by the thymus and heart, according to the ICRP103 publication.

Conclusions: The absorbed dose from thoron was quite large in comparison to radon because thoron has more high-energy particles than radon.

Keywords

Thoron; Radon progeny; ORNL phantom; Gamma radiation dosimetry; MCNP code

Introduction

Radon (^{222}Rn) is the most important sources of natural radioactivity in the air. Radon is a radioactive transformation product of the uranium isotopes—^{238}U and ^{235}U—and thoron (^{232}Th); it exists in different concentrations in soils, minerals, ground water, building materials and air. Thoron (^{220}Rn) decays by emission of an 6.29-MeV α particle. Lead (^{212}Pb) and bismuth (^{212}Bi) isotopes are the β emitting progeny of thoron. Like radon, thoron can migrate from soil into the atmosphere due to its chemical inertness [1].

Radon and its progeny enter the human respiratory tract after inhalation. Since radon is an inert gas, it is not deposited in human airways; it is quickly exhaled. However, radon progeny is electrically charged and its particles readily deposit in the lung. The radon daughters (α, β, γ,

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Table: Comparison of photon dosimetry (in μGy WLM^{-1}) of ^{222}Rn progeny (^{214}Bi, ^{214}pb) and ^{220}Rn progeny (^{212}Pb, ^{212}Bi)

Organ	^{212}pb	^{214}pb	^{212}Bi	^{214}Bi
Kidneys	7.812E-01	3.32E-02	3.14E-02	2.70E-01
Pancreas	1.49E+00	7.84E-02	6.66E-02	5.59E-01
Intestine, small	3.05E-01	8.33E-03	9.59E-03	8.65E-02
Adernals	1.94E+00	1.06E-01	8.98E-02	7.53E-01
Gall bladder	7.81E-01	3.55E-02	3.24E-02	2.77E-01
Heart	3.52E+00	1.95E-01	1.64E-01	1.37E+00
Skin	4.95E-01	1.98E-02	1.95E-02	1.68E-01
Thyroid	1.08E+00	4.83E-02	4.47E-02	3.82E-01
Stomach	1.13E+00	5.53E-02	4.88E-02	4.12E-01
Bone surfaces	8.42E-01	3.96E-02	3.12E-02	2.59E-01
Lungs	9.64E+00	5.66E-01	5.22E-01	3.76 E+00
Esophagus	3.42E+00	1.92E-01	1.60E-01	1.34 E+00
Bladder	1.18E-01	1.32E-03	2.28E-03	2.28E-02
Thymus	2.49E+00	1.31E-01	1.12E-01	9.39E-01
Liver	1.70E+00	9.09E-02	7.77E-02	6.50E-01
Brain	1.92E-01	3.72E-03	5.07E-03	4.73E-02
Breast	2.21E+00	1.11E-01	9.91E-02	8.35E-01
Uterus	1.74E-01	3.11E-03	4.34E-03	4.13E-02
Ovaries	1.88E-01	3.36E-03	4.68E-03	4.39E-02
Testes	6.50E-02	2.68E-04	7.33E-04	8.10E-03
Spleen	1.43E+00	7.45E-02	6.44E-02	5.40E-01

and x-rays) are mainly decayed in the airways before being cleared, either by absorption into the blood stream or by particle transport to the gastrointestinal tract.

In dwellings and closed spaces with poor ventilation accumulation of thoron and its progeny is possible; the extent of this accumulation depends on the strength of the source. Although γ rays are comparatively less damaging to the respiratory system than α and β particles, they are the principal deposited energy in other organs. Because γ rays are much more penetrating than α particles, and because their mean free path in tissues is a few tenths of centimeters for high-energy photons, photons can travel throughout the whole human body without being absorbed [2].

In this study, we compared the radon and thoron dosimetry for γ and x-rays with the Oak Ridge national laboratory (ORNL) adult mathematical phantom using the MCNPX 2.4.0 Monte Carlo transport code system; calculations were done in photon/electron mode.

Materials and Methods

Direct measurement of the absorbed organ doses in the human body is generally not possible. Therefore, anthropomorphic phantoms coupled with Monte Carlo simulations are most commonly used for estimating the absorbed dose. Analytical models of the human body are described in ORNL publications. These phantoms are based on the composition of simple mathematical surfaces like planes, spheres, cylinders, and ellipsoids [3].

The γ energy and yield of each energy per one β emitter isotope of radon progeny (^{214}Pb, ^{214}Bi) and thoron progeny (^{212}Pb, ^{212}Bi), were defined in SDEF card input files as described earlier [4] (Figs 1 and 2). The output files of

the MCNP code contained the mean absorbed dose (in MeV/g per one particle of radiation) in the main organs and other tissues of the human body.

The average absorbed dose (MCNP output), $\overline{{}_T D_R^n}$, is the quotient of the deposited energy due to radiation of type R in the volume of a specific organ or tissue T by its mass from nuclide n (^{214}Pb, ^{214}Bi, ^{212}Bi, ^{212}Pb). The mean absorbed dose per particle of radiation (in μGy WLM^{-1}) from whole lung as a source is calculated using the following equation:

$$ {}_T D_R^n = \overline{{}_T D_R^n}. A_n . I_R^n \quad (1)$$

where An is the activity of each isotope (n) and I_R^n is the yield of radiation. Since $\overline{{}_T D_R^n}$ obtained in simulation, is given per quantum or per particle of radiation, and activity per disintegration, to derive the absorbed dose per one WLM (radon concentration unit), one needs to know the yield of certain types of radiation [2].

For ^{212}Pb, the total activity is 7.05 Bq WL^{-1}; for ^{212}Bi, it is 9.36 Bq WL^{-1}. These activities are quite small in comparison to total activities of radon progenies ^{214}Pb and ^{214}Bi, which are 406.8 and 578.4 Bq WL^{-1}, respectively [5].

Photon absorbed doses were estimated for 24 main organs. The equivalent dose, H_T, is one of the radiobiological protection quantities and is defined as a weighted mean of the absorbed dose in a tissue T, from γ and x-rays; it is calculated by the following equation:

$$ H_T = \sum_n \sum_{x-ray,\gamma} w_R \ {}_T D_R^n \quad (2)$$

where w_R is the radiation weighting factor which depends on the radiation type and energy whose values for photon radiations are equal to 1.

The effective dose, which is the main radiation protection quantity, was obtained by summation of equivalent doses in various tissues and organs of the male and female human body divided by 2. In addition, the equivalent dose in the breast w_T was modified by the tissue weighting factor w_T. The effective dose was calculated as:

$$ E_{eff} = w_{T\,breasts} H_{breasts} + \sum_T w_T \frac{H_{TM} + H_{TF}}{2} \quad (3)$$

where w_T is the tissue weighting factor taken from recent edition of ICRP103 publication [6]. H_{TM} and H_{TF} are the equivalent doses for male and female, respectively.

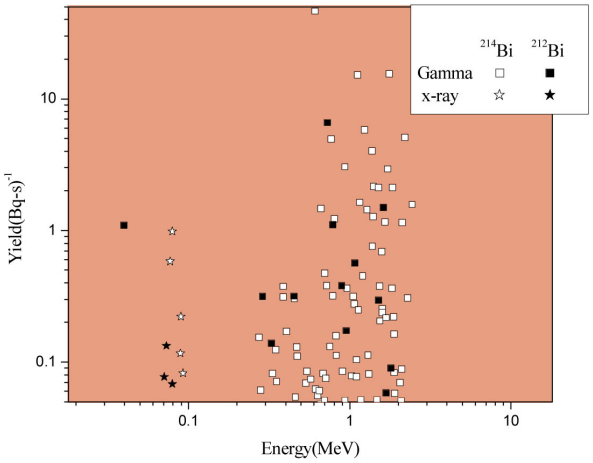

Figure 1: x-ray and γ radiation spectrums of ^{214}Bi and ^{212}Bi; data were extracted from Ref 4.

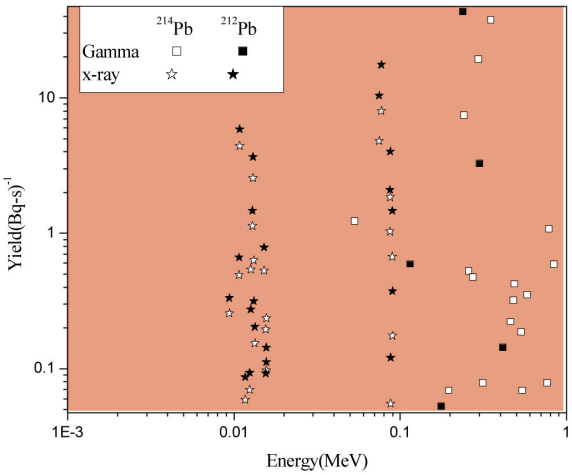

Figure 2: x-ray and γ radiation spectrums of ^{214}Pb and ^{212}Pb; data were extracted from Ref 4.

Results and Discussion

All absorbed dose estimations in this study had an uncertainty less than 0.2% (Table 1).

As expected, the results showed that lungs received higher absorbed dose than other organs since the photon source is defined in the lungs. The second and third organs of the body that received high doses were the heart and thymus, respectively, probably because of their close proximity to the lungs.

The bladder received the least absorbed dose, probably because the bladder is located farthest away from the source of all other organs in the body. It is interesting to note that after the lungs, where the radiation source is actually located, muscle tissue receives the largest absorbed dose.

The thoron progenies, ^{212}Pb and ^{212}Bi, emit β and γ particles with higher energy than radon progeny and deliver higher doses, which when calculated per unit exposure, results in a greater effective dose.

The effective dose (for γ and x-rays) was found to be 3.845 μSv WLM^{-1}. This value is quite large when compared to the effective dose of β and γ-emitting radon progeny, ^{214}Pb and ^{214}Bi, which is 1.687 μSv WLM^{-1}. This is a consequence of the longer half-life of relevant thoron progeny than radon progeny.

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