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Determination of alpha radiation dose to skin due to the application of different radiopharmaceuticals

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Abstract

Artificial alpha-emitting radionuclides are significantly utilized in nuclear medicine. So, the skin of practitioners as well as patients in nuclear medicine and workers in the industry of radiopharmaceuticals may be accidentally contaminated even for a very short time by these radionuclides. The basic concepts of a Monte Carlo computer code for evaluating the mean absorbed dose in skin due to alpha-particles emitted by these radioisotopes were described and discussed. Committed equivalent dose to skin from the deposition of different material samples were evaluated. The influence of the application time, alpha disintegration ratio, half-life of the radionuclide, and contaminated skin surface on committed equivalent dose was investigated.

I. Introduction

The skin is the largest organ of the human body, with a total area of about 20 square feet. It protects individuals from microbes, helps regulate body temperature, and limits the sensation of touch, heat and cold. The skin has three layers: The epidermis, the outermost layer of skin which provides a waterproof barrier and creates the skin tone, the dermis, beneath the epidermis which contains tough connective tissue, hair follicles, and sweat glands, and the deeper subcutaneous tissue (hypodermis) which is made of fat and connective tissue. The critical cells in the skin are in the basal layer of the epidermis . There are considerable variations in the thickness of human epidermis with respect to body site. On the face and trunk the median thickness of the epidermis was 20-40 µm. In general, on the arms and legs it was 40-60 µm, although there were some considerably thicker areas on the hands and feet. A more detailed evaluation of the hands showed fingertips to have the greatest thickness, greater than 160 µm . Alpha-particles are helium nuclei made up of two protons and two neutrons which have short range and high linear energy transfer. Alpha-particle emitting radionuclides are of interest in radioimmunotherapy [1]. Patients and practitioners in nuclear medicine as well as workers in industry of radiopharmaceuticals may be accidentally contaminated by alpha-emitting radiopharmaceuticals. It is then necessary to assess alpha radiation dose to the skin of individuals to avoid any radiation dose enhancement.

II. Methodology

2.1- Calculation method

The epidermis of the human skin is divided into several clearly defined zones [2]. Indeed, when a material layer of 1 mm depth is placed on the skin of an individual (Fig.1), the emitted alpha-particles have ranges of several tens of microns (20 to 100µm). This is comparable with the depth of the basal layer of the epidermis which is more sensitive (50 to 100µm) .

Let us consider a cylindrical material layer of 1 cm² basis surface and 1 mm depth deposited on the skin surface of an individual as shown in fig. 1. An alpha-particle of index j and initial energy generated at point P (Fig.1) at a distance xj from the skin which reaches the skin has a range in skin. Since the deposited material layer has a depth of 1 mm which is greater than the radon diffusion length in the considered materials, alpha particles emitted by radon in ambient air can not reach the skin of individuals.

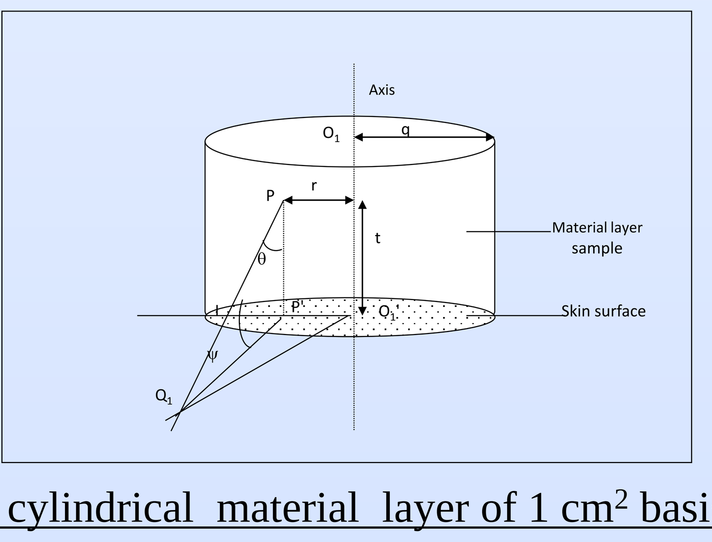

Fig. 1. Arrangement of a cylindrical material layer of 1 cm² basis surface and 1 mm depth deposited on the skin surface of an individual. q is the radius of the radiopharmaceutical layer. $\overline{PI} = x_j$

The distance x_j is given by (Fig.2):

$$x_j = \frac{t}{\cos\theta} \quad \text{if} \quad q \succ \overline{O_1^{'}Q_1} \tag{1}$$

Where:

$$\overline{O_1^{'}Q_1}^2 = r^2 + t^2\,\mathrm{tg}^2(\theta) + 2\,r.t.\mathrm{tg}(\theta).\cos(\psi) \tag{2}$$

q is the radius of the cylindrical material layer.

The calculation of the absorbed dose in skin due to the emitted alpha-particles consists firstly on generating random numbers by using a programme called random subroutine, based on a congruential method [3], and calculating the x_j distances and, R_j and ranges by using a programme called AMADS (Alpha Mean Absorbed Dose in Skin).

The uniform random sampling of the emission point P and emission direction is achieved by computing the distance from the center axis r, the depth t, cosθ (θ between 0 and π/2) and Ψ (fig1) with four uniform random numbers [3]:

$$r = q\sqrt{\xi_1} \qquad , 0 \le \xi_1 \prec 1 \tag{3}$$

$$t = R_j \xi_2 \qquad , 0 \le \xi_2 \prec 1 \tag{4}$$

$$\cos\theta = \xi_3 \qquad , 0 \le \xi_3 \prec 1 \tag{5}$$

$$\psi = 2\pi\pi_4 \qquad , 0 \le \xi_4 \prec 1 \tag{6}$$

where R_j is the range of an alpha-particle of index j and initial energy E_{α_j} in the material sample.

The absorbed dose (Gy) in a cylinder of 1cm² basis surface and R_j^{skin} depth of skin due to an alpha-particle of index j and residual energy $E_{\alpha_j}^{Res}$ is:

$$D_j = \frac{E_{\alpha_j}^{Res} k}{d_{skin} \times \left(R_j^{skin}\right) \times 1cm^2 \times \cos\theta} \tag{7}$$

where k = 1.6.10^{-13} (J MeV^{-1}) is a conversion factor and d_{Skin} is the density of skin.

For a large number N_r^j of alpha-particles of index j reaching the surface skin with a residual energy $E_{\alpha_j}^{Res}$,the mean absorbed dose in skin is:

$$\left\langle D_j(Skin) \right\rangle = \frac{\sum D_j}{N_r^j} \tag{8}$$

2.2 Alpha committed equivalent dose to skin from the application of different material samples

Alpha-equivalent dose rates (Sv.s^{-1}) to the skin of individuals due to an alpha-particle emitted by a radionuclide j from the application of a material sample is given by:

$$\dot{H}_{skin}(j)(t) = \left\langle D_j(skin) \right\rangle K_j A_c^{skin}(j)(t) w_R \tag{9}$$

where $A_c^{skin}(j)(t)$ (Bq) is the alpha-activity, at time t, in skin due to a radionuclide j,W_R is the radiation weighting factor which is equal to 20 for alpha-particles [2], and K_j is the alpha disintegration branching ratio.

The $A_c^{skin}(j)(t)$alpha-activity is given by:

$$A_c^{skin}(j)(t) = \frac{1}{2} A_c^{sample}(j) e^{-\lambda_j t} x1cm^2 xR_j \tag{10}$$

where $A_c^{sample}(j)(t)$ in Bq/cm³ is the alpha-activity due to a radionuclide j inside a material sample, λ_j is the radioactive decay constant of a radionuclide j and R_j (in cm) is the range of an alpha particle of index j in the material sample.

By integrating eq. (9), committed equivalent dose (Sv) to skin due to an alpha-particle of residual energy emitted by a radionuclide j from the application of a material sample is given by:

$$H_{skin}(j) = \frac{\left\langle D_j(Skin) \right\rangle K_j \; W_R}{2\lambda_j} A_C^{sample}(j)\left(1 - e^{-\lambda_j t_a}\right) x1cm^2 xR_j \tag{11}$$

where t_a is the application time of the radiopharmaceutical on skin.

III. Results and discussion

3.1 Mean absorbed dose to skin from deposition of alpha-emitting radionuclides

Mean absorbed dose in skin due to monoenergetic alpha-particles generated in a material layer deposited on the skin of an individual was evaluated by using the AMADS (Alpha mean absorbed dose in skin) Monte Carlo code. The statistical uncertainty of the mean absorbed dose determination is of 1%. It is to be noted that the mean absorbed dose in skin increases, reaches a maximum at E_{α_j} = 3 MeV and decreases when E_{α_j} increases. This is due to the fact that the stopping power of skin for the incident alpha-particles ($E_{\alpha_j}^{Res}/R_j^{Skin}$) increases in the [0-3MeV] energy interval and then decreases for energies larger than 3 MeV. One can also note that only alpha-particles of initial energy greater than 6.75 MeV can reach the sensitive basal layer of the epidermis. Mean absorbed dose in skin was calculated for alpha-particles emitted by different artificial radionuclides used in nuclear medicine. Only alpha-particles emitted by ^{212}Po can reach the basal layer of the epidermis. Mean absorbed dose was calculated for different contaminated skin surfaces belonging to the [1-50 cm²] interval from accidental application of various radiopharmaceuticals. It is to be noted that the mean absorbed dose decreases when the contaminated skin surface increases according to eqs. (7) and (8).

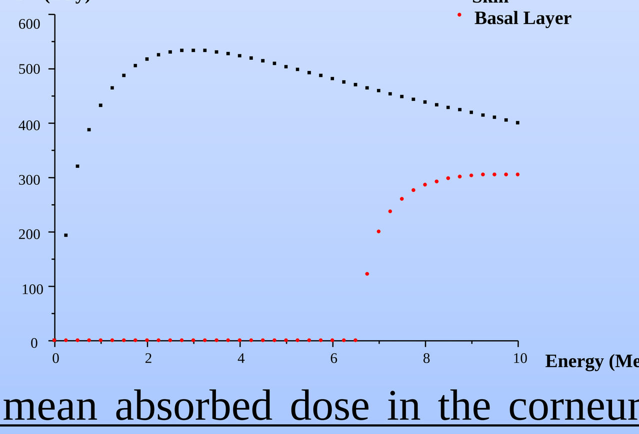

Fig.2. Variation of the mean absorbed dose in the corneum, granulosum and spinosum strata (skin) and basal layer of the epidermis as a function of alpha-particle initial energy.

3.2 Alpha committed equivalent dose to skin from the application of different material samples

When injecting radiopharmaceutical solutions containing alpha emitting nuclei to patients some drops may be deposited on their skin. Workers in radiopharmaceutical industry may also be contaminated by alpha emitting radioisotopes. Committed equivalent dose to skin was determined for different alpha-emitting radiopharmaceuticals from accidental application during 5 and 10 minutes per year. Data obtained are shown in tab. 1. It is to be noted that committed equivalent dose to skin increases with the application time of radiopharmaceuticals. Even if ^{212}Po emits alpha-particles with energy higher than those emitted by the other radionuclides, committed equivalent dose to skin due this radionuclide is negligible compared with those due to the other radionuclides. This is because ^{212}Po has a half-life lower than those of the other radionuclides. One can note that committed equivalent dose due to ^{213}Bi is clearly lower than those due to the other radionuclides. This is due to the fact that ^{213}Bi has a lower alpha disintegration branching ratio (2%) than the other radionuclides. The maximum committed equivalent dose to skin was found equal to 276 mSv y^{-1} cm^{-2}, obtained for accidental application of ^{223}Ra (tab. 1), which is smaller than the dose limit for workers which is of 500 mSv y^{-1} cm^{-2} .

Radionuclide (j)	$H_{Skin}(j)$ (mSv/cm²/y) t_A=5 min	$H_{Skin}(j)$ (mSv/cm²/y) t_A=10 min	$H_{BL}(j)$ (mSv/cm²/y) t_A=5 min	$H_{BL}(j)$ (mSv/cm²/y) t_A=10 min
^{224}Ra	129.38±0.20	258.68±0.40	0	0
^{212}Bi	48.99±0.10	95.25±0.20	0	0
^{213}Bi	2.60±0.005	5.00±0.01	0	0
^{225}Ac	130.86±0.27	261.69±0.55	0	0
^{211}At	56.19±0.12	111.93±0.23	0	0
^{230}U	132.89±0.28	265.77±0.56	0	0
^{210}Po	118.47±0.25	236.95±0.50	0	0
^{223}Ra	138.129±0.29	276.23±0.58	0	0
^{149}Tb	18.49±0.04	36.72±0.08	0	0
^{212}Po	(3.23±0.01)10^{-7}	(3.23±0.01)10^{-7}	(2.29±0.003)10^{-7}	(2.29±0.003)10^{-7}

Table 1. Data obtained for the committed equivalent dose to the corneum, granulosum and spinosum strata (H_{skin}(j)) and basal layer (H_{BL}(j)) of the epidermis from accidental application, during 5 and 10 minutes, of various radiopharmaceuticals. We considered a volume of 20 drops placed on the skin of individuals corresponding to an activity of 20 Bq/cm³. The relative uncertainty is of 0.2 %.

IV. Conclusion

It has been shown by this study that by using a Monte Carlo computer programme, one can determine mean absorbed dose in skin due to alpha-emitting radionuclides from the application of various material samples. A dosimetric model was described for determining committed equivalent dose to skin due to alpha-emitting nuclei from the application of various material samples has been described. It is concluded that committed equivalent dose to skin is influenced by the disintegration branching ratio, half-life of the radionuclide, deposited activity, contaminated skin surface and application time of the material samples. Therefore, medical personnel in hospitals as well as workers in the radiopharmaceutical industry should avoid any contamination by alpha-emitting radionuclides when handling radiopharmaceuticals.

References

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