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An Evaluation of External Beta Absorbed Dose for Contamination of the Skin

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Skin dose is very difficult to be measured directly and is usually estimated. The beta dose rate to the skin expressed in terms of the average surface concentrations of a radionuclide on the skin gives more reliable estimates for this exposure pathway. However, the data in the literature vary as much as an order of magnitude. In this study, external beta-ray dose rate for human skin contamination around an isotropic point source of mono-energetic electrons is calculated. The beta-ray doses rates were computed by performing analytical integration of a semi-empirical point dose rate function. Evaluation of the model is realized by calculating the dose rate for the contamination of the skin at different depths for samples of air collected around the Research Reactor located at the Atomic Energy Authority (Egypt). Meandering of the plume i.e., low wind condition is taken into consideration. The above mentioned treatment is applied for different meteorological states, namely different thermal stability classes, A,B,C,D and E. The maximum beta absorbed dose for the contamination of the skin is for stability class E for nuclide of Cs^{137} at depth of $20\mu m$ from the skin. The results were compared with those previously reported and it was found that some of the present results agree precisely with previous investigations.

Keywords: Point dose rate/ Absorbed Beta dose /Contamination of the skin/ Lowwind condition/analytical integration

Introduction

The absorbed dose resulting from routine or accidental emission of emitting radionuclides plays an important role in nuclear operations [5]. Some radioisotopes are pure β-particle emitters such as $Sr^{90}, Ru^{103}, Zr^{95}$ and others are $\beta - and\ \gamma -$ emitters such as I^{131}, Cs^{137}. It is used for purposes of radiation protection and assessing dose or risk to humans in general terms. External contamination occurs when clothing, hair, or skin become contaminated with radioactive material and it can lead to ingestion or inhalation of the radioactive substance leading to internal contamination. The problem of determining the absorbed dose around a localized β- particle sources in tissue depends mainly on the distribution of dose around a point source of β-particles in tissue and the dose distribution in and around a localized β-particle source which is calculated by a suitable summation of the elementary point source distribution [6]. The radiation dose from external exposure is calculated using the concentration of the radionuclides in the environment as a function of time and distance from the location of the exposed individual or population, the energy of the radiation of interested emission each radionuclide, transmission though body tissue of the radiations incident upon the exposed individuals and resulting in doses to particular body organs [6]. Skin contamination is something that might occur, for instance, if liquid

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radioactive materials are accidentally dripped onto the skin. Alpha particles do not penetrate the dead layer of skin. Some beta particles can deliver a skin radiation dose if they are on the skin long enough.

A backscatter factor has been found by taking the ratio of the planar dose when the scattering material is present (non-homogeneous case) to that when water is present (homogeneous case). Air scattering corrections are often inversely reported such that they are greater than or equal to one [1]. Electron energy, backscattering medium Z, normal depth, and dose averaging area affect the backscatter factors. In backscattering, an electron entering an absorber may undergo sufficient deflection in a manner that it re-emerges from the surface through which it entered. These backscattered electrons do not deposit all of their energy in the absorber, and therefore the backscattering process can have a significant impact on absorbed dose. Electrons with high incident energy and absorbers with low atomic number have the lowest probability for backscattering. Therefore, backscattering typically occurs when low-energy electrons enter a region of high atomic number or high mass density [4]. Electrons scattered from air into the tissue are not taken into the consideration in calculations of the dose rate of the skin outside the contaminated area. This is because the skin contamination is extending over small areas where electrons scattered from air into the tissue do not have an effect on the outside the skin contaminated area in most cases. So, the dose rate immediately beneath the contaminated surface area will then no longer be contributed to these electrons [7].

Skin dose is very difficult to be measured directly and is usually estimated. The irradiated skin depends on the depth of the cells and the energy spectrum of the source. There are various treatments of beta dosimetry problems using numerical solution for an integro-differential transport equation as follows: Dose rates for skin contamination are discussed by Rohloff and Heinzelmann [7] using the Mont Carlo method. Also, a simple method to assess the obtained skin dose from external beta emitters using a semi-empirical point dose rate function numerically is investigated by T.P. Fell [8]. Moreover, Sang-hyun Park et al. [9] used a point kernel method to calculate the beta-ray dose rate from skin contamination by performing numerical integration of the radial dose distribution around an isotropic point source of mono-energetic electrons. In this paper, the integro-differential transport equation is solved analytically using a semi-empirical point dose rate function introduced in previous study [8] and then apply this solution using the data collected from the Second Research Reactor of the Atomic Energy Authority, Egypt [10]. A skin dose limit was proposed by the International Commission on Radiological Protection (ICRP) as $0.5Gy = 50mSvy^{-1}$ averaged over $1cm^2$ (area) for dose for members of the public, for the employees ($18y^+$) is $500mSvy^{-1}$ and for the trainees ($<18y$) is $150mSv\,y^{-1}$ from [2].

The dose conversion factor is used to convert activity level of radionuclides on the skin to dose equivalent. These dose conversion factors may be used to calculate committed doses in any population that has been previously characterized in an adequate manner in an earlier publication [3]. The present work is organized as follows. In the next section, the mathematical formulation of the solution is described. In the third section the application of the solution around the First Research Reactor, Egyptian Atomic Energy Authority is presented and the last section we summarize the conclusions drawn from the study.

Materials and Methods

The total dose rate in a target at a point at a depth z from the boundary is defined as [8]:

$$\dot{D}(z) = \frac{k}{2\rho}\int \chi(x,y,z)(R-\frac{z}{x})^{\alpha}\,dx \qquad (1)$$

where $k = 7.777\times10^{-5}, \alpha = 0.612, \rho$ is the density of the medium, R is the range of beta particles and is given by [7]:

$$R = \frac{-0.11+(0.0121+(E_{max}/1.92)^2)^{\frac{1}{2}}}{\rho}$$

E_{max} is the maximum energy of the beta decay and tabulated in [8] according to the nuclide and $\chi(x,y,z)$ is the uniform concentration in the air source which is defined from Gaussian model of the concentration for an elevated source which has the form [11]:

$$\chi(x,y,z) = (\frac{Q}{\pi u\sigma_y\sigma_z})e^{-\frac{z^2}{2\sigma_z^2}} \qquad (2)$$

where Q is the source emission rate , u is the downwind speed and σ_y and σ_z are the lateral and vertical dispersion coefficients respectively. It is convenient to let [12]

$$\sigma_y = ax^b \tag{3}$$

$$\sigma_z = cx^d \tag{4}$$

The parameters a,b,c,d depend on the atmospheric stability classes and given in Table (1)[13].

Table (1): Parameters σ_y $and \sigma_z$ for an urban location

Pasquil classes	Aa	b	c	d
A-B	1.46	0.71	0.01	1.54
C	1.52	0.69	0.04	1.17
D	1.36	0.67	0.09	0.95
E-F	0.79	0.70	0.40	0.67

The horizontal cross-wind dispersion coefficient space σ_y which is termed $\Sigma_y(x)$ to compensate for the plume meander. The corrected formula Σ_y is proposed as [11]:

$$\Sigma_y = \begin{cases} M\sigma_y & x \le 800 \\ (M-1)\sigma_y(800)+\sigma_y & x > 800 \end{cases} \tag{5}$$

where the empirical factor $M = 6$.

Since in our applications $x \le 800$, substituting from equations (5),(3), (4) and (2) into equation (1) , we obtain:

$$\dot{D}(z) = \frac{Qk}{12\pi uac\rho}\int \left(\frac{(R-\frac{z}{x})^{\alpha}}{x^{b+d}}\right)e^{-\frac{z^2}{2c^2x^{2d}}}dx \tag{6}$$

where $0 < \alpha \le 1$, from [14], we find that:

$$(R-\frac{z}{x})^{\alpha} = R^{\alpha}\sum_{n=0}^{\infty}C(\alpha,n)(\frac{z}{Rx})^n$$

where

$$C(\alpha,n) = \frac{\alpha(\alpha-1)(\alpha-2)....(\alpha-n+1)}{n!}$$

On substituting , equation (6) takes the form:

$$\dot{D}(z) = \frac{QkR^{\alpha}}{12\pi uac\rho}\sum_{n=0}^{\infty}(-1)^n C(\alpha,n)(\frac{z}{R})^n \int x^{-n-b-d}e^{-\frac{z^2}{2c^2x^{2d}}}dx \tag{7}$$

Taking $\mu = n+b+d, m = \frac{z^2}{2c^2}$, we get:

$$\int x^{-n-b-d}e^{-\frac{z^2}{2c^2x^{2d}}}dx = \int x^{-\mu}e^{-mx^{-2d}}dx \tag{8}$$

From the tables of integration [15], the above integration is evaluated in the form:

$$\int x^{-\mu}e^{-mx^{-2d}}dx = \frac{x^{1-\mu}(mx^{-2d})^{\frac{-1+\mu}{2d}}}{2d}\Gamma(\frac{-1+\mu}{2d}, mx^{-2d}) \tag{9}$$

Substituting from equation (9) into equation (7), we get:

$$\dot{D}(z) = \frac{Qkm^{\frac{1-\mu}{2d}}R^{\alpha}}{24\pi uacd\rho}\sum_{n=0}^{\infty}(-1)^n C(\alpha,n)(\frac{z}{R})^n\Gamma(\frac{-1+\mu}{2d}, mx^{-2d}) \tag{10}$$

which is the total dose rate in a target at a point at a depth z.

RESULTS

To realize our model and as an application, we evaluate the dose rate for the contamination of the skin at different depthes for air collected samples around the First Research Reactor in Atomic Energy Authority, Egypt and the experimental data are given in the Table (2).

Table (2): Meteorological data of the nine Convective test runs at Inshas Site [10]

Run no.	Stability	Down distance x(m)	Emission rate Q (Bq)		Wind speed (m/s)
1	A	98	I^{131}	Cs^{137}	
2	A		1028571	0.555429	4
3	A	100	1050000	0.567012	4
4	B	106	42857.14	0.023143	6
5	C	106	471428.6	0.254577	4
6	A	135	492857.1	0.266143	4
7	D	136	514285.7	0.277714	4
8	E	154	1007143	0.543857	4
9	C	165	1043571	0.563529	4
	A	186	1033929	0.558321	4

Tables (3-7) show the beta dose rates ($Sv.s^{-1}$ per $Bq.cm^{-3}$) at different depthes for immersion in air for contamination of the skin for the stability classes (A,B,C,D,E) respectively.

Table (3): the beta dose rates ($Sv.s^{-1}$ per $Bq.cm^{-3}$) at different depths for immersion in air for contamination of the skin for stability A

Nuclide	Depth of the skin(μm)									E_{max} (Mev)
	20	30	40	50	60	70	80	90	100	
I^{131}	7.3×10^{-11}	5.7×10^{-11}	4.4×10^{-11}	3.8×10^{-11}	3.2×10^{-11}	2.9×10^{-11}	2.5×10^{-11}	2.2×10^{-11}	2.1×10^{-11}	0.61
Cs^{137}	9.8×10^{-11}	7.6×10^{-11}	6.02×10^{-11}	5.1×10^{-11}	4.1×10^{-11}	3.8×10^{-11}	3.5×10^{-11}	3.2×10^{-11}	2.9×10^{-11}	1.73
Sr^{90}	5.4×10^{-11}	4.1×10^{-11}	3.2×10^{-11}	2.9×10^{-11}	2.4×10^{-11}	2.1×10^{-11}	1.9×10^{-11}	1.7×10^{-11}	1.6×10^{-11}	0.54

Table (4): the beta dose rates ($Sv.s^{-1}$ per $Bq.cm^{-3}$) at different depths for immersion in air for contamination of the skin for stability B

Nuclide	Depth of the skin(μm)								
	20	30	40	50	60	70	80	90	100
I^{131}	1.9×10^{-11}	1.6×10^{-11}	1.2×10^{-11}	1.1×10^{-11}	8.9×10^{-12}	7.9×10^{-12}	6.9×10^{-11}	6.3×10^{-11}	6.02×10^{-11}
Cs^{137}	2.5×10^{-11}	1.9×10^{-11}	1.6×10^{-11}	1.4×10^{-11}	1.2×10^{-11}	1.05×10^{-11}	9.2×10^{-12}	8.6×10^{-12}	7.9×10^{-11}
Sr^{90}	1.5×10^{-11}	1.14×10^{-11}	9.2×10^{-12}	7.6×10^{-12}	6.7×10^{-12}	5.7×10^{-12}	5.1×10^{-12}	4.8×10^{-12}	4.4×10^{-12}

Table (5): the beta dose rates ($Sv.s^{-1}$ per $Bq.cm^{-3}$) at different depths for immersion in air for contamination of the skin for stability C

Nuclide	Depth of the skin(μm)								
	20	30	40	50	60	70	80	90	100
I^{131}	1.17×10^{-9}	9.51×10^{-10}	7.93×10^{-10}	6.98×10^{-10}	6.02×10^{-10}	5.39×10^{-10}	4.76×10^{-10}	4.44×10^{-10}	4.12×10^{-10}
Cs^{137}	8.56×10^{-10}	6.66×10^{-10}	5.39×10^{-10}	4.44×10^{-10}	3.81×10^{-10}	3.49×10^{-10}	3.17×10^{-11}	2.85×10^{-10}	2.69×10^{-10}
Sr^{90}	4.76×10^{-10}	3.49×10^{-10}	2.85×10^{-10}	2.54×10^{-10}	2.22×10^{-10}	1.9×10^{-10}	1.74×10^{-10}	1.62×10^{-10}	1.49×10^{-10}

Table (6): the beta dose rates ($Sv.s^{-1}$ per $Bq.cm^{-3}$) at different depths for immersion in air for contamination of the skin for stability D

Nuclide	Depth of the skin(μm)								
	20	30	40	50	60	70	80	90	100
I^{131}	1.2367×10^{-9}	9.83×10^{-10}	7.93×10^{-10}	6.98×10^{-10}	6.34×10^{-10}	5.71×10^{-10}	5.07×10^{-10}	4.76×10^{-10}	4.44×10^{-10}
Cs^{137}	1.6489×10^{-9}	1.268×10^{-9}	1.08×10^{-9}	9.2×10^{-10}	8.24×10^{-10}	7.29×10^{-10}	6.66×10^{-10}	6.34×10^{-10}	5.71×10^{-10}
Sr^{90}	9.20×10^{-10}	7.29×10^{-10}	6.02×10^{-10}	5.07×10^{-10}	4.44×10^{-10}	4.12×10^{-10}	3.81×10^{-10}	3.49×10^{-10}	3.17×10^{-10}

Table (7): the beta dose rates ($Sv.s^{-1}$ per $Bq.cm^{-3}$) at different depths for immersion in air for contamination of the skin for stability E

Nuclide	Depth of the skin(μm)								
	20	30	40	50	60	70	80	90	100
I^{131}	5.89×10^{-9}	4.89×10^{-9}	4.19×10^{-9}	3.7×10^{-9}	3.35×10^{-9}	3.08×10^{-9}	2.86×10^{-9}	2.68×10^{-9}	2.52×10^{-9}
Cs^{137}	7.79×10^{-9}	6.46×10^{-9}	5.53×10^{-9}	4.89×10^{-9}	4.42×10^{-9}	4.06×10^{-9}	3.77×10^{-9}	3.54×10^{-9}	3.34×10^{-9}
Sr^{90}	4.34×10^{-9}	3.60×10^{-9}	3.08×10^{-9}	2.72×10^{-9}	2.46×10^{-9}	2.26×10^{-9}	2.1×10^{-9}	1.97×10^{-9}	1.86×10^{-9}

Discussion and Conclusions

In the present work, the absorbed dose by human skin for external beta-ray was calculated. This aim is achieved analytically by a method based on performing analytical integration of a semi-empirical point dose rate function.

Evaluation of the model is realized by calculating the dose rate for the contamination of the skin at different depths for samples of air collected around the Research Reactor located at the Atomic Energy Authority (Egypt).

Meandering of the plume i.e., low wind condition is taken into consideration. The above mentioned treatment is applied for different meteorological states, namely different thermal stability classes, A,B,C,D and E.

The results of our recent treatment can be summarized as follows:

1- The maximum dose in the stability A is $9.83\times10^{-11} Sv.s^{-1}$ for Cs^{137}.

2-in the stability B is $2.6\times10^{-11} Sv.s^{-1}$ for Cs^{137}.

3- in the stability C is $1.17\times10^{-9} Sv.s^{-1}$ for I^{131}.

4- in the stability D is $1.65\times10^{-9} Sv.s^{-1}$ for Cs^{137}.

5- in the stability E is $7.61\times10^{-9} Sv.s^{-1}$ for Cs^{137}.

The maximum beta absorbed dose for the contamination of the skin is equal $8.2\times10^{-9} Sv.s^{-1}$ per $Bq.cm^{-3}$ for stability class E for nuclide of Cs^{137} at depth of $20\mu m$ from the skin.

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