Original Article:

Calculation of exposure rate constant for ^{60}Co, ^{22}Na and ^{111}In Sources with FLUKA Monte Carlo Code

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ABSTRACT

Exposure rate constant (Γ) relates activity of a point source to exposure rate at certain distance. It's an important parameter in radiation protection, medical uses and radiological assessments. In this study, exposure rate constant for three radionuclides include ^{60}Co, ^{22}Na and ^{111}In were calculated with FLUKA Monte Carlo method. Each source was simulated and exposure rate at different distances of 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300cm from the sources were measured. For dose measurements, a farmer ionization chamber was simulated with active volume of 0.6cm^3, inner electrode of aluminium with diameter of1mm and wall of pure graphite with thickness of 0.75mm. Calculated exposure rate constants for ^{60}Co, ^{22}Na and ^{111}In at 20 to 300cm from the source ranged from 33.45 to 0.16 mR/(mCi.h), 29.12 to 0.10 mR/(mCi.h) and 8.73 to 0.03 mR/(mCi.h) respectively which show a decreasing trend. Comparison of our results with other studies show that there are good agreement for ^{60}Co and ^{22}Na; the present values for exposure rate constant for ^{111}In was higher than previous reports.

Keywords: Exposure Rate Constant (Γ); Monte Carlo; FLUKA; Cobalt-60; Sodium-22; Indium-111

INTRODUCTION

Nowadays, the Monte Carlo method is widely used in various researches and applicable field comprises in radiation sciences [1]. The FLUKA is a multi-purpose Monte Carlo code for handling interaction and transportation of hadrons with energies up to 10 TeV, heavy ions, electromagnetic and charged particles from 1PeV to less than 1 keV, transport of neutrons with energies lower than 19.6 MeV, nucleus-nucleus interactions, calorimetry, detector design, cosmic rays, accelerator physics, radiation therapy, dosimetry, activation, etc. [2-4]. In this study, the FLUKA code was used for estimation of exposure rate constant (Γ) for three gamma-emitter radionuclides in different distances. Exposure rate constant relates activity of a point source (A) to exposure rate ($\dot{X}$) in the air at a certain distance (d) [5, 6]. This constant is very important in radiation protection, medical uses and radiological assessments and it's an important factor used in external dose assessment [7]. While $(\frac{\mu_{en}}{\rho})_i$ is mass energy absorption coefficient in the air for photons of energy E_i and Y_i be yield, exposure rate constant can be written as: [6, 8, 9]

Equation 1) $\Gamma=\frac{1}{4\pi}\sum_i(\frac{\mu_{en}}{\rho})_i Y_i E_i$

and relation between activity, exposure rate and exposure rate constant for a point source is as follow:[6, 7]

Equation 2) $\dot{X}= (\Gamma\times A)/d^2$

MATERIALS AND METHODS

In this study, three radionuclides including ^{60}Co, ^{22}Na and ^{111}In were simulated with the FLUKA code. ^{60}Co has half-life of 5.271 years and emits two gamma rays with two energies (1.17 and 1.33 MeV). ^{60}Co is used in external radiation therapy and brachytherapy. There are 20 isotopes of sodium, but only two of them have half-life more than 1 minute. ^{22}Na has half-life of 2.602 years and emits a gamma ray with energy of 1.274 MeV. ^{111}In has half-life of 2.83 days and emits two gamma rays with

0.172 and 0.247 Mev [10]. Table 1 indicates characteristics of simulated radionuclides. All sources were simulated for given activity and exposure rate for each radionuclides and were measured at distances of 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300 cm from the sources. For dose measurements, a Farmer ionization chamber was simulated with active volume of $0.6cm^3$. Inner electrode is made of aluminium with diameter of 1mm; wall thickness was 0.75 mm and was made of pure graphite (figure 1). In all cases, the simulated ionization chamber was placed at the intended position with its axis perpendicular to the radiation axis. The program was run for 5 cycles. Then, with the use of equation 2, exposure rate constant was calculated in each distance. All of the simulation was performed by FLUKA Monte Carlo code with cut-off energy 1keV for photons.

Table 1. Characteristics of radionuclides simulated in this study

Nuclide	Half life	f-factor (cGy/R)	HVL (mm Pb)	Gamma radiation energy (MeV)
^{60}Co	5.271 (y)	0.965	15.6	1.17, 1.33
^{22}Na	2.602 (y)	0.965	9.2	1.275
^{111}In	2.83 (d)	0.951	0.257	0.171, 0.245

The FLUKA use flair system written in Python 2.5+ and different cards to data entry. In this study, BEAM card was used for define beam characteristics, HI-PROPE card to define sources, BEAMPOS card to define position of sources and START card for set the number of primary histories. Radioactive decays and transport conditions for each radionuclides defined with RADDECAY, IRRPROFI and DCYTIMES cards. Output of code was controlled with DCYSCORE and USRBIN. In geometry, it's necessary to define black body and void. Black body was a sphere with radius of 100000cm and void was a sphere with radius of 10000cm.

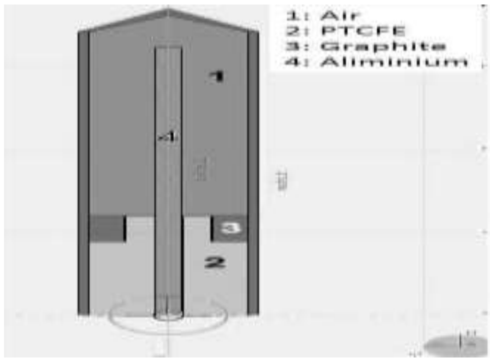

Figure 1. Schematic of simulated Farmer ionization chamber

RESULTS

Measured exposure rate for ^{60}Co in 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300 cm from the source were 56820, 25260, 14160, 6300, 3540, 2274, 1578, 1010, 568 and 252 R/h respectively. Calculated exposure rate constant in 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300 cm from the source were 33.45, 14.86, 8.36, 3.71, 2.09, 1.34, 0.93, 0.61, 0.29 and 0.16 mR/(mCi.h) respectively.

Measured exposure rate for ^{22}Na in 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300 cm from the source were 0.00291, 0.001366, 0.00075, 0.00039, 0.00021, 0.00012, 8.33×10^{-5}, 5.12×10^{-5}, 2.18×10^{-5} and 1.09×10^{-5} R/h respectively. Calculated exposure rate constant in 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300 cm from the source were 29.12, 13.32, 7.56, 3.92, 2.15, 1.21, 0.83, 0.51, 0.22 and 0.10mR/(mCi.h) respectively.

Measured exposure rate for ^{111}In in 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300 cm from the source were 0.00524, 0.00272, 0.00180, 0.00058, 0.00039, 0.00025, 0.000142, 9.07×10^{-5}, 5.34×10^{-5} and 2.27×10^{-5}R/h respectively. Calculated exposure rate constant in 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300 cm from the source were 8.73, 4.54, 3.01, 0.96, 0.65, 0.41, 0.24, 0.15, 0.08 and 0.03 mR/(mCi.h) respectively.

Table 2 shows the summary of the results. Also figure 2-a, 2-b and 2-c show measured exposure rate and different distances for ^{60}Co, ^{22}Na and ^{111}In respectively.

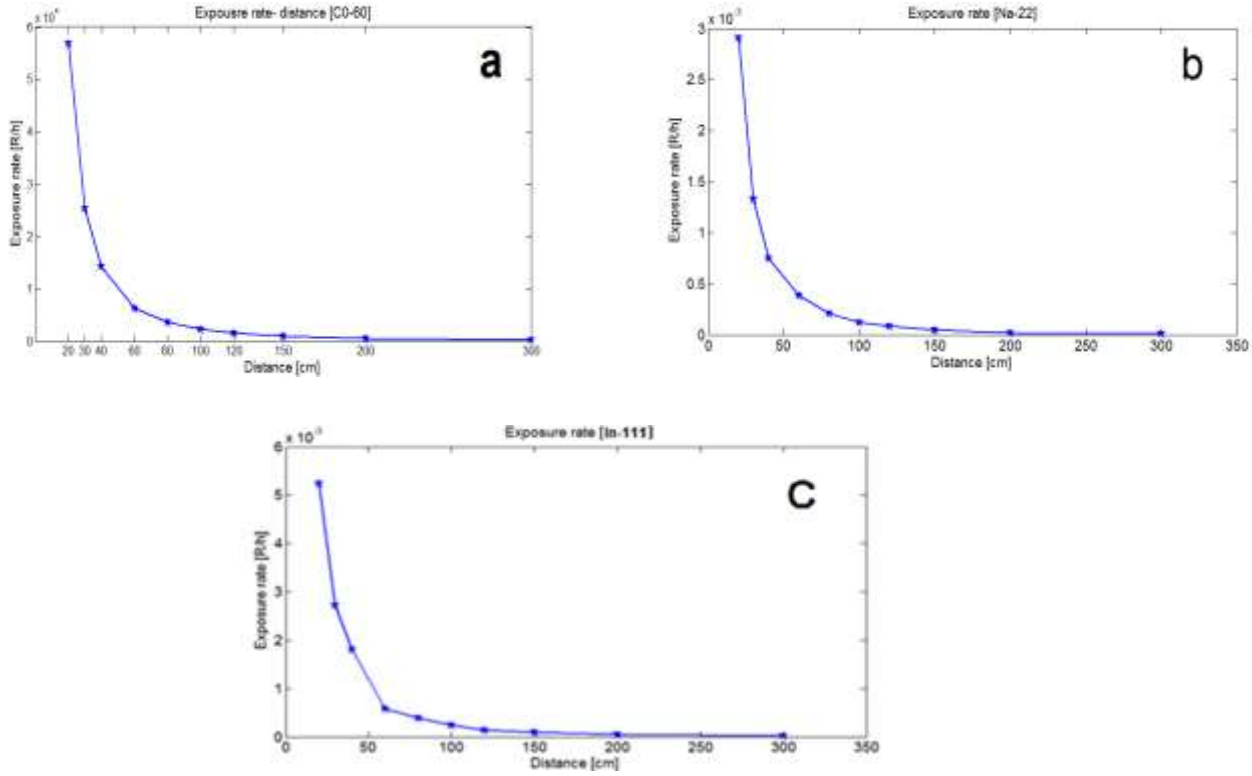

Figure 2. Exposure rate at different distances for a) ^{60}Co, b) ^{22}Na and c) ^{111}In

Table 2. Exposure rate and exposure rate constant for ^{60}Co, ^{22}Na and ^{111}In

	^{60}Co		**^{22}Na**		**^{111}In**	
Distance (cm)	**Exposure rate constant (mR/(mCi.h))**	**Exposure rate (mR/h)**	**Exposure rate constant (mR/(mCi.h))**	**Exposure rate (mR/h)**	**Exposure rate constant (mR/(mCi.h))**	**Exposure rate (mR/h)**
20	33.45	56820	29.12	0.00291	8.73	0.00524
30	14.86	25260	13.32	0.00133	4.54	0.00272
40	8.36	14160	7.56	0.00075	3.01	0.00180
60	3.71	6300	3.92	0.00039	0.96	0.00058
80	2.09	3540	2.15	0.00021	0.65	0.00039
100	1.34	2274	1.21	0.00012	0.41	0.00025
120	0.93	1578	0.83	8.33×10^{-5}	0.24	0.000142
150	0.61	1010	0.51	5.12×10^{-5}	0.15	9.07×10^{-5}
200	0.29	568	0.22	2.18×10^{-5}	0.08	5.34×10^{-5}
300	0.16	252	0.10	1.09×10^{-5}	0.03	2.27×10^{-5}

DISCUSSION

Nowadays, the Monte Carlo method is widely used in various researches and applicable field compromises radiation sciences [1]. In this study we used FLUKA Monte Carlo Code to calculate exposure rate constant for three radionuclide at different distances from sources. Comparison of our results with the other reports in distance of 1 meter from the source indicates in table 3.

Our value for ^{60}Co (1.34 mR/mCi.h) has good agreement with the other studies (1.32 [5], 1.29 [6], 1.36 [11] and 1.37 [12]). Our value for ^{22}Na (1.21 mR/mCi.h) was near of reported values (1.20 (Gusev) [5], 1.18 (Stabin et al) [6], 1.34 (UC San Diego) [13] and 1.33 [12]). Our value for ^{111}In (0.41 mR/mCi.h) was more than Stabin et al [6] (0.34 mR/mCi.h) and UC San Diego value [14] .

CONCLUSION

Overall, comparison of our calculated values indicates good agreement with the other studies which confirms that the FLUKA has ability to handle radioactive sources.

Table 3. Comparison of exposure rate constants with other studies

	^{60}Co	^{22}Na	^{111}In
Our study	1.34	1.21	0.41
Gusev	1.32	1.20	-
Stabin et al	1.29	1.18	0.34
UC San Diego	1.36	1.34	0.12
Matrin	1.37	1.33	-

"The authors declare no conflict of interest"

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