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Radiation protection from external exposure to radionuclides: A Monte Carlo data handbook

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ABSTRACT

The availability of a resource collecting dose factors for the evaluation of the absorbed doses from external exposure during the manipulation of radioactive substances is fundamental for radiological protection purposes. Monte Carlo simulations are useful for the accurate calculation of dose distributions in complex geometries, particularly in presence of extended spectra of multi-radiation sources. We considered, as possible irradiation scenarios, a point source, a uniform planar source resembling a contaminated surface, several source volumes contained in plastic or glass receptacles, and the direct skin contamination case, implementing the corresponding Monte Carlo simulations in GAMOS (GEANT4-based Architecture for Medicine-Oriented Simulations). A set of 50 radionuclides was studied, focusing the attention on those ones mainly used in nuclear medicine, both for diagnostic and therapeutic purposes, in nuclear physics laboratories and for instrument calibration. Skin dose equivalents at 70 µm of depth and deep dose equivalents at 10 mm of depth are reported for different configurations and organized in easy-to-read tables.

1. Introduction

Nowadays, radioactive substances are widely used in medical, industry, research, military and energy production fields. Radiological protection is a crucial topic for operators involved in these activities, and the availability of data references for dose-rates coming from different practical irradiation scenarios is necessary for the assessment of radiological risk [1,2].

A resource currently available is the Radionuclide and Radiation Protection Data Handbook [3], whose results were obtained using the analytical approaches available in 2002, such as VARSKIN Mod. 2 [4] and Microshield ver. 4.10 [5]. The limitations of these calculation tools particularly emerge in evaluating the skin doses in presence of thick absorbers, when the bremsstrahlung X-ray emission is not negligible, or when the effects of range straggling are evident, as pointed out in Refs. [6–10]. A further limitation of the data contained in Ref. [3] concerns the restricted number of geometric configurations for which skin and deep doses are evaluated.

On the other hand, the availability of Monte Carlo codes for the simulation of radiation transport and interaction in matter allows to get realistic evaluations of radiation absorbed doses in complex geometries [11–16].

In this paper, we selected a set of radionuclides for which the superficial (70 µm depth) and deep (10 mm depth) dose equivalents in tissue were evaluated by means of Monte Carlo simulations in GEANT4-based Architecture for Medicine-Oriented Simulation, GAMOS, version 5.1.0 [17].

Different configurations were considered in order to provide information about exposure in the most common scenarios of external irradiation and radioactive contamination that can occur when manipulating radioactive substances in medical applications or other-purpose nuclear laboratories. As in Ref. [3], a point source, a uniform planar source resembling a contaminated floor, several sources contained in receptacles, and direct skin contamination were considered. A number of combinations of source-target distances and source volumes larger than that considered in Ref. [3], was assumed.

2. Materials and methods

Monte Carlo simulations were carried out with GAMOS, GEANT4-based Architecture for Medicine-Oriented Simulations, version 5.1.0 [17], on Fedora Core Linux Operative System, version 4.4.14, release 200.fc22, x86-64. GAMOS is a friendly interface to GEANT4 [18], in

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Table 1
List of radionuclide sources. The average energy of the emitted particles (α, β^+, β^-) is reported.

Nucl.	Decay	$T_{1/2}$	< E > (keV)	Nucl.	Decay	$T_{1/2}$	< E > (keV)	Nucl.	Decay	$T_{1/2}$	< E > (keV)
^{11}C	β^+	20.4 m	385.6	^{13}N	β^+	10.0 m	491.82	^{15}O	β^+	2.0 m	735.28
^{18}F	β^+	109.8 m	249.8	^{22}Na	β^+	2.6 y	194.11	^{24}Na	β^-	15.0 h	553.84
^{32}P	β^-	14.3 d	771.3	^{41}Ar	β^-	109.3 m	464.45	^{44}Sc	β^+	3.9 h	632.6
^{51}Cr	EC	27.7 d	–	^{52}Mn	β^+	21.1 m	1133.55	^{52}Fe	β^+	8.3 h	340.0
^{57}Co	EC	271.7 d	–	^{60}Co	β^-	5.3 y	96.08	^{62}Cu	β^+	9.7 m	1280.52
^{64}Cu	β^+	12.7 h	278.21	^{67}Cu	β^-	61.8 h	141.21	^{62}Zn	β^+	9.3 h	259.0
	β^-		190.2								
^{67}Ga	EC	3.3 d	–	^{68}Ga	β^+	67.6 m	739.56	^{68}Ge	EC	270.8 d	–
^{73}Se	β^+	39.8 m	145.46	^{75}Se	EC	119.8 d	–	^{77}Br	β^+	57.0 h	151.9
^{86}Y	β^+	48.0 m	652.0	^{89}Zr	β^+	78.4 h	395.5	^{89}Sr	β^-	50.5 d	584.56
^{90}Sr	β^-	28.7 y	195.8	^{90}Y	β^-	64.1 h	933.61	^{99}Mo	β^-	65.9 h	390.31
^{99m}Tc	IT	6.0 h	–	^{109}Cd	EC	461.4 d	–	^{111}In	EC	2.8 d	–
^{123}I	EC	13.3 h	–	^{124}I	β^+	4.2 d	193.27	^{125}I	EC	59.4 d	–
^{131}I	β^-	8.0 d	182.74	^{133}Xe	β^-	5.2 d	100.10	^{133}Ba	EC	10.5 y	–
^{137}Cs	β^-	30.0 y	187.87	^{153}Sm	β^-	46.5 h	224.15	^{177}Lu	β^-	6.7 d	40.5
^{186}Re	β^-	3.7 d	320.98	^{188}Re	β^-	17.0 h	764.25	^{192}Ir	IT	241 y	–
^{198}Au	β^-	2.7 d	312.39	^{201}Tl	EC	72.9 h	–	^{210}Bi	β^-	5.0 d	389.0
^{223}Ra	α	11.4 d	5775.60	^{241}Am	α	432.2 y	5462.48	–	–	–	–

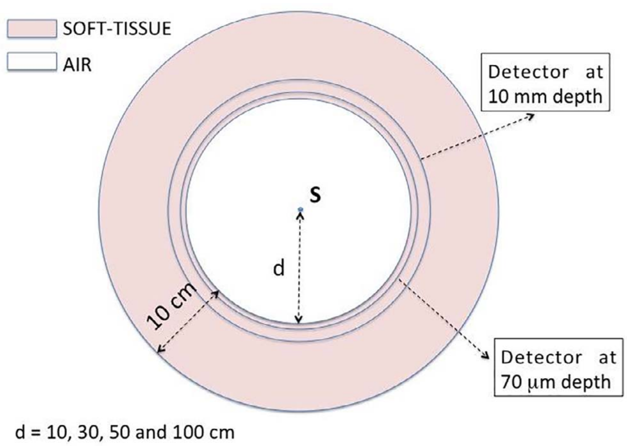

Fig. 1. Simulation geometry used for skin and deep dose evaluations in the case of a radioactive point-like source. Dimensions are not to scale.

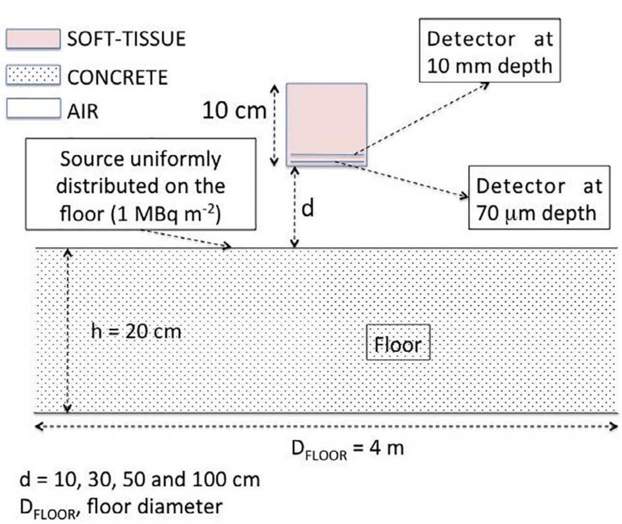

Fig. 2. Simulation geometry used for skin and deep dose evaluations in the case of a planar source. Dimensions are not to scale.

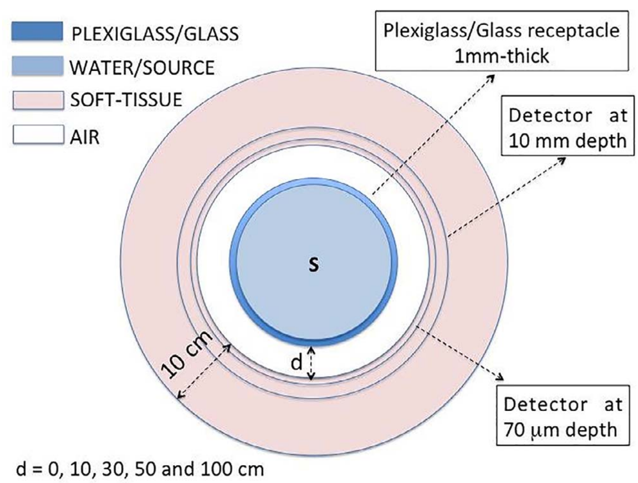

Fig. 3. Simulation geometry used for skin and deep dose evaluations in case of a radioactive solution contained in a plexiglass or glass cylindrical receptacle. Dimensions are not to scale.

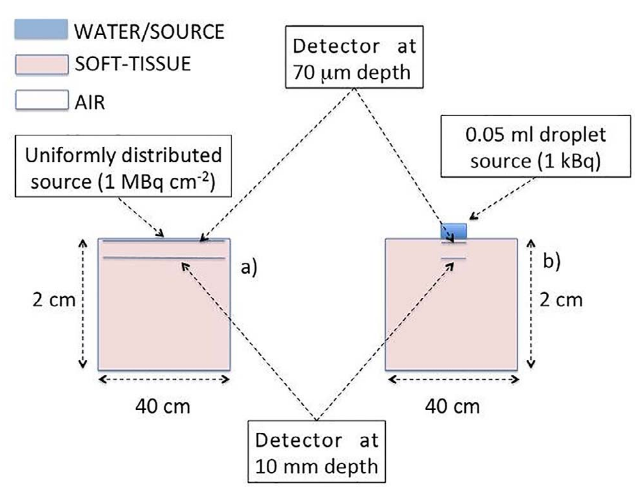

Fig. 4. Simulation geometries used for skin and deep dose evaluations in case of a radioactive substance in contact with skin: (a) radioactive source uniformly distributed on the skin; (b) 0.05 ml droplet radioactive source. Dimensions are not to scale.