Exposition to ^{137}Cs deposited in soil – A Monte Carlo study

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Abstract: In the event of environmental contamination with radioactive materials, one of the most dangerous materials is ^{137}Cs. In order to evaluate the radiation doses involved in an environmental contamination of soil, with ^{137}Cs, we carried out a computational dosimetric study. We determined the radiation doses conversion coefficients (CC) for E and H_T, using a male and a female anthropomorphic phantom, coupled with the MCNPX (2.7.1) Monte Carlo simulation software, for three different types of soil. The highest $CC[H_T]$ values were for the gonads and skin (male) and bone marrow and skin (female). We found no difference for the different types of soil.

Keywords: Monte Carlo simulation, ^{137}Cs, ambiental dosimetry, anthropomorphic phantoms

1. INTRODUCTION

As a consequence of the radiological accidents of Chernobyl (Ukraine) in 1986, Goiânia (Brazil) and, recently, Fukushima (Japan), there is a great concern regarding the radiation doses from these accidents. In such accidents, the soil may be contaminated by ^{137}Cs, which is one of the most dangerous radioactive materials from such accidents. This contaminants may spread for several km^2 [1,2].

Some papers previously evaluated the doses from ^{137}Cs in soil, using mathematical phantoms, to represent the exposed individuals [3]. These phantoms, however, present a simplified anatomical structure. Intending a more detailed simulation, we proposed, in this work, the use of a more realistic scenario.

The main objective of this work is to carry out a detailed dosimetric evaluation of expositions from different soils, contaminated with ^{137}Cs. This will be done using Monte Carlo simulations [4] coupled with adult anthropomorphic phantoms, named FASH and MASH [5].

2. MATERIALS AND METHODS

The dosimetric evaluation was carried out using a ^{137}Cs radioactive source, which emits photons with energies of 662 keV. We considered this source as soil contaminant, from spill of radioactive material from a radiological accident [2].

This source is emitting photons isotropically, which are interacting with the individuals at the surface. The results were obtained using the radiation transport code MCNPX (version 2.7.1)

[4], and the absorbed doses were determined over the organs and tissues of the adult virtual anthropomorphic phantoms MASH3 (male, 1.76 m height and 73 kg) and FASH3 (female, 1.63 m height and 60 kg). A detailed description of these phantoms may be found elsewhere [5].

The geometrical arrangement, used in the MCNPX code, is presented in Figure 1. The soil was represented by a cylinder with a depth of 2 cm and 5 m radius. The radioactive material was uniformly and separately inserted in the soil.

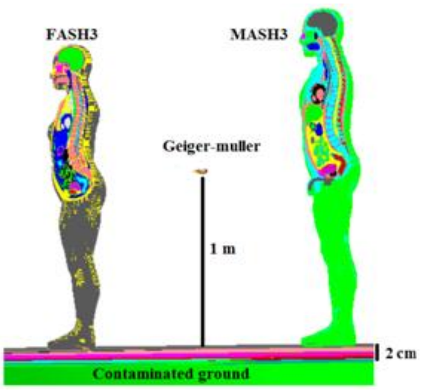

Figure 1. Exposition scenario with the FASH3 and MASH3 phantoms placed on contaminated soil.

We also investigated the influence of chemical and physical characteristics of the soil, named soils 1, 2 and 3, on the determined dosimetrical values. Their description is presented in table 1.

The absorbed doses were estimated separately for each source and soil, and calculated for several organs and tissues. The weighting factors w_T for each organ and tissue, recommended by ICRP 103 [6] were applied to the conversion coefficients (*CC*) for equivalent dose (*CC[H_T]*) to each organ and tissue. With these values, we determined the *CC* for effective dose (*CC[E]*), as stated in equation 1.

Table 1. Soil composition used in the Monte Carlo simulations.

Soil	Density (g/cm³)	Composition (%)	
1	2.00	Si (21.61) Al (8.2) Fe (4.5) Mn (0.1) C (2.4) Ca (5.1)	Na (0.6) K (2.33) P (0.02) H (3.04) O (51.5)
2	1.25	H (16.87) O (27)	Al (1.976) Si (8.963)
3	1.60	H (2.1) C (16) O (57.7) Al (5.0)	Si (27.1) K (1.3) Ca (4.1) Fe (1.1)

$$CC(E) = \sum_T w_T \left[\frac{CC(H_T)_{Male} + CC(H_T)_{Female}}{2} \right] \quad (1)$$

were w_T is the weigting factor for each organ and tissue, $CC(H_T)_{Male}$ is the *CC[H_T]* for the male phantom, and $CC(H_T)_{Female}$ for the female phantom.

All results were normalized by the air kerma, measured with a Geiger-Müller Pancake Probe (GM), computationally modeled (see Figure 2), and positioned 1 m above the ground. A detailed description of the GM may be found at [7]. The MC simulations were carried out with 10^8 histories.

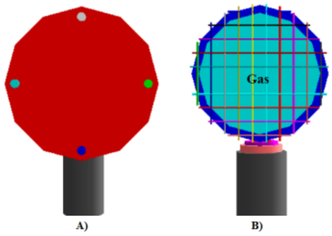

Figure 2. Geometry of the GM counter - external (A) and internal (B) frontal views.

3. RESULTS AND DISCUSSION

The *CC[H_T]* and *CC[E]* normalized by the air kerma, measured 1 m above the ground are presented in tables 2, 3 and 4, respectively. All uncertainties are below 1%.

According to the data listed in tables 2 and 3, we may note that the *CC[H_T]* were higher for the gonads, and skin, in the male phantom, while the skin and bone marrow presented the highest values for the female phantom. These structures are all located near the ground, were the radioactive sources are inserted.

Considering the different soil constitutions, the CC values presented a small variation, as may be seen from Table 2, which indicates no different shielding effects.

Table 2. *CC[H_T]*/air kerma measured 1 m above the ground (Sv/Gy) for the MASH3 virtual anthropomorphic phantom for the different soils.

Organs	Soil 1	Soil 2	Soil 3
Bone marrow	0.63	0.64	0.62
Colon wall	0.61	0.61	0.60
Lung	0.57	0.58	0.57
Stomach wall	0.55	0.55	0.55
Breast	0.75	0.76	0.76
Reminder tissues[1]	0.054	0.055	0.054
Gonads	0.84	0.86	0.82
Bladder wall	0.66	0.67	0.64
Oesophagus	0.48	0.49	0.48
Liver	0.57	0.57	0.56
Thyroid	0.44	0.45	0.43
Bone surface	0.15	0.15	0.15
Brain	0.55	0.55	0.55
Salivary glands	0.21	0.21	0.21
Skin	0.85	0.85	0.84
Eyes	0.61	0.61	0.60

[1]Adrenals, extrathoracic region, gall bladder, heart, kidneys, lymph nodes, muscles, oral cavity, pancreas, uterus, small intestine and spleen

Table 3. *CC[H_T]*/air kerma measured 1 m above the ground (Sv/Gy) for the FASH3 virtual anthropomorphic phantom for the different soils.

Organs	Soil 1	Soil 2	Soil 3
Bone marrow	0.86	0.87	0.85
Colon wall	0.60	0.61	0.60
Lung	0.64	0.64	0.64
Stomach wall	0.56	0.56	0.56
Breast	0.77	0.77	0.76
Reminder tissues[1]	0.047	0.048	0.47
Gonads	0.64	0.65	0.63
Bladder wall	0.69	0.71	0.68
Oesophagus	0.57	0.56	0.57
Liver	0.57	0.58	0.57
Thyroid	0.55	0.55	0.55
Bone surface	0.13	0.13	0.12
Brain	0.59	0.59	0.59
Salivary glands	0.23	0.23	0.23
Skin	0.86	0.87	0.85
Eyes	0.67	0.65	0.65

[1]Adrenals, extrathoracic region, gall bladder, heart, kidneys, lymph nodes, muscles, oral cavity, pancreas, uterus, small intestine and spleen

Table 4. *CC[E]*/air kerma measured 1 m above the ground (Sv/Gy) for the MASH3 e FASH3 virtual anthropomorphic phantoms.

Soil	*CC[E]*
1	0.57
2	0.57
3	0.56

4. CONCLUSION

In this work we evaluated the doses involved in an environmental contamination of soil, with ^{137}Cs. The results showed that differences in soil composition did not change significantly the CC vlaues. Besides, the highest *CC[H_T]* values were for the gonads and skin (male) and bone marrow and skin (female). Therefore, the *CC[H_T]*/air kerma established in this study will be useful to readily estimate the equivalent dose, during an environmental contamination of soil with ^{137}Cs.

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