CAN THE EQUIVALENT SPHERE MODEL APPROXIMATE ORGAN DOSES IN SPACE?

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INTRODUCTION
For space radiation protection it is often useful to calculate dose or dose equivalent in blood forming organs (BFO). It has been customary to use a 5cm equivalent sphere to simulate the BFO dose. However, many previous studies have concluded that a 5cm sphere gives very different dose values from the exact BFO values. One study [1] concludes that a 9cm sphere is a reasonable approximation for BFO doses in solar particle event environments.

METHODS
In this study we use a deterministic radiation transport [2] to investigate the reason behind these observations and to extend earlier studies. We take different space radiation environments, including seven galactic cosmic ray environments and six large solar particle events, and calculate the dose and dose equivalent in the skin, eyes and BFO using their thickness distribution functions from the CAM (Computerized Anatomical Man) model [3]. The organ doses have been evaluated with a water or aluminum shielding of an areal density from 0 to 20 g/cm². We then compare with results from the equivalent sphere model and determine in which cases and at what radius parameters the equivalent sphere model is a reasonable approximation. Furthermore, we address why the equivalent sphere model is not a good approximation in some cases.

RESULTS
For solar particle events, we find that the radius parameters for the organ dose equivalent increase significantly with the shielding thickness, and the model works marginally for BFO but is unacceptable for the eye or the skin. For galactic cosmic rays environments, the equivalent sphere model with an organ-specific constant radius parameter works well for the BFO dose equivalent, marginally well for the BFO dose and the dose equivalent of the eye or the skin, but is unacceptable for the dose of the eye or the skin.

The ranges of the radius parameters are also being investigated, and the BFO radius parameters are found to be significantly larger than 5 cm in all cases, consistent with the conclusion of an earlier study [1]. The radius parameters for the dose equivalent in GCR environments are approximately between 10 and 11 cm for the BFO, 3.7 to 4.8 cm for the eye, and 3.5 to 5.6 cm for the skin; while the radius parameters are between 10 and 13 cm for the BFO dose.

REFERENCES
Can the Equivalent Sphere Model Approximate Organ Doses in Space?

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Abstract

It has been customary to use a 5 cm equivalent sphere to approximate the BFO dose; however, previous studies have shown that the dose is very insensitive to the choice of sphere size. In this study, we use a deterministic transport code with organ geometries from the Computerized Anatomical Man model to investigate whether the Equivalent Sphere Model (ESM) can approximate organ doses in space radiation environments. We find that, for galactic cosmic rays environments, the model with an organ-specific constant radius parameter works well for the BFO dose and the dose equivalent of the eye or the skin. For solar particle events, the radius parameters for organ doses increase with the shielding thickness, and the model works marginally for BFO but is unacceptable for the eye or the skin. The ranges of the radius parameters are also given, and for BFO they are found to be significantly larger than 5 cm in all cases.

Introduction

It is often useful to calculate the dose or dose equivalent in blood-forming organs (BFO), the skin, or the eye. Although it has been customary to use a 5 cm equivalent sphere to simulate the BFO dose, many previous studies have concluded that a 5 cm sphere gives very different dose values from the exact BFO values. One study [1] concludes that a 3 cm sphere is a reasonable approximation for BFO doses in solar particle event environments.

Method


The skin, eye and BFO thickness probability distributions were extracted from the cumulative thickness distribution [6] from the CAM model [3] as shown in Fig.2.

We then calculate dose (D) and dose equivalent (H) of organ / according to

\[ D = \int D(\rho) f(\rho) d\rho, \quad H = \int H(\rho) f(\rho) d\rho. \]

The ESM radius parameters are then determined from

\[ D(R^o) = D_v, \quad H(R^o) = H_v. \]

Results

Dose-depth curves:

The dose and dose equivalent in water, with or without water or Aluminum shielding of 0.2-20 g/cm^2, are calculated as a function of water depth. The results on dose equivalent without shielding are shown below. Note that radius parameters do not depend on the normalization of dose-depth curves.

Radius parameters without shielding:

From Table 1 for SPEs, we see that the BFO radius parameters for different SPEs are within 20% of each other. They are within a factor of 2 for the eye. However, the skin radius parameters for the Aug. 1972 SPE are much bigger than for the other SPEs.

Table 1: Radius parameters (in cm) for organ doses

Radius parameters in presence of shielding:

The dependence of the radius parameter of each organ on the shielding thickness, as shown in Fig.5 for SPEs. We find that for organ doses, the radius for different SPEs are within 20% of each other. The change is very large and ESM will not work. For dose in the eye and skin, the increase is only that the ESM will not work.

Summary

We have studied whether the Equivalent Sphere Model (ESM) works in SPE and GCR environments for BFO, eye or skin. For SPEs, we find that the ESM works marginally for BFO dose but is unacceptable for the eye or the skin. For GCRs, the model works well for the BFO dose equivalent, marginally for the eye and skin. The radius parameters of BFO are found to be significantly larger than 5 cm in all cases. Detailed ranges are shown in Table 3.

References: