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/cm^2. 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

[1] Bier S.G., Townsend L.W. and Maxson W.L. (1998) *Adv Space Res* 21, 1777-1779. [2] Wilson J.W. et al (1995) NASA TP-3495. [3] Billings M.P. and Yucker W.R. (1973) NASA CR-134043.

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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 this gives conservative dose values. In this study, we use a deterministic radiation transport 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 equivalent and marginally well for the BFO dose and the dose equivalent of the eye or the skin. For solar particle events, the radius parameters for organ dose equivalent 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 9 cm sphere is a reasonable approximation for BFO doses in solar particle event environments.

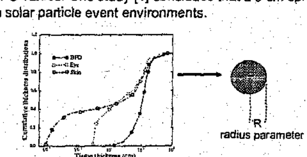

Fig.1 Using an equivalent sphere to represent an organ avoids time-consuming calculations that use the actual thickness distribution function.

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 6 large solar particle events (SPEs) and 7 Galactic Cosmic Ray environments (GCRs), and calculate the dose and dose equivalent in the skin, eye and BFO using their thickness distribution functions from the Computerized Anatomical Man (CAM) model [3]. The organ doses are evaluated with a water or aluminum shielding of an areal density from 0 to 20 g/cm2. We determine in which cases and at what radius parameters the equivalent sphere model is a reasonable approximation.

Method

The six solar particle events that we use include the Aug. 4, 1972; Aug. 12, 1989; Sept. 29, 1989; Oct. 19, 1989; Mar. 23, 1991 events [4] and the Jan. 20, 2005 event [5]. The GCR environments include the solar maximum environments in 1958-1959, 1970-1971, 1981-1982, 1989; and the solar minimum environments in 1965, 1977 and 1986-1987 [2]. We then calculate the dose-depth curves using HZETRN [2] with or without shielding materials.

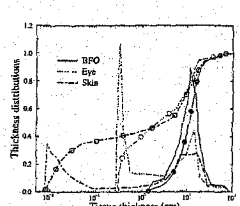

Fig.2 Thickness distributions of skin, eye and BFO from the CAM model. Curves with circles represent the cumulative distributions.

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

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

$$D_i = \int D(t) f_i(t) dt, \quad H_i = \int H(t) f_i(t) dt.$$

The ESM radius parameters are then determined from

$$D(R_i^D) = D_i, \quad H(R_i^H) = H_i.$$

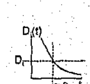

Fig.3 Determine the ESM radius parameter.

Results

Dose-depth curves:

The dose and dose equivalent in water, with or without water or Aluminum shielding of 0-20 g/cm², 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.

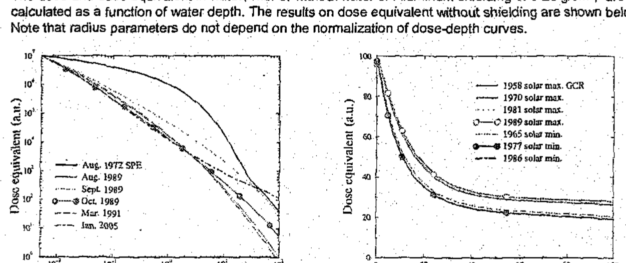

Fig.4 Dose equivalent (in arbitrary units) in water without shielding for SPEs (left) and GCRs (right).

Radius parameters without shielding:

From Table 1 for SPEs, we see that the BFO radius parameters for different SPEs are within ~25% 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 from for the other SPEs.

Table 2 For GCRs, shows that the radius parameters of each organ are much larger than the values in SPEs. They are also on the same order of magnitude as the average thickness of the organ <t> (shown in the last column of Table 2). This is because the dose-depth curves in GCRs change much more slowly with depth compared with those in SPEs. For the organ dose equivalent, the radius parameters are close to each other for each of the three organs, especially for BFO. But for organ dose, they are close to each other only for BFO. Jansen's Inequality explains that the radii for dose equivalent are smaller than <t> because the dose equivalent-depth curves are mostly convex.

SPE Event #	1	2	3	4	5	6
R^H_{BFO}	6.8	6.6	7.4	7.1	6.4	7.7
R^D_{BFO}	6.9	6.8	7.7	7.2	6.6	8.0
R^H_{Eye}	1.1	0.68	0.77	0.69	0.67	0.69
R^D_{Eye}	1.2	0.74	0.87	0.76	0.74	0.78
R^H_{Skin}	0.21	0.038	0.043	0.035	0.039	0.035
R^D_{Skin}	0.41	0.055	0.070	0.049	0.057	0.049

Table 1: Radius parameters (in cm) for organ dose (D) and dose equivalent (H) in different SPE environments when there is no extra shielding.

	Solar Maximum GCR				Solar Minimum GCR			Organ <t> (cm)
GCR #	1	2	3	4	5	6	7	
R^H_{BFO}	10.7	10.6	10.6	10.7	10.3	10.2	10.2	13.
R^D_{BFO}	11.9	11.6	11.6	11.6	11.0	11.0	11.0	
R^H_{Eye}	4.8	4.7	4.7	4.6	4.1	3.9	3.9	6.8
R^D_{Eye}	12.	9.3	10.	11.	5.6	5.1	5.1	
R^H_{Skin}	5.5	5.3	5.4	5.5	4.5	4.3	4.3	7.5
R^D_{Skin}	18.	14.	15.	17.	7.3	6.6	6.6	

Table 2: same as Table 1 but for GCR environments.

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 see moderate increase of the radius for BFO; and R~7-11 fm, consistent with the 9 cm sphere previously suggested [1]. For eye and skin, the increase is so large that ESM will not work.

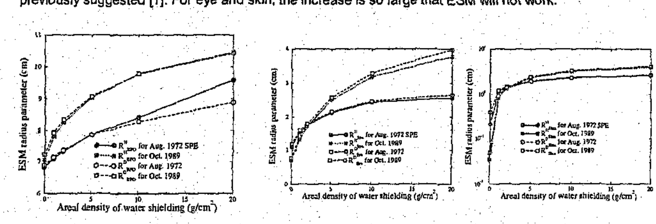

Fig.5 Radius for BFO (left), eye (middle) and skin (right) as a function of shielding thickness in SPEs.

Results for GCRs are shown below in Fig.6. We see that the radii for organ dose equivalent do not change much with shielding thickness; thus ESM may be applied, especially for BFO. For dose in the eye and skin, the change is very large and ESM will not work.

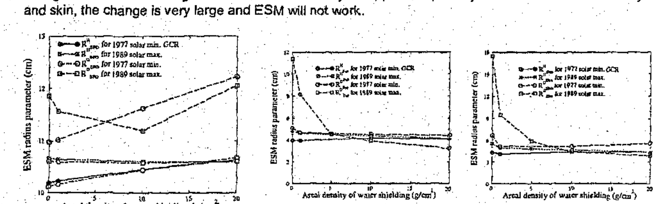

Fig.6 Radius for BFO (left), eye (middle) and skin (right) as a function of shielding thickness in GCRs.

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 ESM works marginally for BFO but is unacceptable for the eye or the skin. For GCRs the model works well for the BFO dose equivalent, marginally for the BFO dose and the dose equivalent of the eye or the skin, but is unacceptable for the dose in the eye or 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.

Radius Parameter (cm)	for GCRs	for SPEs
R^H_{BFO}	10.-11.	6.8-10.5
R^D_{BFO}	10.-13.	6.9-10.6
R^H_{Eye}	3.7-4.8	[illegible]
R^D_{Eye}	[illegible]	[illegible]
R^H_{Skin}	3.5-5.6	[illegible]
R^D_{Skin}	[illegible]	[illegible]

Table3: How does the Equivalent Sphere Model work? Color coding: Well, Marginally, Badly

References:

[1] Bier, Townsend and Maxson, *Adv. Space Res.* 21, 1777-1779 (1998).
[2] Wilson et al., NASA TP-3495 (1995).
[3] Billings and Yucker, NASA CR-134043 (1973).
[4] Xapsos et al., *IEEE Trans. on Nucl. Sci.* 47, 2218 (2000).
[5] Mewaldt et al., *Proc. 29th Int'l Cosmic Ray Conf.* 1, 111 (2005); Mewaldt, private comm.
[6] Nealy, Striepe and Simonsen, NASA TP-3211 (1992).