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A NOTE ON IMPORTANCE FUNCTIONS FOR THE SHIELDING OF MANNED SPACE VEHICLES

R. G. Alsmiller, Jr.

OAK RIDGE NATIONAL LABORATORY
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Contract No. W-7405-eng-26

Neutron Physics Division

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R. G. Alsmiller, Jr.

MARCH 1964

*Work performed under NASA Order Nos. T-7632 and R-104.

OAK RIDGE NATIONAL LABORATORY
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Abstract

The tissue dose calculations of Kinney and Zerby have been used to calculate several importance functions which are of interest in the shielding of manned space vehicles. The functions considered are concerned with the dose from primary and secondary particles in the tissue which arise from a solar-flare proton spectrum that has penetrated an aluminum shield. The secondary particles which are produced in the aluminum are not considered.

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I. Introduction

In a previous report[1] (hereinafter referred to as 1) results were given for two "importance functions" which are of interest in the shielding of manned-space vehicles. An importance function as that term was used in 1, measures the importance of each energy region in a given proton flare spectrum in producing some definite physical effect. Thus, a large variety of importance functions may be defined.

In this note results are given for several more importance functions. While the functions discussed in 1 were concerned with the surface dose from primary and secondary particles which emerge from an aluminum shield, the functions discussed here are concerned with the dose from primary and secondary particles in tissue which arise from a primary proton beam that has penetrated an aluminum shield.

The calculations presented in this note are based on the tissue dose calculations of W. E. Kinney *et al.*[2] The results refer specifically to primary proton beams which are normally incident on slab shields and yield little if any information about the more general case of isotropic incidence.

In Section II the various importance functions are defined and their meanings discussed. In Section III calculated values of the importance functions are given and conclusions drawn. In the appendix the relation between the importance functions given in 1 and the more general functions discussed in this note is considered.

II. Definition of Importance Functions

To understand the significance of the term importance function and the various functions which may be defined consider Fig. 1.

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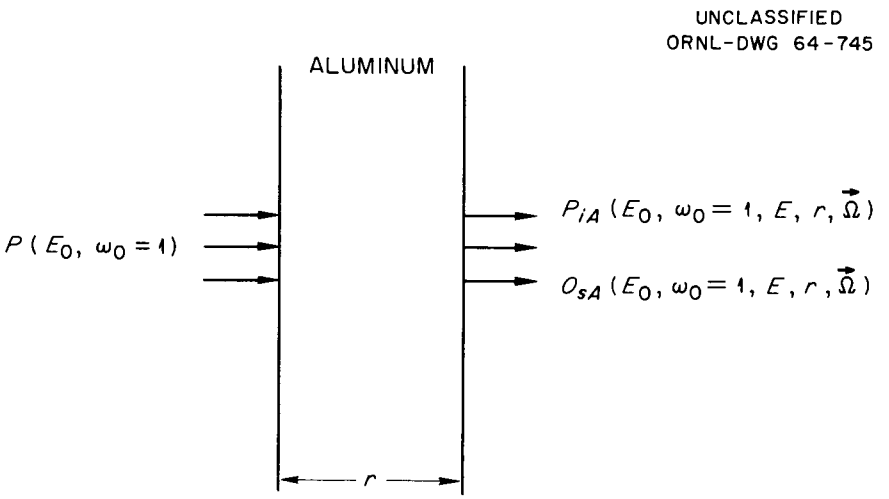
1. R. G. Alsmiller, Jr. and J. E. Murphy, *Space Vehicle Shielding Studies: Calculations of the Attenuation of a Model Solar Flare and Monoenergetic Proton Beams by Aluminum Shields*, ORNL-3317 (1963).

2. W. E. Kinney and C. D. Zerby, private communication. (A brief description of this work may be found in ORNL-3499, Vol. II, p 56.) I would like to thank Mr. Kinney and Dr. Zerby for allowing me to use their results prior to their publication.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ALUMINUM
$P(E_0, \omega_0 = 1)$
$P_{iA}(E_0, \omega_0 = 1, E, r, \vec{\Omega})$
$O_{sA}(E_0, \omega_0 = 1, E, r, \vec{\Omega})$
r

Fig. 1.

Let $P(E_o,\omega_o)$ be an infinite monoenergetic, monodirectional proton flux of energy E_o and direction ω_o and let this flux be incident normally on an infinite slab of aluminum of thickness r. That is, we consider an incident proton flux of the form

$$P(E_o,\omega_o) = P_o\ \delta(E - E_o)\ \frac{\delta(\omega - \omega_o)}{2\pi}\ ,$$

where

P_o = normalizing constant,

$\omega = \cos\theta$,

$\omega_o = \cos\theta_o$,

(all angles are measured with respect to a z axis which is normal to the slab), and we take the very special case

$$\omega_o = 1\ .$$

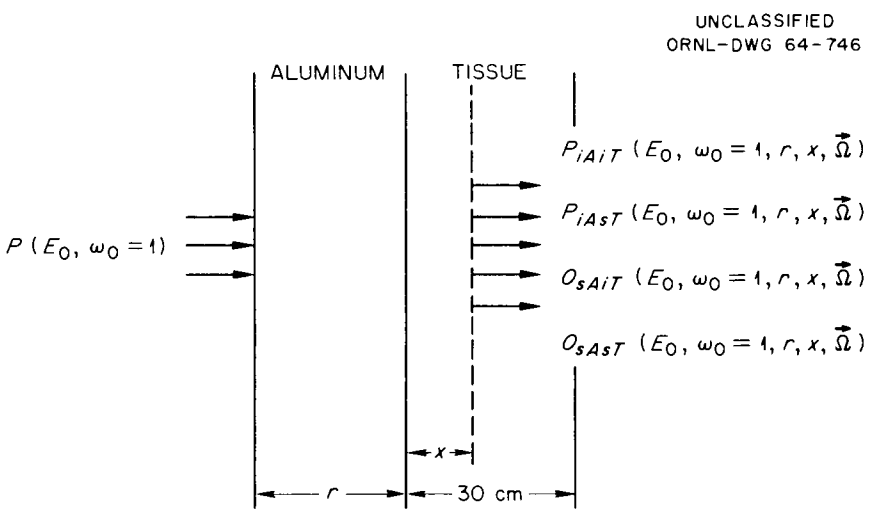
We may distinguish two fluxes leaving the aluminum slab:

$P_{iA}(E_o,\omega_o{=}1,E,r,\vec{\Omega})$ = angular flux of primary protons per unit energy range, i.e., those protons which did not undergo nuclear reaction in the aluminum;

$O_{sA}(E_o,\omega_o{=}1,E,r,\vec{\Omega})$ = angular flux of all secondary particles per unit energy range, including protons, neutrons, heavy nuclei, etc.

In these functions the notation $\omega_o = 1$ has been used to emphasize that only normal incidence is considered. Of course, the same definitions could be used with an arbitrary ω_o.

Consider next the geometry shown in Fig. 2. The situation is the same as in Fig. 1 except that an infinite slab of tissue, of thickness 30 cm, now follows the aluminum. At any depth x in the tissue four fluxes may be distinguished:


UNCLASSIFIED
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ALUMINUM
TISSUE
$P_{iAiT}(E_0, \omega_0 = 1, r, x, \vec{\Omega})$
$P_{iAsT}(E_0, \omega_0 = 1, r, x, \vec{\Omega})$
$P(E_0, \omega_0 = 1)$
$O_{sAiT}(E_0, \omega_0 = 1, r, x, \vec{\Omega})$
$O_{sAsT}(E_0, \omega_0 = 1, r, x, \vec{\Omega})$
x
r
30 cm

Fig. 2.

$P_{iAiT}(E_o,\omega_o=1,E,r,x,\vec{\Omega})$ = angular flux per unit energy range of primary protons in the tissue which arise from the flux P_{iA},

$P_{iAsT}(E_o,\omega_o=1,E,r,x,\vec{\Omega})$ = angular flux per unit energy range of secondary particles in the tissue which arise from the flux P_{iA},

$O_{sAiT}(E_o,\omega_o=1,E,r,x,\vec{\Omega})$ = angular flux per unit energy range of "primary" particles in the tissue which arise from the flux O_{sA},

$O_{sAsT}(E_o,\omega_o=1,E,r,x,\vec{\Omega})$= angular flux per unit energy range of secondary particles in the tissue which arise from the flux O_{sA}.

It is important to note that in the above definitions P_{iA} and O_{sA} are the fluxes which are calculated in the absence of the tissue. To emphasize this, we note that between the fluxes of Fig. 1 and Fig. 2 the following relations exist:

$$P_{iA}(E_o,\omega_o=1,E,r,\vec{\Omega}) = P_{iAiT}(E_o,\omega_o=1,E,r,x,\vec{\Omega})\Big|_{x=o} ,$$

$$O_{sA}(E_o,\omega_o=1,E,r,\vec{\Omega}) = O_{sAiT}(E_o,\omega_o=1,E,r,x,\vec{\Omega})\Big|_{x=o} ,$$

and

$$P_{iAsT}(E_o,\omega_o=1,E,r,x,\vec{\Omega})\Big|_{x=o} \neq 0 ,$$

$$O_{sAsT}(E_o,\omega_o=1,E,r,x,\vec{\Omega})\Big|_{x=o} \neq 0 .$$

At the depth x in the tissue each of these fluxes will be depositing energy, and thus a dose may be associated with each of them. We shall use the notation

$D_{PiAiT}(E_o,\omega_o=1,r,x)$ = dose rate per unit incident flux from the flux P_{iAiT},

$D_{PiAiT+PiAsT}(E_o,\omega_o=1,r,x)$ = dose rate per unit incident flux from the fluxes P_{iAiT} and P_{iAsT}, etc.

Let $F(E_o)$ be a time-integrated isotropic proton flare spectrum (protons/MeV cm^2 ster.). A generic importance function, I, is defined by the equation

$$I_P(E_o,\omega_o=1,r,x) = F(E_o)\ D_P(E_o,\omega_o=1,r,x)\ ,$$

where P may be any flux one wishes to consider. From the definition of D_P it follows that the integral of I over E_o gives the dose at x due to the flux P when the flare spectrum is incident normally on the aluminum.*

The largest contribution to the integral will, of course, come from those values of E_o for which I is largest. Thus the magnitude of I is a measure of the importance per MeV of a particular energy region in the incident spectrum in producing the specific dose under consideration.

In addition to the value of the functions at a specific x we shall in some cases be interested in the functions averaged over all x. For future reference we define $\bar{I}_P$ by

$$\bar{I}_P(E_o,\omega_o=1,r) = F(E_o)\ \frac{1}{30}\int_0^{30} D_P(E_o,\omega_o=1,r,x)\ dx\ .$$

---

*Importance functions as they are defined here will have units of rem/MeV steradians. When something other than normal incidence is to be considered one would consider I to be a function of ω_o and define an energy importance function, I', as

$$I'_P(E_o,r,x) = 2\pi \int_{-1}^{1} I_P(E_o,\omega_o,r,x)\, d\omega_o\ .$$

In addition to the importance functions defined above there is another closely related class of functions which are of interest. A primary proton of energy E_o will lose energy on traversing the aluminum and will arrive at the aluminum-tissue interface with an energy E_{oT}. These energies are related through the equation

$$\int_{E_{oT}}^{E_o} \frac{dE}{S(E')} = r \ ;$$

i.e.,

$$E_o = E_o(E_{oT}, r) \ ,$$

where $S(E')$ = stopping power of aluminum. Using this relation, the importance functions can be considered to be a function of E_{oT}. To retain the integral property of the functions, it is appropriate to introduce a Jacobian and define the new class of functions, J_P, through the equation

$$J_P(E_{oT}, \omega_o=1, r, x) = I_P\left[E_o(E_{oT}, r), \omega_o=1, r, x\right] \frac{S(E_o)}{S(E_{oT})} \ .$$

The integral of J_P over E_{oT} now has the same value and meaning as the integral of I_P over E_o; however, J_P may now be considered to measure the importance of a given energy region at the aluminum-tissue interface while I_P measures the importance of a given energy region in the incident spectrum. One also has, of course

$$\overline{J}_P(E_{oT}, \omega_o=1, r, x) = \overline{I}_P\left[E_o(E_{oT}, r), \omega_o=1, r, x\right] \frac{S(E_o)}{S(E_{oT})} \ .$$

III. Results and Discussion

In this section numerical results for the functions I_{PiAiT}, I_{PiAsT}, J_{PiAiT}, and J_{PiAsT} will be given. Throughout this section the function I_{PiAsT} will be broken into two parts: a contribution from secondary protons and a contribution from heavy nuclei. The function itself is,

of course, to be obtained by adding the two contributions. It is important to note that all results are given in rems; i.e., an RBE has been included.[2]

For purposes of comparison three quite different flare spectra have been considered. The time-integrated differential energy spectra used are shown in Fig. 3.[3] Also a spectrum representative of the protons in the Van Allen belt has been considered.[4] This spectrum is shown in Fig. 4.*

In Fig. 5 the importance functions I_{PiAiT} and I_{PiAsT} are plotted against E_0 for the case of the Bailey model flare incident with

$$r = 9.38 \text{ g/cm}^2$$

and

$$x = 5 \text{ cm.}$$

The lowest energy for which the curves are given correspond to a proton of energy 100 MeV incident on the tissue. This is the lowest energy for which the calculations of Kinney are available. It should be noted that at an energy such that a primary proton cannot penetrate 9.38 g/cm^2 of aluminum (~ 97 MeV) all of the functions necessarily go to zero.

All of the curves fall off very rapidly with increasing energy so most of the area under the curves comes at the lowest energies. In general the figure indicates that the most important energy in the incident spectrum for producing a dose from primary protons and from secondary particles in the tissue is an energy just slightly larger than the energy which a primary proton must have to get through the aluminum shield. The secondary particles will contribute approximately 20% of the total dose. The contribution to the secondary dose from the heavy nuclei is roughly comparable to the contribution from the secondary protons.**

---

3. The time-integrated integral energy spectra from which these differential spectra were obtained were supplied by W. L. Gill, private communication.

4. S. C. Freden and R. S. White, "Particle Fluxes in the Inner Radiation Belt," J. Geophys. Res. 65, 1377-1383 (1960).

*Since the Freden-White spectrum is not integrated over time, the importance functions from this spectrum will have units of rem/MeV·ster·sec.

**In considering this last statement it must be remembered that the comparison is being made in rems and a large RBE (20) has been used for the heavy nuclei.[2]

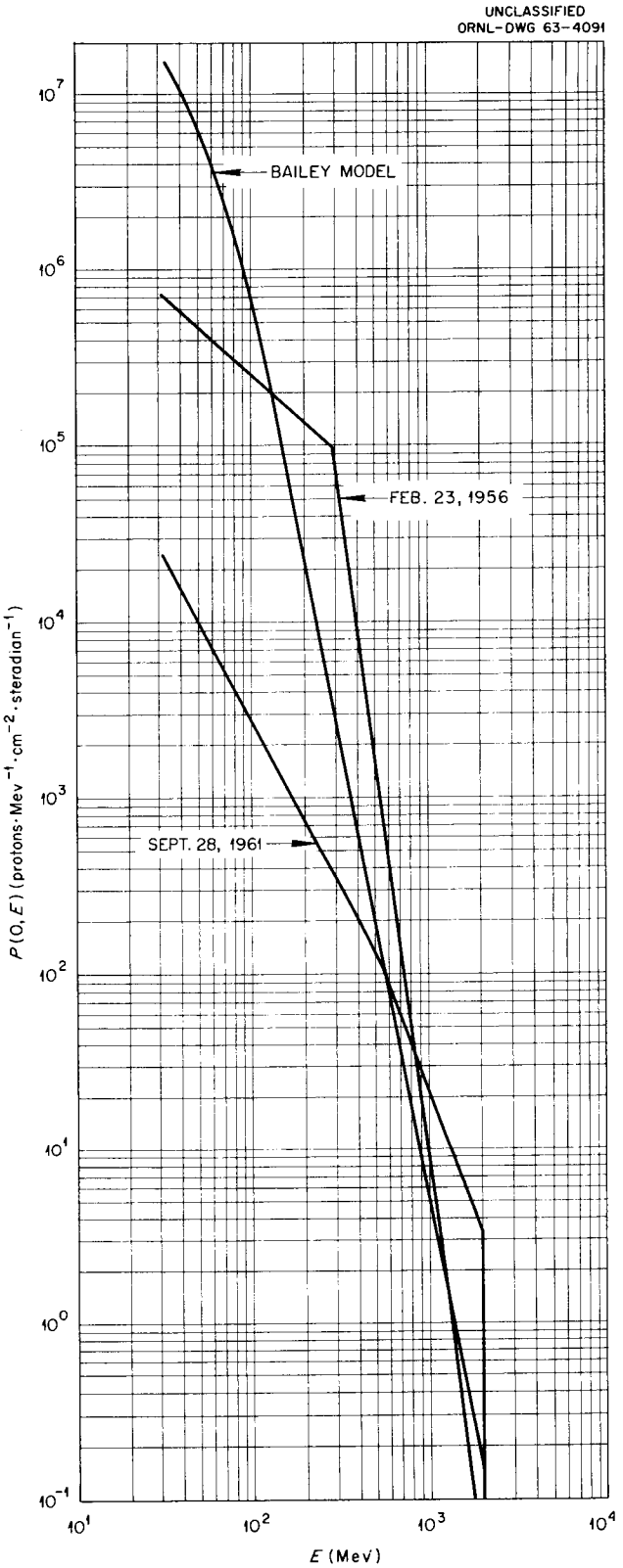

Fig. 3. Time-Integrated Differential Energy Spectra.

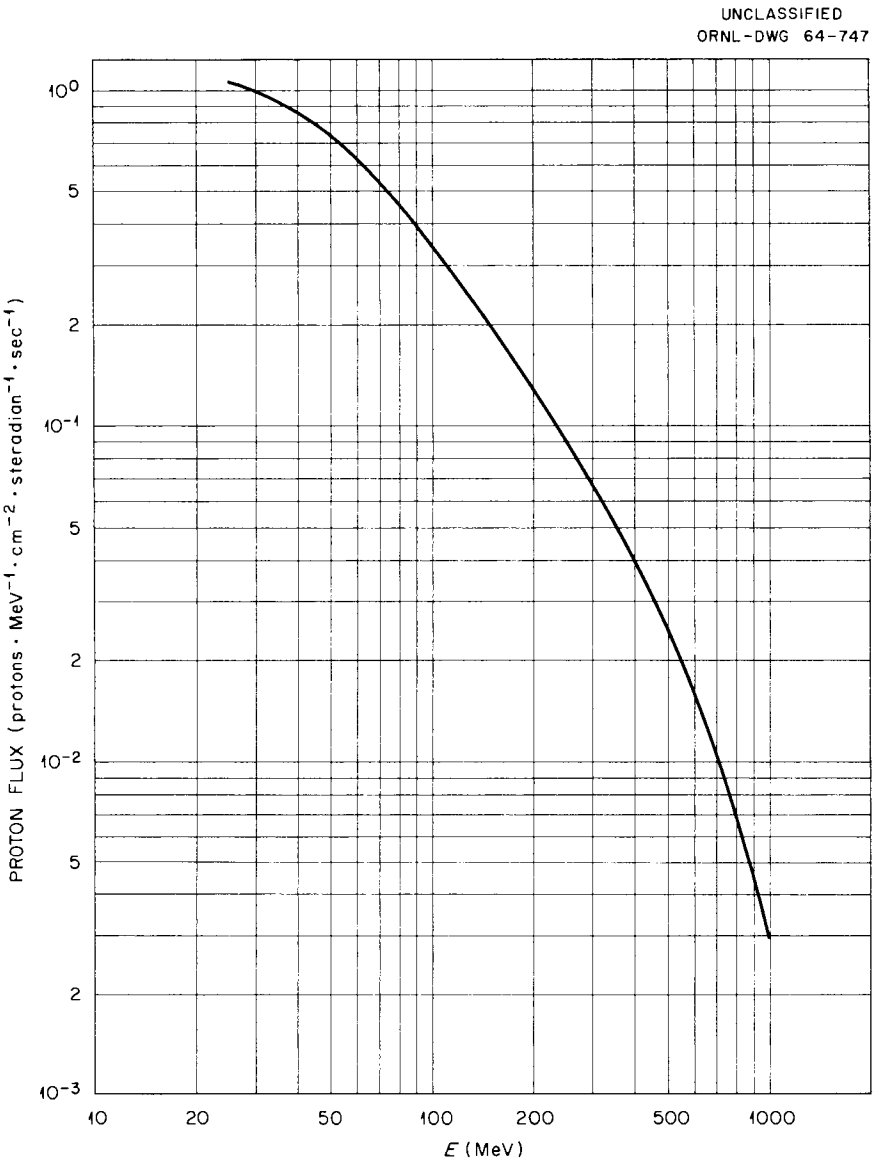

Fig. 4. Freden White Spectrum of Protons in Lower Radiation Belt.

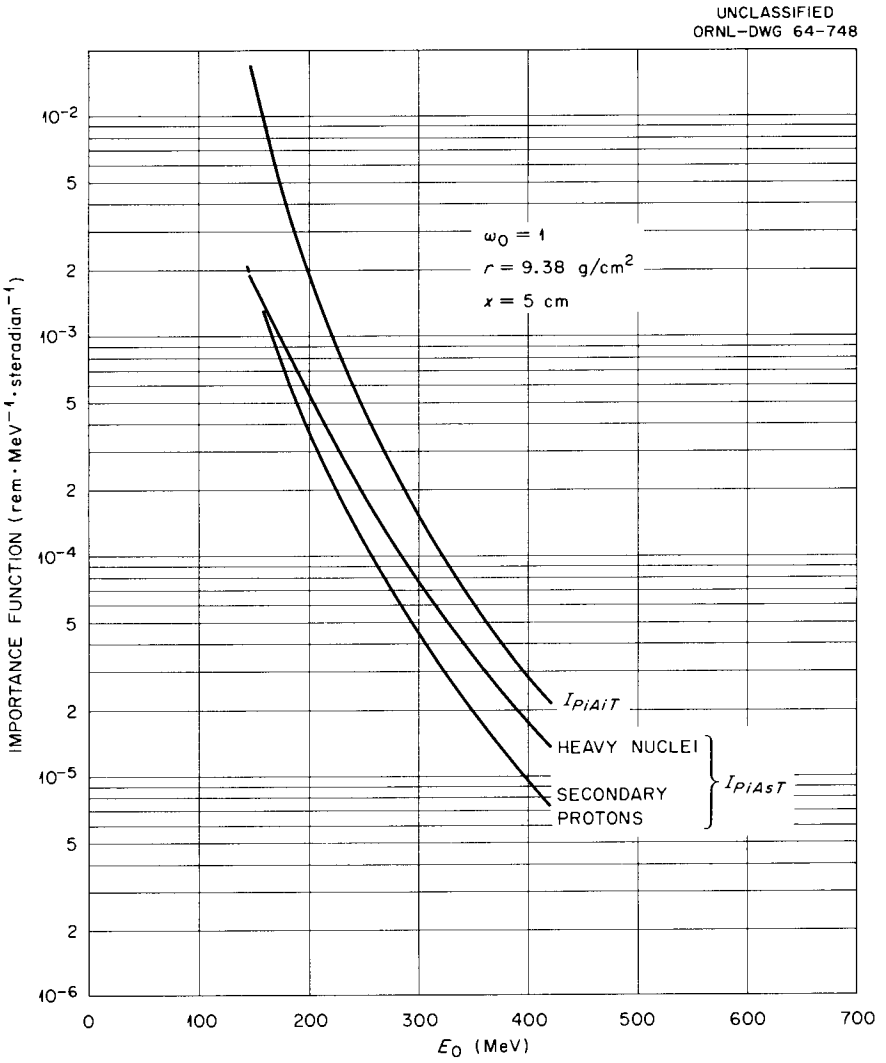

Fig. 5. Bailey's Model Flare.

In Fig. 6 the functions J_{PiAiT} and J_{PiAsT} are plotted against E_{oT} for the case of the Bailey flare incident with

$$r = 9.38 \text{ g/cm}^2$$

and

$$x = 5 \text{ cm.}$$

These curves are similar to the curves of Fig. 5 but contain slightly different information. If experimental measurements are to be made using monoenergetic proton beams in tissue, it is the curves of Fig. 6 which indicate the most appropriate energy for these beams since E_{oT} is the energy of protons incident on the tissue.

Since we have no information about the shape of the curves for energies of less than 100 MeV, it is not possible to decide exactly what energy would be best for experimental measurement; however, it is clear that proton energies of the order of 100 MeV or less are of the most interest.

Numerical values of these importance functions are given for a variety of cases in Tables 1 through 6. In all cases considered with x = 5 cm the curves have the same general shape as those in Figs. 5 and 6 and lead to conclusions similar to those stated above.

When one considers the average whole-body dose rather than the 5-cm dose the situation changes. For the Bailey flare at the larger r values (see Table 5) and for the Freden-White spectrum at all r values (see Table 6 and Fig. 7) the secondary curves (whose sum gives $\overline{I}_{PiAsT}$) do not continue to rise as the energy decreases but rather they exhibit a broad maximum in the vicinity of 200 MeV. The secondary contribution to the total dose is somewhat less in this case than in the previous cases. Insofar as the total dose is concerned, the low-energy region is still of most importance but if one is interested in the dose from secondaries only, the higher energy regions become important.*

*Since the dose from primary particles is readily calculable, experimental measurements are usually concerned with measuring secondary particles.

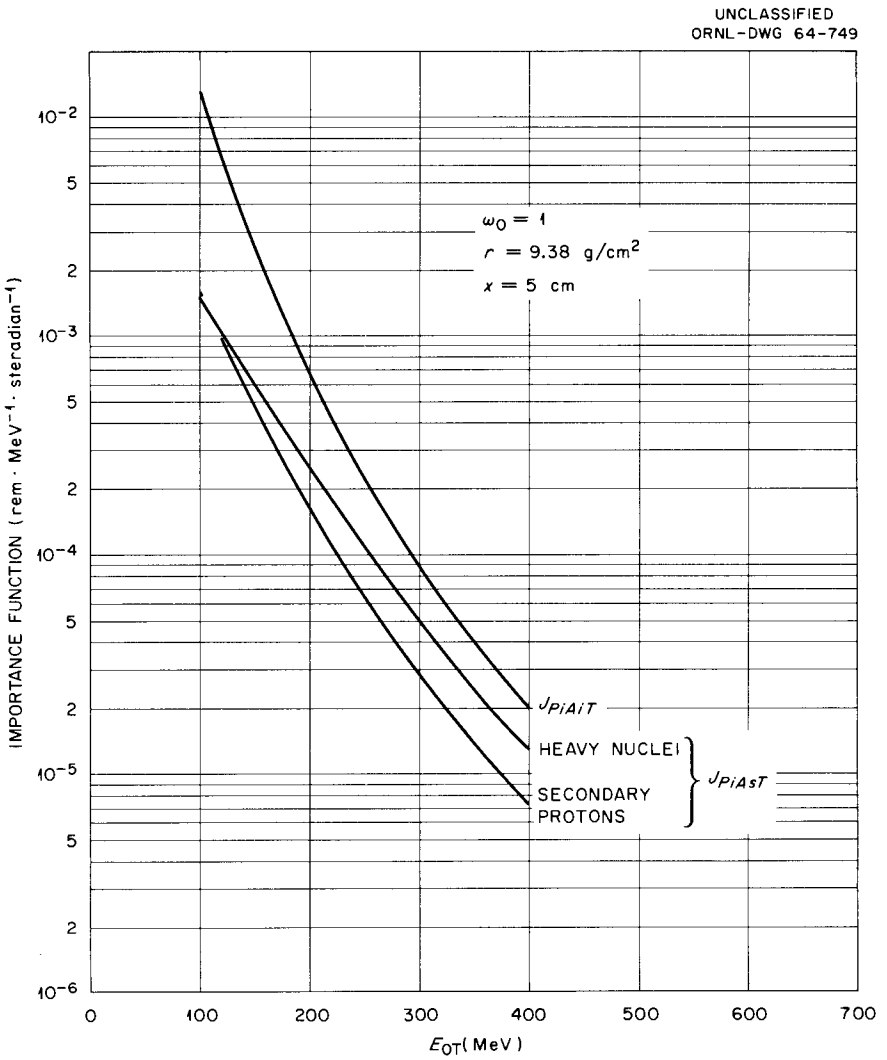

Fig. 6. Bailey's Model Flare.

Table 1. Bailey Flare, $\omega_o = 1$, x = 5 cm

		Importance Function (rem/MeV•ster)					
			I_{PiAsT}			J_{PiAsT}	
E_{oT} (MeV)	E_o (MeV)	I_{PiAiT}	Secondary Protons	Heavy Nuclei	J_{PiAiT}	Secondary Protons	Heavy Nuclei
				r = 0			
					x 10^{-3}	x 10^{-3}	x 10^{-3}
100					115	13.6	12.8
200					1.72	.415	.648
300					.160	.0507	.0866
400					.0306	.00105	.0194
				r = 9.38 g/cm^2			
		x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}
100	146	172	20.3	19.2	131	15.6	14.7
200	231	7.27	1.75	2.73	6.66	1.60	2.50
300	325	.951	.302	.516	.911	.289	.494
400	422	.211	.0723	.133	.206	.0707	.130
				r = 30.5 g/cm^2			
		x 10^{-5}	x 10^{-5}	x 10^{-5}	x 10^{-5}	x 10^{-5}	x 10^{-5}
100	224	153	18.1	17.1	88.7	10.5	9.92
200	294	17.1	4.12	6.44	13.6	3.28	5.13
300	379	3.53	1.12	1.91	3.13	.994	1.70
400	470	.993	.341	.627	.918	.315	5.80
				r = 49.2 g/cm^2			
		x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}
100	281	400	47.3	44.7	203	24.0	22.7
200	344	64.0	15.4	24.1	46.9	11.3	17.6
300	423	16.6	5.28	9.02	14.0	4.45	7.60
400	511	5.32	1.83	3.36	4.79	1.64	3.02

Table 2. Sept. 28, 1961 Flare, $\omega_o = 1$, x = 5 cm

		Importance Function (rem/MeV·ster)					
			I_{PiAsT}			J_{PiAsT}	
E_{oT} (MeV)	E_o (MeV)	I_{PiAiT}	Secondary Protons	Heavy Nuclei	J_{PiAiT}	Secondary Protons	Heavy Nuclei
			r = 0				
					x 10^{-6}	x 10^{-6}	x 10^{-6}
100					436	51.6	48.8
200					54.8	13.2	20.6
300					20.6	6.55	11.2
400					10.2	3.50	6.44
			r = 9.38 g/cm^2				
		x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}
100	146	197	23.3	22.0	151	17.8	16.9
200	231	38.7	9.33	14.6	35.5	8.54	13.3
300	325	16.4	5.21	8.90	15.7	4.99	8.53
400	422	8.33	2.86	5.26	8.14	2.80	5.14
			r = 30.5 g/cm^2				
		x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}
100	224	74.4	8.82	8.36	43.1	5.10	4.82
200	294	21.4	5.16	8.06	17.1	4.11	6.42
300	379	11.0	3.22	5.50	8.99	2.86	4.88
400	470	5.46	1.88	3.45	5.05	1.73	3.19
			r = 49.2 g/cm^2				
		x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}
100	281	43.0	5.09	4.81	21.8	2.58	2.44
200	344	13.7	3.30	5.16	10.0	2.42	3.78
300	423	6.77	2.15	3.68	5.71	1.81	3.10
400	511	3.78	1.30	2.38	3.40	1.17	2.14

Table 3. Feb. 23, 1956 Flare,* $\omega_o = 1$, x = 5 cm

		Importance Function (rem/MeV·ster)					
			I_{PiAsT}			J_{PiAsT}	
E_{oT} (MeV)	E_o (MeV)	I_{PiAiT}	Secondary Protons	Heavy Nuclei	J_{PiAiT}	Secondary Protons	Heavy Nuclei
				r = 0			
					x 10^{-4}	x 10^{-4}	x 10^{-4}
100					431	51.1	48.3
200					103	24.8	38.7
291*					55.4	17.2	30.2
300					41.4	13.2	22.5
400					4.35	1.49	2.74
				r = 9.38 g/cm^2			
		x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}
100	146	278	33.0	31.1	213	25.2	23.8
200	231	82.4	19.8	31.0	75.4	18.2	28.4
264*	291	57.0	18.9	26.8	54.0	17.9	25.4
300	325	22.6	7.20	12.3	21.7	6.90	11.8
400	422	2.59	.888	1.63	2.53	.868	1.60
				r = 30.5 g/cm^2			
		x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}
100	224	155	18.3	17.3	89.5	10.6	10.0
185*	291	68.4	14.2	20.6	52.1	10.8	15.7
200	294	48.1	11.6	18.1	38.2	9.22	14.4
300	379	5.61	1.78	3.04	4.97	1.60	27.0
400	470	.916	.314	.578	8.46	.291	.535
				r = 49.2 g/cm^2			
		x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}	x 10^{-4}
100	281	106	12.6	11.9	53.8	6.37	6.02
118*	291	93.1	12.0	12.6	52.2	6.74	7.07
200	344	12.8	3.08	4.80	9.35	2.25	3.52
300	423	1.97	.626	1.07	1.66	.528	.902
400	511	.394	.135	.249	.355	.122	.224

*Since the flare spectrum in this case has a discontinuous derivative at E_o equal to 280 MeV, the importance functions will also have a discontinuous derivative. To aid in drawing the curves an estimate of the value of the functions at the point where the discontinuity occurs is given.

Table 4. Freden-White Spectrum, $\omega_o = 1$, x = 5 cm

		Importance Function (rem/MeV.ster)					
			I_{PiAsT}			J_{PiAsT}	
E_{oT} (MeV)	E_o (MeV)	I_{PiAiT}	Secondary Protons	Heavy Nuclei	J_{PiAiT}	Secondary Protons	Heavy Nuclei
				r = 0			
					x 10^{-9}	x 10^{-9}	x 10^{-9}
100					57.5	6.81	6.43
200					9.54	2.30	3.59
300					3.64	1.16	1.98
400					1.81	.623	1.15
				r = 9.38 g/cm^2			
		x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}
100	146	30.3	3.59	3.39	23.2	2.75	2.60
200	231	6.65	1.60	2.50	6.09	1.47	2.29
300	325	2.89	.917	1.57	2.76	.878	1.50
400	422	1.51	.518	9.53	1.47	.506	.931
				r = 28.1 g/cm^2			
		x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}
100	216	13.8	1.63	1.54	8.14	.965	.911
200	288	3.97	.955	1.49	3.20	.770	1.20
300	373	1.87	.595	1.02	1.67	.531	.908
400	465	1.03	.353	.650	.963	.331	.608
				r = 46.9 g/cm^2			
		x 10^{-9}		x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}
100	273	8.03	.953	.900	4.12	.488	.461
200	339	2.56	.616	.961	1.89	.454	.709
300	418	1.29	.411	.703	1.10	.348	.595
400	506	.724	.248	.457	.654	.224	.413

Table 5. Bailey Model, $\omega_o = 1$

		Importance Function (rem/MeV·ster)					
			$\bar{I}_{PiAsT}$			$\bar{J}_{PiAsT}$	
E_{oT} (MeV)	E_o (MeV)	$\bar{I}_{PiAiT}$	Secondary Protons	Heavy Nucleai	$\bar{J}_{PiAiT}$	Secondary Protons	Heavy Nuclei
				r = 0			
					x 10^{-4}	x 10^{-4}	x 10^{-4}
100					393	19.7	41.4
200					21.7	3.56	5.52
300					1.59	.638	.684
400					.285	.165	.152
				r = 9.38 g/cm^2			
		x 10^{-5}	x 10^{-5}	x 10^{-5}	x 10^{-5}	x 10^{-5}	x 10^{-5}
100	146	588	29.5	61.9	450	22.6	47.4
200	231	91.7	15.0	23.3	84.0	13.8	21.3
300	325	9.49	3.80	4.07	9.09	3.64	3.90
400	422	1.96	1.14	1.05	1.92	1.11	1.02
				r = 30.5 g/cm^2			
		x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}
100	224	524	26.4	55.3	303	15.2	32.0
200	294	216	35.4	54.8	172	28.2	43.6
300	379	35.2	14.1	15.1	31.2	12.5	13.4
400	470	9.24	5.35	4.93	8.54	4.95	4.56
				r = 49.2 g/cm^2			
		x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}	x 10^{-6}
100	281	137	6.87	14.4	69.3	3.48	7.31
200	344	80.8	13.2	2.05	59.1	9.69	15.0
300	423	16.6	6.65	7.12	14.0	5.60	6.00
400	511	4.96	2.87	2.64	4.46	2.58	2.38

Table 6. Freden-White Spectrum, $\omega_o = 1$

		Importance Function (rem/MeV·ster)					
			$\bar{I}_{PiAsT}$			$\bar{J}_{PiAsT}$	
E_{oT} (MeV)	E_o (MeV)	$\bar{I}_{PiAiT}$	Secondary Protons	Heavy Nuclei	$\bar{J}_{PiAiT}$	Secondary Protons	Heavy Nuclei
				r = 0			
					x 10^{-9}	x 10^{-9}	x 10^{-9}
100					19.7	.989	2.07
200					12.0	1.97	3.05
300					3.64	1.46	1.56
400					1.69	.979	.902
				r = 9.38 g/cm^2			
		x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}
100	146	10.4	.522	1.09	7.94	.399	.837
200	231	8.39	1.38	2.13	7.68	1.26	1.95
300	325	2.88	1.15	1.24	2.76	1.10	1.18
400	422	1.40	.813	.749	1.37	.795	.733
				r = 28.1 g/cm^2			
		x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}	x 10^{-9}
100	216	4.71	.236	.496	2.79	.140	.294
200	288	5.00	.820	1.27	4.03	.660	1.02
300	373	1.87	.749	.802	1.67	.669	.716
400	465	.957	.550	.512	.896	.519	.479
				r = 46.9 g/cm^2			
		x 10^{-10}	x 10^{-10}	x 10^{-10}	x 10^{-10}	x 10^{-10}	x 10^{-10}
100	275	27.5	1.38	2.90	14.1	.709	1.49
200	339	32.2	5.28	8.18	23.8	3.90	6.04
300	418	12.91	5.18	5.55	10.9	4.38	4.70
400	506	6.74	3.90	3.60	6.09	3.52	3.26

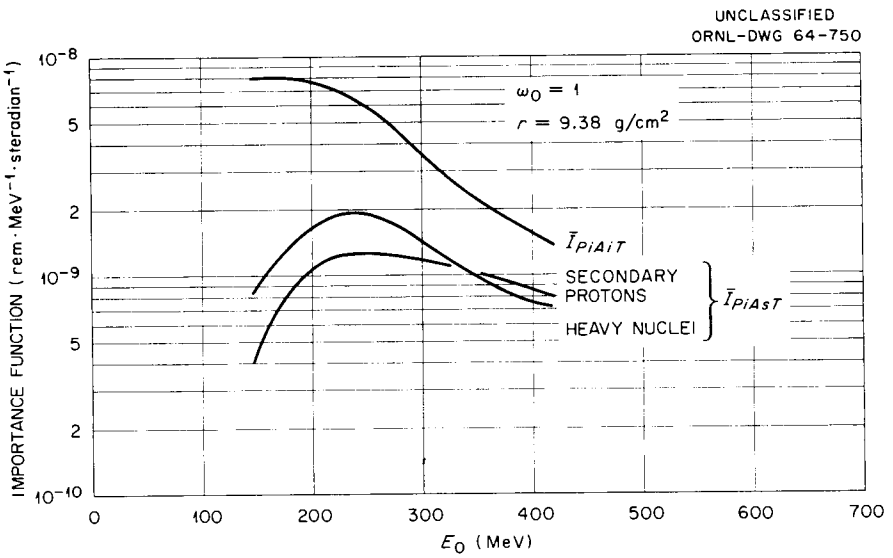

Fig. 7. Freden White Spectrum.

Appendix

The importance functions calculated in 1 constitute special cases of the more general functions discussed in Section II.

In the notation of Section II the functions I_1 and I_2 in 1 may be written

$$I_1 = I_{PiAiT+PiAsT+OiAiT+OiAsT}(E_o, \omega_o=1, r, x)\Big|_{\substack{\text{vicinity}\\ \text{of}\\ x=o}} , \qquad \text{(A1)}$$

$$I_2 = I_{OiAiT+OiAsT}(E_o, \omega_o=1, r, x)\Big|_{\substack{\text{vicinity}\\ \text{of}\\ x=o}} \qquad \text{(A2)}$$

It is indicated that the functions are to be evaluated in the vicinity of $x = 0$ rather than at $x = 0$ to emphasize that the crudeness of the method of calculation used in 1 does not allow an explicit determination on this point. It is probably best to think of the results for I_1 and I_2 in 1 as representing the functions of Eqs. A1 and A2 averaged over a small (not very well defined) region in the vicinity of $x = 0$.

It is very important in considering the results given in 1 to note that the primary dose is always defined by

$$\text{Primary Dose} = D_{PiAiT+PiAsT}(E_o, \omega_o=1, r, x)\Big|_{\substack{\text{vicinity}\\ \text{of}\\ x=o}} ;$$

i.e., when primary protons enter the tissue and produce secondaries which deposit energy, this energy deposition is included as part of the primary dose. Thus no information about the importance function I_{PiAsT} is given in 1.

It is to be noted that even if one neglects any difference between aluminum and tissue, so that the importance functions become functions of $r + x$, the function $I_{OiAiT+OiAsT}$ evaluated at $r + x$ contains different information from the function I_{PiAsT} evaluated at the same $r + x$.

Acknowledgment

I would like to thank W. E. Kinney for many helpful discussions concerning his dose calculations.

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