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Transmission of Betatron Bremsstrahlung through Materials

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Attenuation of dose rate of bremsstrahlung produced by 20 and 32 MeV electrons was calculated using attenuation kernel method for iron, lead, ordinary concrete, and heavy concrete brriers. The results are shown as attenuation curves.

I. INTRODUCTION

Betatrons have been constructed in many hospitals recently. Guide and data books of the shield design was published.[1~3] In the usual calculation, of the data of one-tenth thickness or attenuation coefficient of one-third maximum energy are used.

On the construction of the betatron of Kyoto University Hospital, the author made check calculation by multi-group attenuation kernel method. This method usually applied to the reactor shielding calculation,[4] but no paper of application of the method to the bremsstrahlung appeared on periodicals befor the betatron construction.*

Experimental results of the penetration of betatron bremsstrahlung was published recently.[5] The penetration calculation was carried out for the same material by the author using same computer code for the betatron shielding, and compared to the experimental results. The results of the calculation is shown in this paper.

II. PENETRATION OF BREMSSTRAHLUNG

The calculation was carried out by the multi-group attenuation kernel method. The explosure dose rate of a point A at a distance of x cm from a point isotropic bremsstrahlung source S and the absorber of t cm thick wall placed perpendicular to the line SA is shown as,

$$D=\frac{1}{4\pi x^2}\sum_i \eta(E_i)B(E_i, t)E_iQ(E_i)\Delta E_i e^{-\mu(E_i)t} \tag{1}$$

where E_i is an intermediate energy of the interval ΔE_i, $\eta(E_i)$ transfer coefficient from energy fluence to explosure dose rate, $B(E_i, t)$ a build-up factor for the gamma ray of energy E_i and for an absorber of thickness t, $Q(E_i)\Delta E_i$ photon number of i-th energy interval emitting from a point isotropic source per second, $\mu(E_i)$ attenuation coefficient of gamma rays.

The energy intervals were decided considering the change of mass attenuation coefficients and bremsstrahlung spectra with energy as shown in Table I. Spectra of thin target bremsstrahlung for the incident electron energy of 32 MeV and 20 MeV

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* Kyoto University Hospital Betatron was constructed in 1966.

Table I. Intermediate Energy of Interval, E_i, Interval Width, ΔE_i, and X-ray Spectra Q_i in Equation (1).

Energy Interval			X-ray Spectra Arbitrary Units	
Intermediate Energy, MeV	Upper Energy MeV	Width MeV	$E_0=32$ MeV	$E_0=20$ MeV
0.2500	0.5000	0.5000	0.74660	3.3000
0.6000	0.7000	0.2000	0.30750	1.8000
0.8000	0.9000	0.2000	0.22900	1.2000
1.2000	1.5000	0.6000	0.15060	0.8000
2.0000	2.5000	1.0000	0.08750	0.4500
3.0000	3.5000	1.0000	0.05670	0.2800
4.0000	4.5000	1.0000	0.04110	0.2000
5.0000	5.5000	1.0000	0.03180	0.1500
6.2500	7.0000	1.5000	0.02430	0.1080
8.0000	9.0000	2.0000	0.01800	0.0820
10.0000	11.0000	2.0000	0.01350	0.6000
12.0000	13.0000	2.0000	0.01070	0.0460
14.0000	15.0000	2.0000	0.00870	0.0355
16.0000	17.0000	2.0000	0.00720	0.0280
18.0000	19.0000	2.0000	0.00620	0.0160
20.0000	21.0000	2.0000	0.00530	0.0030
22.0000	23.0000	2.0000	0.00460	
24.0000	25.0000	2.0000	0.00400	
26.0000	27.0000	2.0000	0.00350	
29.5000	32.0000	5.0000	0.00230	

were interpolated from a theoretical value[6] are shown in the table in arbitrary units.

The mass attenuation coefficients of iron, lead, ordinary concrete were interpolated from the table calculated by Davisson,[7] the coefficient of heavy concrete was composed by Fe (54.81 wt%) O (35.6 wt%), Si (4.5 wt%), Al (0,37 wt%), H (0.25 wt%), Ca (4.48 wt%), Mg (0.08 wt%).

Build-up factors of gamma rays for these material were interpolated by Barger's formula

$$B(E_i, t)=1+c(E_i)\mu(E_i)te^{d(E_i)\mu(E_i)t} \tag{2}$$

where $c(E_i)$ and $d(E_i)$ are parameters. The values of these parameters were obtained from tables in a paper written by Trubey.[8] For the gamma-ray energy over 10 MeV the build-up factors of 10 MeV were used in this calculation because there is no published data of build-up factors in this region.

III. RESULTS OF CALCULATION AND COMPARISON WITH EXPERIMENT

Results of calculation are shown in Figs. 1. to 4. For the purpose to know the contribution of build-up factors, calculated data without build-up factor are shown in these figures.

In these figures measured values[5] are plotted. They show good agreement.

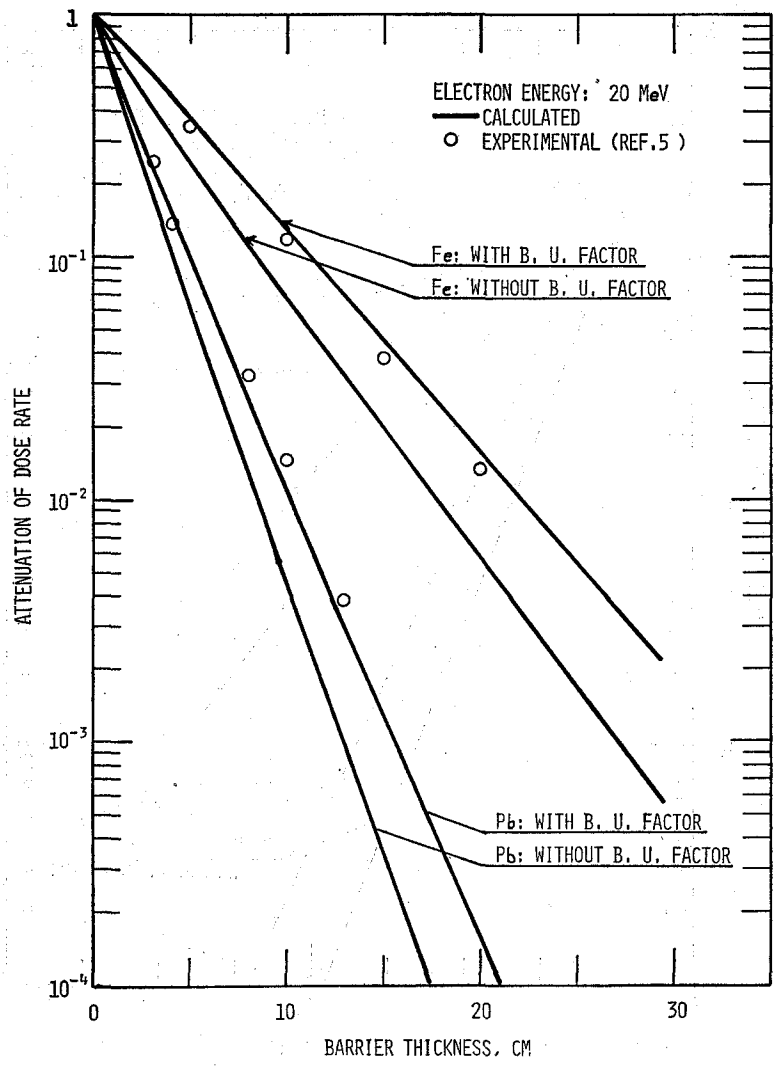

Fig. 1.

Figs. 1–4 X-ray dose rate transmitted through barriers.

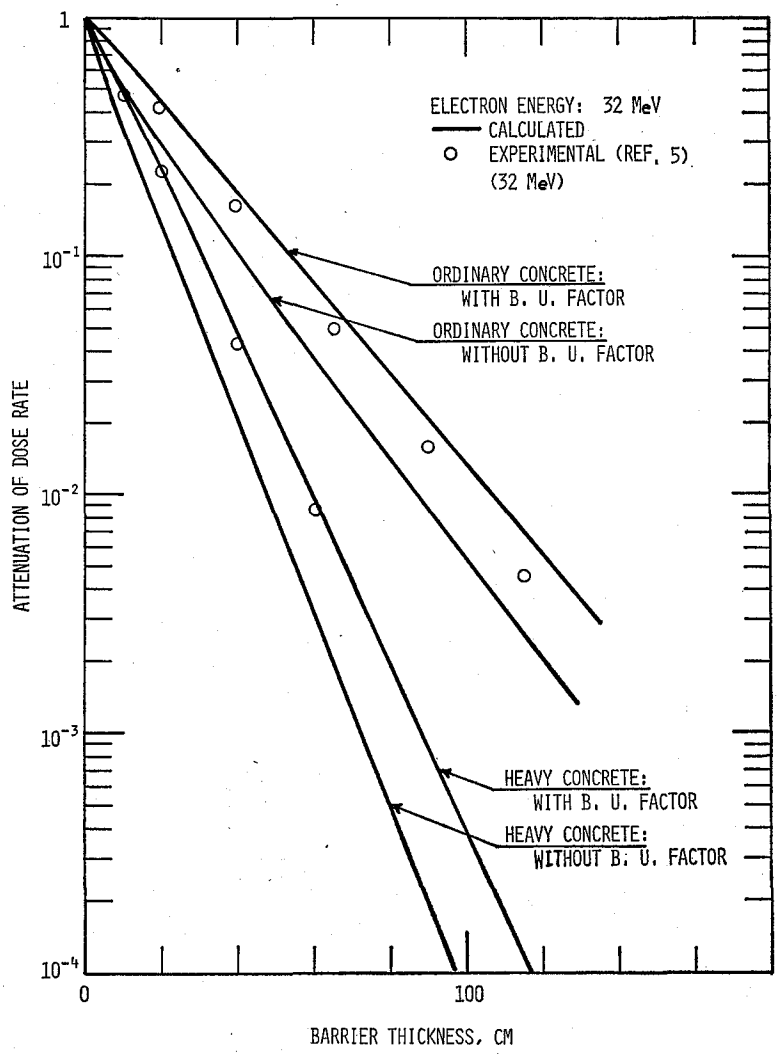
ELECTRON ENERGY: 32 MeV
CALCULATED
EXPERIMENTAL (REF. 5)
(32 MeV)
ORDINARY CONCRETE:
WITH B. U. FACTOR
ORDINARY CONCRETE:
WITHOUT B. U. FACTOR
HEAVY CONCRETE:
WITH B. U. FACTOR
HEAVY CONCRETE:
WITHOUT B. U. FACTOR
ATTENUATION OF DOSE RATE
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
0
100
BARRIER THICKNESS, CM

Fig. 2.

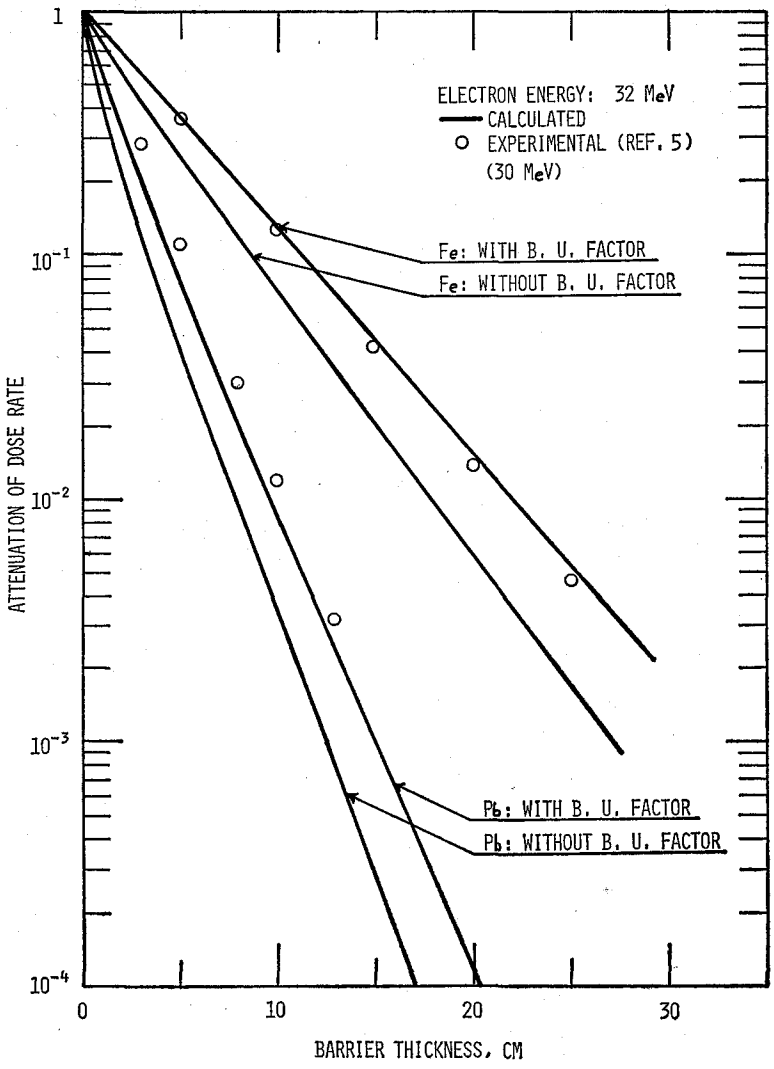
ELECTRON ENERGY: 32 MeV
CALCULATED
EXPERIMENTAL (REF. 5)
(30 MeV)
Fe: WITH B. U. FACTOR
Fe: WITHOUT B. U. FACTOR
Pb: WITH B. U. FACTOR
Pb: WITHOUT B. U. FACTOR
ATTENUATION OF DOSE RATE
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
0
10
20
30
BARRIER THICKNESS, CM

Fig. 3.

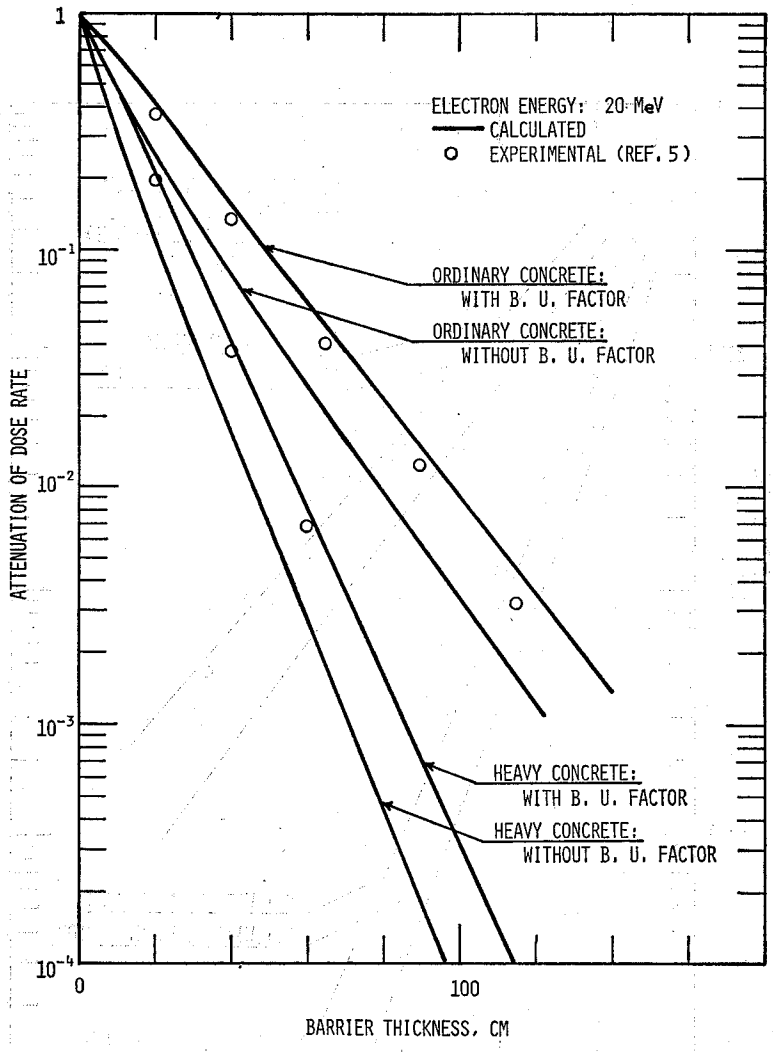

Fig. 4.

ACKNOWLEDGMENT

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