BUILDUP FACTORS OF HIGH ENERGY NEUTRONS UPTO 400 MeV

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ABSTRACT

Dose buildup factors of high energy neutrons ($\leq$400 MeV) were calculated and fitted with a simple approximate formula for iron and concrete, which were typical shield materials in accelerator facilities. The calculation for the dose buildup factors of double layered slabs, namely iron followed by concrete, were also made. The change in the value of the buildup factor due to the variation in the atomic composition was studied in detail for the concrete shield.

INTRODUCTION

The point kernel calculation is accepted as simple but useful shielding calculation method for gamma rays. The buildup factors are the key data for this method. To simplify the shielding calculation for high energy neutrons at accelerators, the application of the point kernel method to neutrons is investigated. For this purpose, an attempt is made to extend the concept of the buildup factor, that is basically defined only for gamma rays, to high energy neutrons, and detailed numerical study is made on this newly defined neutron buildup factor.

METHOD OF CALCULATION

The one dimensional discrete ordinates code ANISN[1] was used to calculate the neutron flux in iron and concrete slabs. Atomic compositions of iron and concrete assumed in this calculation are shown in Table I. The cross sections used here were obtained by collapsing the 100-group cross sections DLC-87[2] which cover neutron energy range from the thermal to 400 MeV into 12 neutron groups. In the collapsing process, energy fluxes of neutrons in 200-cm thick iron or concrete slab, which were calculated for source neutrons having an uniform spectrum at energies 160-400 MeV, was utilized as a weighting function. The group structure of the 12-group cross sections is shown in Table II.

Table I Atomic Density of Shield

	Concrete ($1/cm^3$)	Iron ($1/cm^3$)
Fe	9.96+20[a]	8.39+22
O	4.28+22	-
Si	1.69+22	-
H	7.07+21	-
Al	1.20+21	-
Ca	2.07+21	-

[a] Read as 9.96×10^{20}

Table II Energy Group Structure

Group	boundary (MeV)	Group	Boundary (MeV)
1	400	7	1.50-1[a]
2	160	8	1.50-2
3	50	9	1.58-3
4	14.9	10	1.01-4
5	5.49	11	1.07-5
6	1.65	12	4.14-7
			1.00-10

[a] Read as 1.50×10^{-1}

A monoenergy beam source which was normally incident on the shield of concrete or iron was assumed. The flux calculation was repeated with 12 group cross sections by scanning source energy group from 1 through 12. The obtained fluxes in the shield were converted to dose equivalence by using fluence to dose conversion factors.[3]

We defined the neutron buildup factor by the following equation;

$$H_i(\Sigma_i x) = B_i(\Sigma_i x)\, S_0\, \mathrm{Exp}(-\Sigma_i x) / F_i, \qquad (1)$$

where i is the number of source group, Σ_i is attenuation coefficient of source neutrons (1/cm), x is the shield thickness (cm), $B_i(\Sigma_i x)$ is the dose buildup factor at the depth $\Sigma_i x$, $H_i(\Sigma_i x)$ is the dose equivalence (mrem), S_0 is source intensity ($1/cm^3$), and C_i is the fluence to dose conversion factor at source energy ($1/cm^2$/mrem).

The buildup factors obtained by Eq. (1) were fitted with Eq. (2).

$$B_i(\Sigma_i x) = 1 + A_i\ (1 - \mathrm{Exp}(-B_i \Sigma_i x))\ \mathrm{Exp}(C_i \Sigma_i x), \qquad (2)$$

where A_i, B_i and C_i are fitting constants.

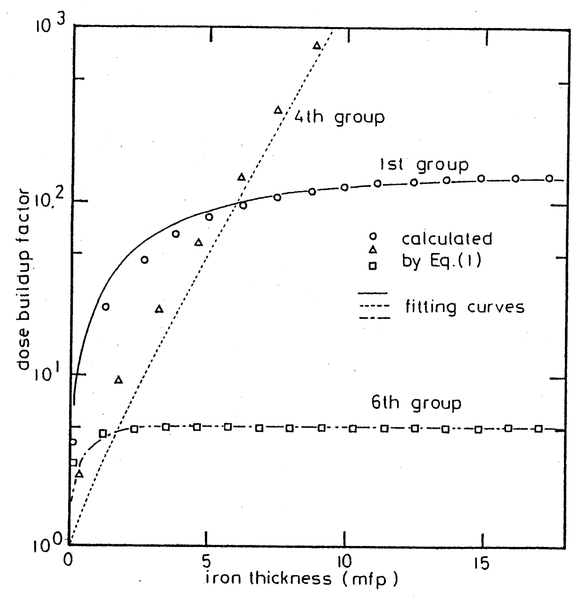

Fig.1 comparisons between data of the buildup factor directly obtained by ANISN and those approximated by Eq.(2) for iron

Comparisons between data of the buildup factor directly obtained by ANISN and those approximated by Eq. (2) are shown in Fig. 1 for iron. Buildup factors of 3rd, 4th and 5th groups increase exponentially, since attenuation coefficients of incident neutrons in these groups are less than those of low energy group neutrons, by which the dose is dominated.

BUILDUP FACTORS FOR DOUBLE LAYERED SHIELD

Double layered shields are often used in accelerator facilities. As a typical example of such shield, we chose a slab of iron followed by concrete, and the characteristics of the dose buildup factor for this double layered slab were studied. The ANISN calculation was carried out by the same procedure as for the single layered shields. The dose buildup factor for the double layered shield was defined similarly to Eq. (1) for the ith group source neutrons by Eq. (3).

$$H_i(\Sigma_1x_1+\Sigma_2x_2) = B_i(\Sigma_1x_1+\Sigma_2x_2) \quad S_0 \quad \mathrm{Exp}(-\Sigma_1x_1-\Sigma_2x_2) \; / \; F_i , \qquad (3)$$

where x_n is the thickness of the nth layer, Σ_n is the attenuation coefficient of ith group neutron in the nth layer.

Fig. 2 shows dose buildup factors of the iron-concrete double layered shields for the incidence of 1st, 4th and 6th group neutrons.

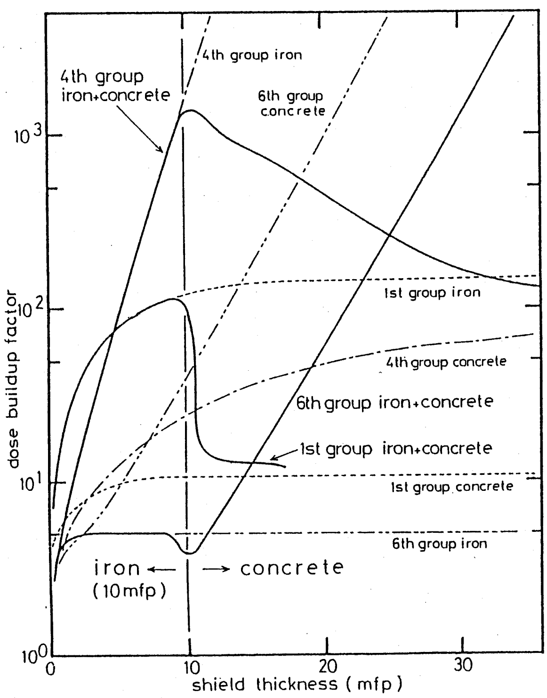

Fig.2 dose buildup factors of the 10 mfp iron-concrete double layered shields

For the 1st group source, the dose buildup factor of the double layered shield decreases rapidly in the 2nd layer and approaches to the value of the single layered concrete shield.

The buildup factor of the double layered shield, in the 4th group incidence case, increases rapidly in the 1st layer, but in the 2nd layer the value decreases slowly, and finally it becomes almost the same value as for the concrete monolayer.

At the 6th group, the buildup factor of the double layer shows in the 1st layer the same trend as in the iron single layer. The value of the buildup factor starts decreasing at a point near the boundary of the two layers, and becomes the smallest at the boundary, then it increases in the 2nd layer. The curve of the buildup factor at the 6th group for the double layered slab is parallel, in the 2nd layer, to that for the concrete monolayer.

IMPACT OF COMPOSITION CHANGE TO BUILDUP FACTOR OF CONCRETE

The composition of concrete varies slightly from case to case depending on the mixing rate of aggregates, water and cement. Here the dependence of the attenuation coefficient and the buildup factor on the variation in the atomic composition in concrete was tested. In the calculation, the 1st, 4th, 6th , and 9th group incidence cases were considered. The composition shown in Table I was considered as the reference case.

First, the dependence of the attenuation coefficient on the atomic density change was studied. For H, Si and O, the atomic density of each element was changed from -30% to +30% to the reference value. For Al, Ca and Si, the rate of variation was -20% to 20%. Through numerical tests, it was known that the attenuation coefficient was closely in proportion to the atomic density of each element. Consequently, the attenuation coefficient was fitted with the next formula:

$$\Sigma = \Sigma_0 + \sum_{i=1}^{6} a_i \, (d_i - d_{0i}), \qquad (4)$$

where i means an elememt number in concrete; Σ, Σ_0 are the attenuation coefficients for the varied case and the reference case, respectively; a_i is a constant obtained by the numerical tests; d_i and d_{0i} are the atomic densities of the element i ($1/cm^3$) for the varied and reference cases.

In the next step, the dependence of the buildup factor on the atomic composition was tested. Here only three elements, i.e. H, O, Si, which were main components in concrete, were taken up. The atomic composition of each element was changed by $\pm 30\%$ to the reference case and the impact due to this change to the buildup factor was investigated. The attenuation coefficient for each case was estimated by Eq. (4).

For incedent groups of 1 through 4 the 30% variation in the H density resuted in 37% change at maximum in the buildup factor at 10 mfp (120 cm) and the same variation in Si or O density gave rise to 15% change at maximum in the buildup factor at the same depth. When the source neutron energy was lower than the above cases, the buildup factor was influenced much more by the same variation in the atomic compositions. However, the attenuation of low energy neutrons is much larger than that of high energy neutrons, and usually the low energy neutrons contribute less to the dose at the end of the thick shield as compared to the high energy neutrons.

This means the buildup factors for the reference case are applied generally within about 40% error, together with the attenuation coefficients being estimated by Eq. (4).

REFERENCES

1) W. W. Engle, Jr., K-1963, Union Carbide Co. (1967).
2) R.G. Alsmiller,Jr., and J.Barish, ORNL/TM-7818 (1981).
3) ICRP Publication 21 (1971).