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# STATUS OF NEUTRON SHIELDING FOR THE IPCR SSC

S. Fujita, S. Yamaji, and T. Shikata

The Institute of Physical and Chemical Research, Wako-shi, Saitama, Japan

Abstract.- Calculations of neutron shielding by a hemi-spherical concrete covering at the center of which a point source is located was carried out by two different methods and results were compared. Rough estimation of skyshine for a point source enclosed by a cylindrical covering was also performed using the empirical equation of Thomas by means of two methods.

1. Introduction.- The Riken SSC will operate protons in the energy range up to 200 MeV, deuterons, alpha particles, carbon, nitrogen, and neon ions up to 135 MeV/A, and heavier ions in lower energy region. The maximum beam current will be 1μA.

Among the neutrons ejected by nuclear reactions between energetic ion beams and targets, the number of high energy neutrons will differ by no more than a factor of two for various combinations of target materials and incident particles with the same energy per nucleon, after refs. 1, 2, and 3. So we considered following two typical reactions as sources of neutrons to design the shielding wall and beam dump : 1) proton beams incident on a thick aluminum target and 2) carbon beams incident on a thick iron target. Spectra of neutrons which will be emitted in the above two cases for beam current of 1μA are shown in refs. 1, 4 and 6.

We have decided for the allowed radiation levels, the value of 100 mrem/W (2 mrem/h when one week is considered as 48 h) in the radiation control area, 30 mrem/W (0.6 mrem/h when one week is considered as 48 h) on the outer surface of the shielding wall, and 10 mrem/W (0.06 mrem/h when one week is considered as 168 h) at the boundary with inhabitants. In addition to these values, we adopted internally a value of 5 mrem/Y at the boundary with inhabitants as the design goal of the shielding.

In designing the building, we intend not to shield the whole facility including the cyclotron, beam transport systems and all other things in the building by the use of very wide concrete walls but to shield some localized places where lots of neutrons are expected to be ejected. We will estimate the neutron dose due to the direct attenuation for ordinary concrete shield in section 2a and the skyshine effect in section 2b. For both estimations, we neglected, in our previous work[6] as well as in ref.4, the effect of inelastically scattered neutrons concerning to the attenuation of the neutron number in the concrete. This kind of calculation is denoted by A. The present work denoted by B include the effect of inelastically scattered neutrons. The results for both cases A and B are compared to each other in section 2.

2. Methods of calculations and results.

2a. Direct attenuation.- Concerning to the estimation of the attenuation of neutron flux in the concrete wall, we have adopted two different methods. One method(denoted by A) is based on the example of Brill[5], and the results have been published elsewhere[6]. The attenuation of neutron flux is expressed by the relation

$$\phi = \frac{\phi_o}{r^2} \exp(-\mu d), \qquad (1)$$

where $\phi$ is the neutron flux density (n/cm$^2$) at distance r from the point source, $\phi_o$ is the neutron flux density at the source (n/sr), $\mu$ is the linear absorption coefficient (cm$^{-1}$) of ordinary concrete, and d is the thickness of shielding wall. The other calculation (denoted by B) was performed by using the data of Alsmiller et al.[7], and of Roussin et al.[8]. To begin with, in our shielding design, relations between neutron dose equivalent and depth into concrete slab are required for source energies up to 200 MeV. For that, we used two kinds of calculated results of dose equivalent as a function of the depth. One is that of Alsmiller et al.[7] in which the attenuation of the neutron flux in a slab of silicon dioxide with 5 % water by weight is treated for the incident neutron energies ranging from 50 MeV to 400 MeV, and the other is that of Roussin et al.[8] in which the attenuation in the concrete is treated for the incident neutron energies from 15 MeV to 75 MeV. The ratio of the dose equivalent in the concrete with respect to that in silicon dioxide as a function of the depth can be obtained both by the results at the incident energy of 50 MeV. Then, we obtained the attenuation curves in the concrete for the incident neutron energies more than 75 MeV, multiplying the curves for the corresponding energies in silicon dioxide[7] by the ratio obtained above. Then attenuation curves of dose equivalent for the various depth were obtained as a function of energy of incident neutrons. To make use of these curves to the calculation of attenuation of neutrons ejected from a point source, the following model was considered: The dose equivalent $D_B$ at the outer surface of a spherical covering of thickness d for a monoenergetic point source with strength $\phi_o$(n/sr) is expressed as follows,

$$D_B = D'_B \frac{R^2}{(R + d)^2}, \qquad (2)$$

where, as shown in Fig. 1a, R is the radius of the inner surface of a spherical covering, $D'_B$ is the dose equivalent at the depth d into a thick concrete slab for the case of the parallel neutron flux of density $\phi_o/R^2$ normally incident on it. Utilizing our previous

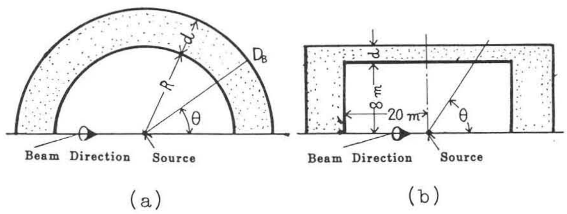


Fig. 1. Calculational geometries: (a) hemi-spherical covering for the calculations of attenuation of neutron flux, (b) cylindrical covering for the calculation of skyshine.

results[6)] of the dose equivalent at the same position, $D_A$, the dose equivalent $D_B$ is expressed as follows,

$$D_B = D_A \frac{D'_B}{K}, \qquad (3)$$

where $K = e^{-\mu d}/c$, and c is a conversion factor for neutrons. The energy distribution of the source neutrons was divided into 10 groups with equal interval of 20 MeV from 0 MeV to 200 MeV for the case of proton incident on a thick aluminum target and into 7 groups with the same intervals for the case of carbon incident on a thick iron target. All neutrons in each group was assumed to have the same energy which is equal to the maximum energy of each group. Calculating the quantities $D_B$ for these sampled monochromatic source neutrons with the help of Eq.(3) and summing them up, we obtained the dose equivalent on the outer surface of the spherical covering for the point source of neutrons ejected by the reactions mentioned above. If the direction of neutrons passing through the concrete covering is assumed to be unaltered, the dose equivalent at distance r ($r \geq R + d$) is easily determined, and these results are shown in Fig. 2. Here, a larger value between the calculated values of $r^2$·dose-equivalent for both cases (p on Al and C on Fe) was selected in each angular region. From these curves one can easily determine the shield thickness in various directions with respect to the ion beams. For example, the design of a beam dump shield is shown in Fig. 3. Figs. 2 and 3 show that the calculated results B shown by the solid curves are considerably larger than those A shown by the dashed curves. This suggests the importance of the contribution due to the neutrons scattered inelastically, which were neglected in the case A. For instance, the number of high energy neutrons at the depth of 3 meters in the slab of 6 meter-thickness for the 50 MeV incident neutron, which is taken from ref.7, was found to be about one order larger than that in the case A.

2b. Skyshine.- Calculation of the skyshine for a point neutron source enclosed by a cylindrical covering was carried out with a geometry shown in Fig. 1b. The energy distribution of the source neutron was divided in the same way as in section 2a. Path length in the roof of the ejected neutrons differs with the ejection angle θ, if the neutrons passing through the roof were assumed to keep their initial directions. The roof was subdivided into many small areas and their effective path length was estimated, respectively. Then neutron source strength on the outer surfaces of these small portions of roof Q was determined with the help of the results obtained in section 2a. The skyshine effects

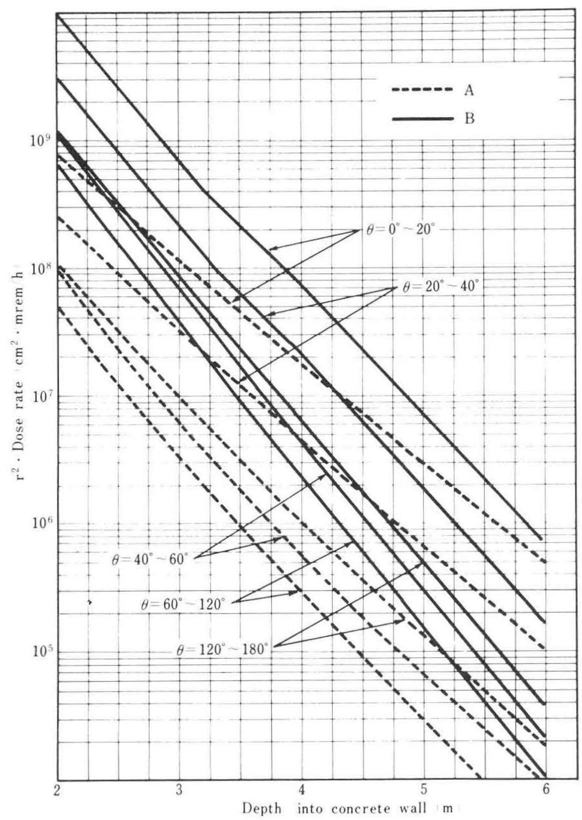


Fig. 2. Dose rate multiplied by $r^2$ vs depth into concrete covering.

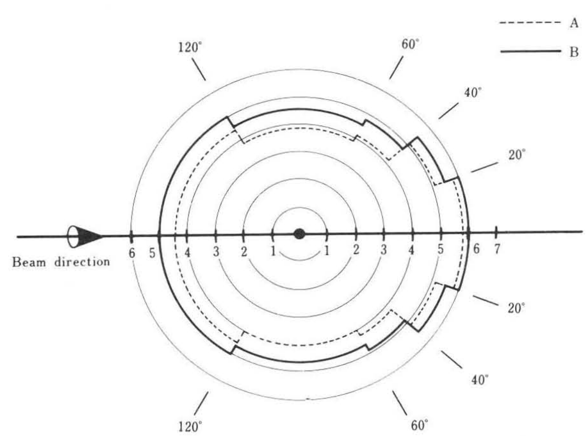


Fig. 3. Design of a beam dump shield of concrete ($\rho = 2.4$ g/cm$^3$). Iso-dose rate contour is taken to be 2 mrem/h. Two curves show the results of the method A and B, respectively.

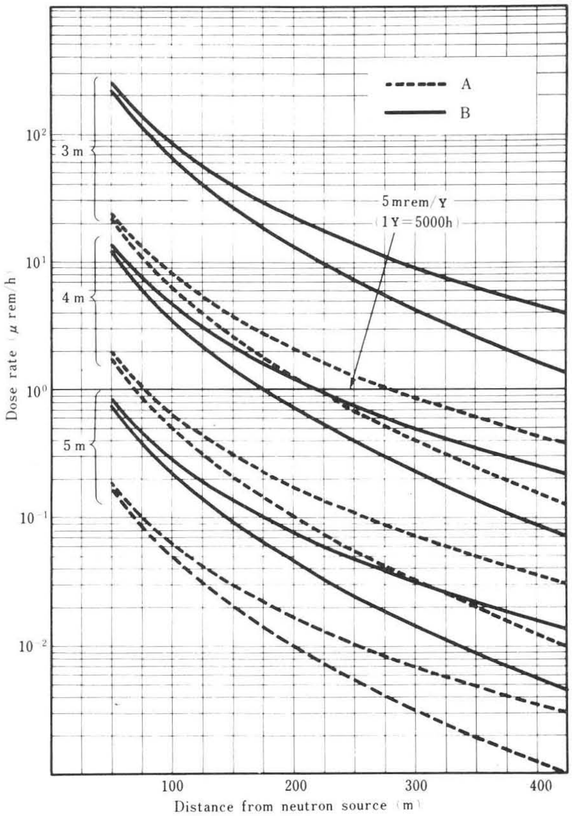


Fig. 4. Spatial distribution of neutron skyshine. Upper curves of each group with two curves correspond to the attenuation length λ = 850 m and lower ones correspond to λ = 267 m.

due to these small portions of roof for a monoenergetic neutron can be estimated by empirical equation of Thomas,

$$\phi(r) = \frac{aQ}{4\pi r^2}\left\{1 - \exp\left(-\frac{r}{\alpha}\right)\right\} \exp\left(-\frac{r}{\lambda}\right). \qquad (4)$$

Here $\phi(r)$ stands for the flux density at distance r from the source along the ground surface, a and α stand for the fitting parameters which reproduce the experimental data, λ stands for the attenuation length in air. Following values were taken for a = 2.8, α = 56 m, λ = 267 m or 850 m. The total skyshine effects as a function of r were obtained for several values of the roof width by summing the results of Eq.(4) both over all subdivided portions of the roof and energy intervals and are shown in Fig. 4. Here, also, the values of results obtained by the method B are considerably larger than that by the method A. One can estimate the width of the roof required for getting severe condition of radiation level at the boundary with inhabitants, i.e., 1 μrem/h as 4.5 meters at the distance of 100 meters for the case B from this figure. This is for the extreme case that all neutrons produced by our sampled reactions with the beam intensity of 1 μA contribute to the skyshine. However, as was mentioned in the introduction, some special places where many neutrons are produced are shielded locally to the safety radiation level for people to be able to work. If these shieldings are well organized, the skyshine effect can hardly be expected at large distances, because almost all neutrons are stopped by the localized beam dump. Therefore, this estimated value of 4.5 meters of the roof width can be considered to be the upper limit and smaller values are allowed according to the goodness of the localized shieldings.

3. Concluding remarks.- That the radiation level of the case B is considerably higher than that of A may suggest the importance of the contribution due to the inelastically scattered neutrons in the case B. However, the neutrons from the backscattering effect may be included in the neutron yields calculated by Alsmiller et al. at the intermediate distance in the slab. Therefore, the contribution due to the neutrons produced by backscattering must be subtracted from our results B. We may get a little smaller results than those of B. We are now trying to carry out Monte Carlo calculation to know the backscattering effect. At present, we conclude that the radiation shielding is desired to be designed by using the results of B.

As was mentioned already, in designing the building, we intend to shield several localized places where great numbers of neutrons are expected to be ejected. Since the use of ordinary concrete alone requires large space as shown in Fig. 3, the beam dump shieldings are now being designed by a suitable combination of iron and concrete.

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