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CHARACTER OF THE RADIATION FIELD AND SHIELDING AT THE 184-INCH CYCLOTRON*

By B. J. Moyer, R. Hildebrand, N. Knable, T. J. Parmley, and H. York

The beam of 200 Mev deuterons in the 184-inch cyclotron gives rise to a conical spray of fast neutrons. (Refer to papers A 10 and A 11 of this meeting) with an upper limit of neutron energy somewhat above 100 Mev. The angle of the cone from axis to half-height is about 5.5° for a target of high atomic number, as measured by Helmholz, MacMillan, and Sewell with carbon detectors.

In planning for final shielding of the cyclotron it was necessary to study the attenuation of the neutron beam in concrete. Due to the nature of the information desired the experimental arrangement employed was that shown in Figure 1. The monitor and detector employed were aluminum-walled ionization chambers, with DC Amplification, indicating on microammeters placed outside the magnetic field of the cyclotron.

With this same arrangement data were also obtained with water as an absorber, contained in steel tanks made to fit into the cavity and in front of it.

Results of these measurements are given in Figure 2(a). The data for water have been corrected for the absorbing contribution of the tank walls. The displacements of the linear portions of the absorption plots are evidence of transition effects to be discussed later in this paper. In Figure 2(b) are shown concrete absorption data obtained with carbon disc detectors using the C 12 (n,2n) C 11 reaction whose threshold is about 20 Mev.

The present cyclotron shielding is shown in plan view by Figure 3. A two-foot roof of concrete completely covers the enclosure. Besides the neutron beam cone from the probe there was found to be a general spray of neutrons due to the deuteron beam grazing the interior of the dee. Consequently, fast neutrons are projected in considerable intensity throughout 180° of azimuth. Some observations concerning the shielding may be summarized as follows:

(1) The fast neutron beam is readily detectable after 5-1/2 feet of concrete. Radiation level readings in the center of the beam cone outside the shield are 10 to 20 times those in the building at large. Additional absorption experiments and the existence of a paraffin transition effect show the persistence of a fast, directed beam.

(2) With an ionization reading of 24 r/hr in the center of the neutron beam cone 1 foot outside the tank wall (9 3/4 feet from the probe), the ionization just outside the shielding in the center of the beam is 10 mr/hr, while the general building areas are 0.5 to 1.5 mr/hr. These quoted measurements are made with Al-walled ionization chambers, and correspond to a deuteron beam of about 0.2×10^{-6} amp.

(3) Above the concrete roof under the same beam conditions the radiation level averages 25 mr/hr, but the contribution to general building radiation from "skyshine" and building roof back-scattering is estimated from certain experiments to be not over 10%.

(4) Measurements with a BF_3 proportional counter have indicated diffusion of slow neutrons through various access openings from the enclosure. Absolute measurement of slow neutron flux outside the concrete give values of the order of 10^3 cm^{-2} sec^{-1} for beam strengths similar to that mentioned above.

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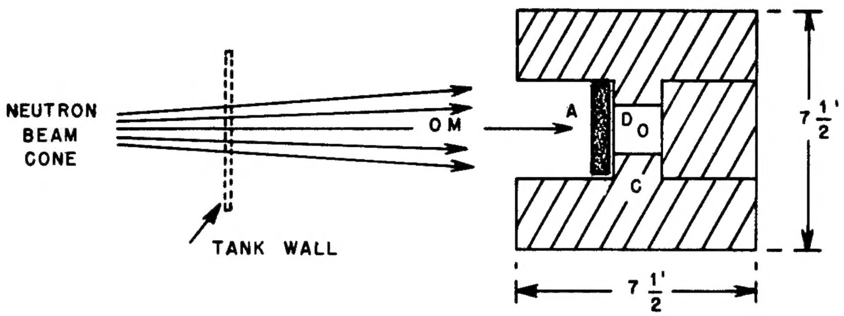
* Presented at the meeting of the American Physical Society held at Stanford University on July 11 and 12, 1947.



A - Slab under test. Dimensions 3′ x 3′ x thickness
C - Concrete "Igloo"
D - Detector, in cubical cavity 1-1/2″ edge
M - Beam moniter

Figure 1. Arrangement for testing shielding properties of concrete (Median plane section).

It was considered of interest to measure the shielding properties of such elements as could be conveniently secured in the form of slabs. Such measurements were made with Lauritsen electroscopes placed in line with the neutron beam and including slabs of the test material between them. Results, for thicknesses only of several inches, are displayed in Figure 4, for graphite, paraffin, aluminum, copper, and lead. The transition effects occur as the neutron beam approaches equilibrium with the secondary and scattered particles produced in the absorbing medium.

Thus since Pb yields fewer ionizing secondaries (protons) capable of penetrating the ionization chamber walls than does the iron of the cyclotron tank wall (plus a few feet of air), it displays a negative transition effect. Paraffin yields a transition increase of 60% following Fe, and of 100% following Pb with similar geometry.

Experiments using carbon disc detectors sandwiched between slabs of absorber gave exponential attenuation with half-value determination which were generally made with better precision than those with ionization chambers. Tabulation of results are shown in Table 1.

Table 1. Attenuation of fast neutron intensity by slabs of various materials.

Material	Half-value thickness		Cross section per atom	
	Ioniz. ch. (Inches)	Carbon det. (Inches)	Ioniz. ch. (Barns)	Carbon det. (Barns)
Pb	9.3	5	0.92	1.71
Cu	6.2	---	.53	----
Al	11.8	12.4	.38	.35
C	18	12.6	.19	.27
CH_2	21	25	----	----
H	---	---	.07	(<.01)

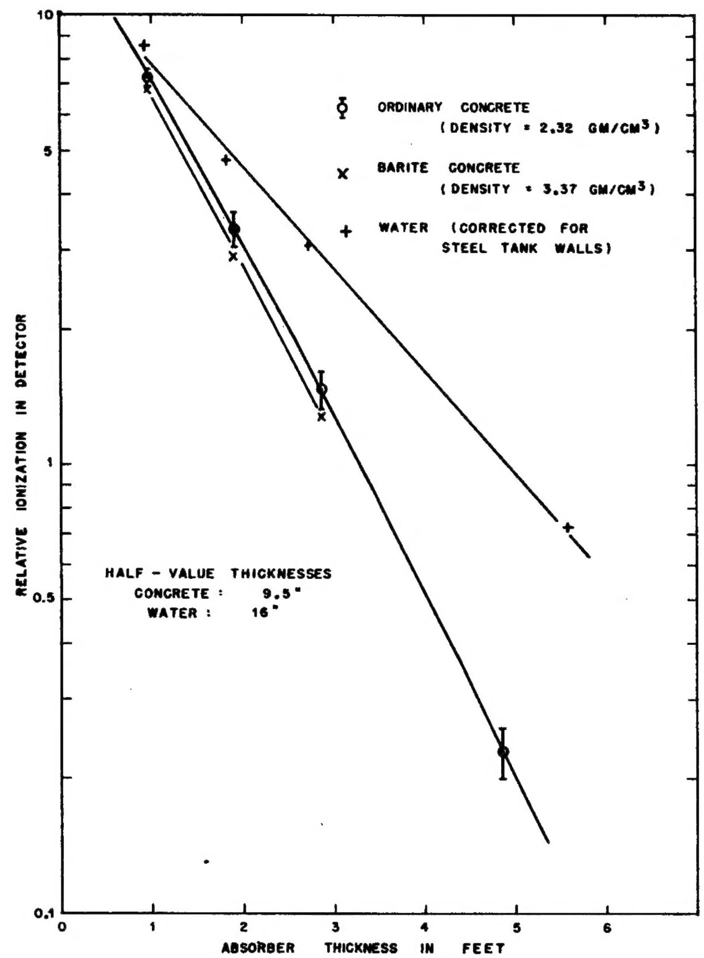


Figure 2a. Reduction of intensity by concrete and water.

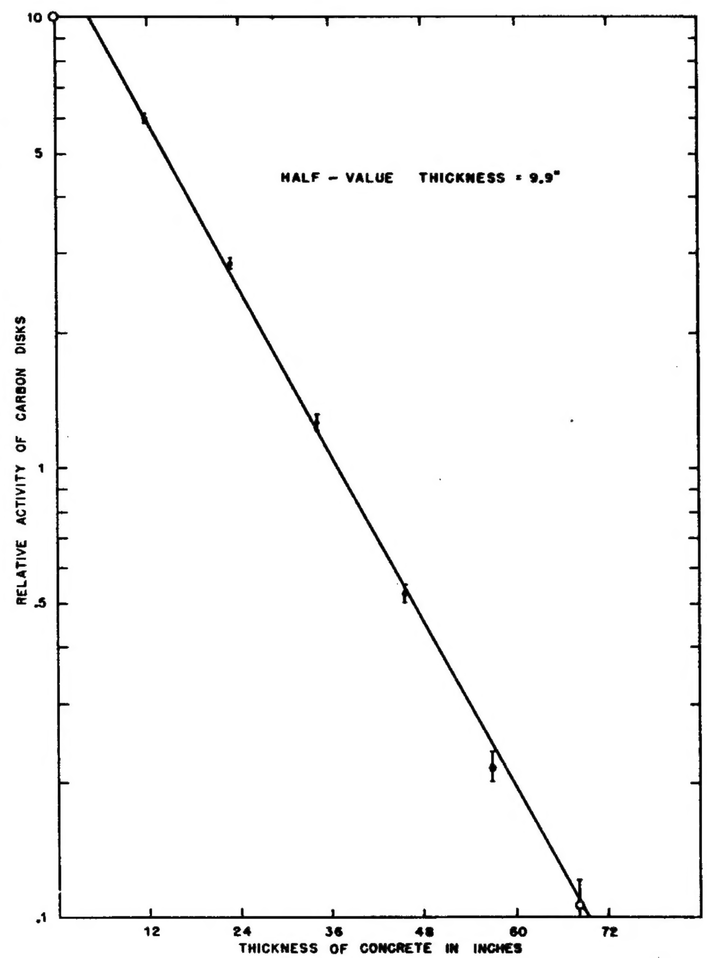


Figure 2b. Fast neutron attenuation in concrete carbon disk detectors.

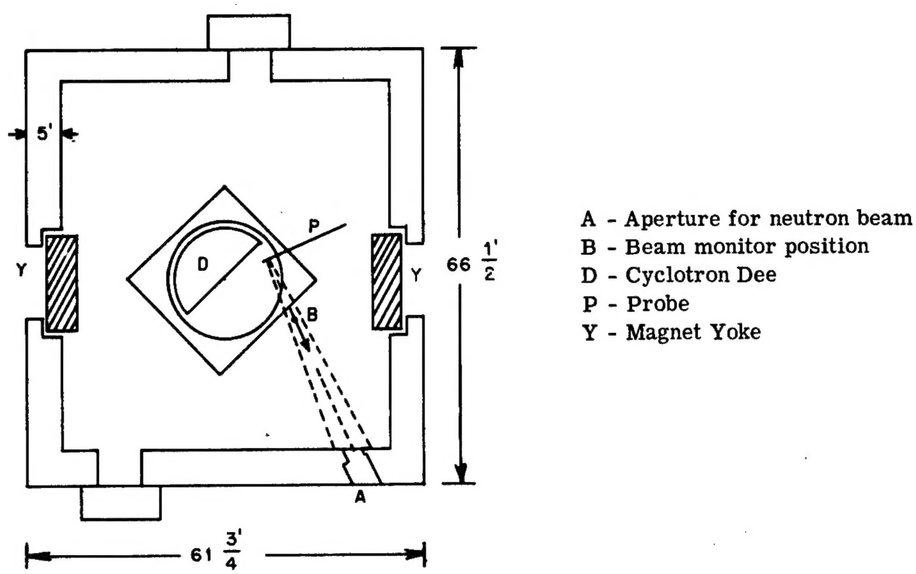


Figure 3. Plan view of 184-inch cyclotron shielding.

The carbon detector data show evidence of transition effects in the case of Pb and of concrete (see Figure 2 (b)). Presumably this is due to the fact that there is considerable activation of the carbon detectors by neutrons scattered at appreciable angles with energies over 20 Mev in these materials containing heavier atoms.

Because of the geometry employed, these measurements are neither a true determination of pure scattering nor pure absorption, yet it may be of interest to display graphically the dependence upon atomic number of the attenuation cross section thus measured. This is shown in Figure 5, in which the increase in nuclear cross section with Z, and the decrease in cross section per nucleon with Z are shown.

The reason for displaying the cross section per nucleon lies in the fact that the momentum transfer in the collisions of the high-energy neutrons is such as to impart energies comparable to and larger than the binding energies of nuclear particles. The relative effectiveness of a nuclear particle in attenuating the high energy neutron beam will decrease when it is bound into a large nucleus due to a "shadow" effect, since the mean free path of a high-energy neutron within a nucleus is not large compared with nuclear dimensions. Also the absorption of the high-energy neutrons by their conversion into protons through mesotron exchange is predicted to be smaller in cross section per proton for protons bound into nuclei than for free protons due to the operation of the exclusion principle by which the nuclear neutron resulting from the exchange reaction must fall into an allowed and unoccupied momentum state.

The practical deductions with regard to shielding materials are that one should seek substances which combine high density with low atomic number. Among convenient and practical materials none would seem better than concrete.

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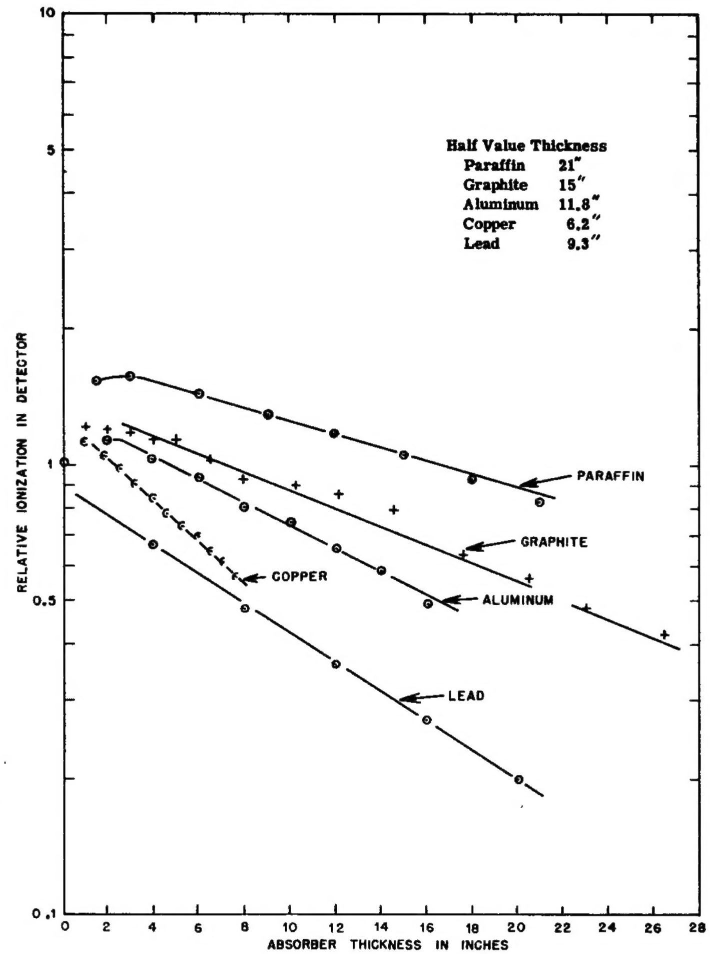

Figure 4. Reduction of intensity by slabs of various materials in neutron beam.

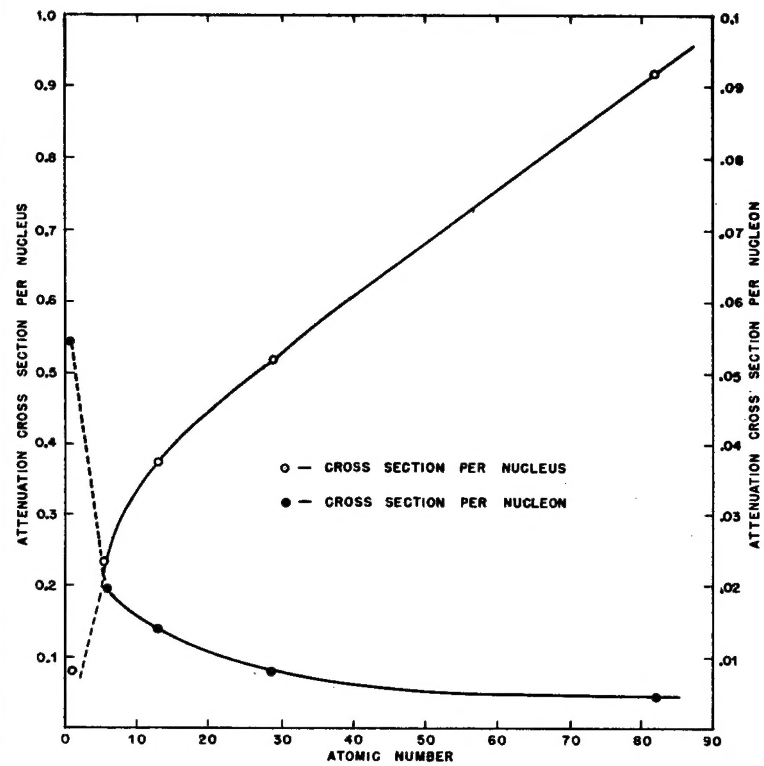

Figure 5. Cross sections for reduction of neutron beam intensity versus atomic number (Ionization chamber detectors).