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HALF-VALUE THICKNESS MEASUREMENTS OF ORDINARY CONCRETE FOR NEUTRONS FROM CYCLOTRON TARGETS*†

H. M. Butler and K. M. Wallace
Health Physics Division
and
C. B. Fulmer
Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

1. Introduction

Half-value thicknesses of a wall of ordinary concrete bricks were determined for neutrons emitted from a variety of cyclotron beam-target combinations. These thickness determinations were made at the Oak Ridge Isochronous Cyclotron(1) (ORIC). This machine is a variable energy accelerator for a variety of charged particles with the particle beams being used in a wide range of experiments. The radiation shielding requirements for such an installation are much more variable than for a nuclear reactor or less versatile accelerator. A thickness of shielding may be quite adequate for one experiment but be grossly inadequate for the next. The shielded doors for the cyclotron room, as can be seen in Figure 1, for example, weigh 65 tons each and are five feet thick. They are hinge mounted doors which can be moved by hand and which require only 45 pounds constant force for movement. Most of the remaining permanent shielding installed at ORIC is approximately the same effective thickness as the doors.

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If the maximum requirements to accommodate all experiments are always provided in the fixed shielding, it may be needlessly expensive both in installation cost and in valuable space occupied by the shield. Knowledge of half-value thicknesses of shielding used at a facility can, therefore, be valuable information for the saving of both money and space as it may sometimes be more practical to use a modest permanent shield that meets the requirements most of the time and use administrative control and local shielding around the target when target and beam conditions require it.

In the work reported here, measurements were made on both sides of a thin (80 cm) concrete block wall that was erected in one of the target rooms being modified at ORIC. The wall divided the room shown in Figure 2, into two target rooms (hereafter referred to as north and south) for different types of experiments. When the beam is on target in one of the rooms, it will often be desirable for experimenters to have access to the other room. The north room was planned exclusively for experiments with low intensity beams of heavy ions and consequently radiation leakage through the concrete wall into the south room will be low. In the south room, however, targets are bombarded with high intensity beams (up to 10 μA's) of light particles. Thus the important radiation leakage is from a target in the south room through the 80 cm thick concrete block wall into the north room. When this occurs, access to the north room will be controlled by administrative procedure based on measurements observed in this and other studies.

Radiation dose rates of fast neutrons were measured in both rooms for beams of protons, deuterons, alpha particles and carbon ions on thick targets of carbon, aluminum, copper and tantalum at target station A in the south room. Attenuation factors provided by the wall for each of these reactions were converted into half-value thicknesses.

2. Description of Measurements

Figure 3 shows the floor plan of the two target areas following addition of the concrete block wall. The concrete blocks were of standard size (16" x 8" x 4"), and each row was stacked from floor to ceiling in a staggered manner to eliminate streaming through the joints. The floor plan indicates that a significantly thicker wall would render inaccessible one of the accelerator beam lines that is directed to the room.

For the measurements of radiation leakage through the wall, the cyclotron beam was focused to a spot of $\sim$ 1 cm diameter at the target station labeled A. For all of the measurements reported here the targets were thick enough to stop the beam of incident particles resulting in a nearly point source of neutrons and other radiations.

A portable fast neutron survey meter was positioned at location B in the south room 5.5 meters from the target. This survey meter was observed via television and used by the cyclotron operators to regulate the beam intensity on the target.

The neutrons detected in the north room are due to leakage from the target at A in the south room through the 80 cm wall and from the cyclotron room through the 213 cm concrete wall seen at the top of Figure 3. About 25% of the accelerated beam is normally extracted and delivered to the target at A with the remaining ions lost in collision with accelerator components before they reach the target. The latter do not significantly affect the measurements, however, as fast neutrons resulting from beam losses in the cyclotron room and leaking into the north room are attenuated by a much larger factor than those from a target at A.

For most of the measurements the beam intensity was adjusted to yield a dose rate of 2 rem/hr at position B. Then with the beam maintained at a constant intensity neutron dose rate measurements were made at B and directly across the wall at C with pairs of two types of instruments. One of the instrument types was a modified version of the Hurst fast neutron proportional counter.[2] The ratio of the neutron dose measured by this instrument to the dose in tissue has been shown to be 1.45 ± 5% over the energy range 150 Kev to 14 Mev. Supplementary measurements were made with a portable fast neutron survey meter. This meter, the ORNL Model Q-2047,[3] has a response such that the dose equivalent obtained is within ± 25% of the NCRP recommended limits on fluence over the energy range .15 to 5 Mev. The gamma sensitivity and low background response of both instruments are well known[3],[4] with each having the capability of detecting low dose rates due to fast neutrons in the presence of high gamma radiation fields (50 - 100 R/hr). Although the detection capabilities of neither have been calibrated for neutrons having energies > 14 Mev, the data reported here correspond well with that of Johnson and Ohnesorge[5] who used threshold detector techniques that could measure yields of neutrons above 20 Mev.

The dose rate measured by the fast neutron monitor at location B is due to radiation coming directly from the target and also to radiation reflected from the walls of the room. An estimate of the contribution due to reflection was obtained by moving the detector to a position equidistant between A and B. If reflections were unimportant, the measured dose rate per unit beam intensity on the target at A would be a factor of 4 larger than at B. The measured deviation from this indicated that about one-third of the radiation level of fast neutrons at B is due to reflections. This indicates that a modest shield around the target will significantly reduce the shield wall thickness requirement. In conjunction with the measurements reported here, data were also obtained regarding leakage through the wall of radiations other than neutrons. Gamma radiation levels were also measured at B and C for a number of target-beam combinations. These results are reported elsewhere[6] and combined with the data reported here one can extrapolate radiation leakage from cyclotron targets through concrete walls of a range of thicknesses.

3. Results and Discussion

The shield wall thickness requirements at accelerator installations are usually determined by neutron production rates, especially for higher energy neutrons. Estimates based on the data by Johnson and Ohnesorge,[5] and of Wadman,[7] and others indicate that a concrete wall 100-120 cm thick would provide adequate shielding for most accelerator-produced radiation fields which might be generated in the room described here. In addition, Wallace,[8] as seen in Figure 4, predicted half-value thicknesses for neutrons attenuated by ordinary concrete to be approximately four inches for the range of energies common to most ORIC operations.

The half-value thicknesses obtained in this work for fast neutrons from a variety of beam particle-target combinations are shown in Table 1 and range from 9 to 10.5 cm with uncertainties of ± 5% based on reproducibility of results. As was predicted in the references mentioned above, the half-value thicknesses increased with bombarding energy. One slight aberration was observed for 31 Mev protons on tantalum. It may be noted that the half-value thickness for neutrons produced by 20 Mev protons on tantalum was found to be 9.7 cm while that for 31 Mev protons also on tantalum was 9.3 cm. In addition, there appeared to be little difference in the half-value thickness for neutrons generated by alpha particles on any of the four targets bombarded.

Direct nuclear reactions in the target result in a larger yield of higher energy neutrons than compound nuclear reactions. The data here indicate slightly larger half-value thicknesses for neutron spectra produced from carbon and aluminum targets than for copper and tantalum which suggest that neutrons from direct nuclear reactions are more probable in the lighter element targets.

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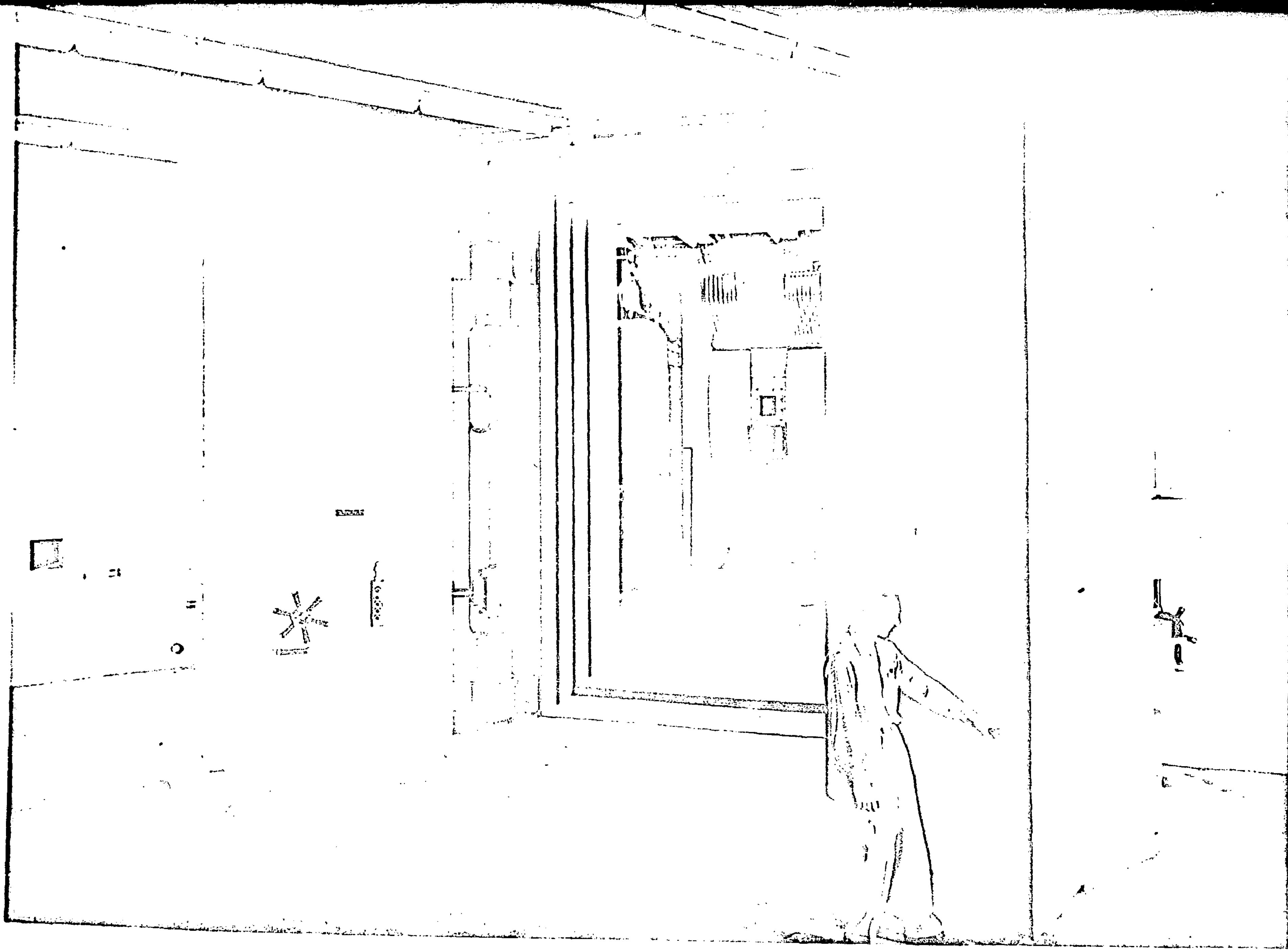

Fig. 1. Shielded Doors at Main Cyclotron Vault

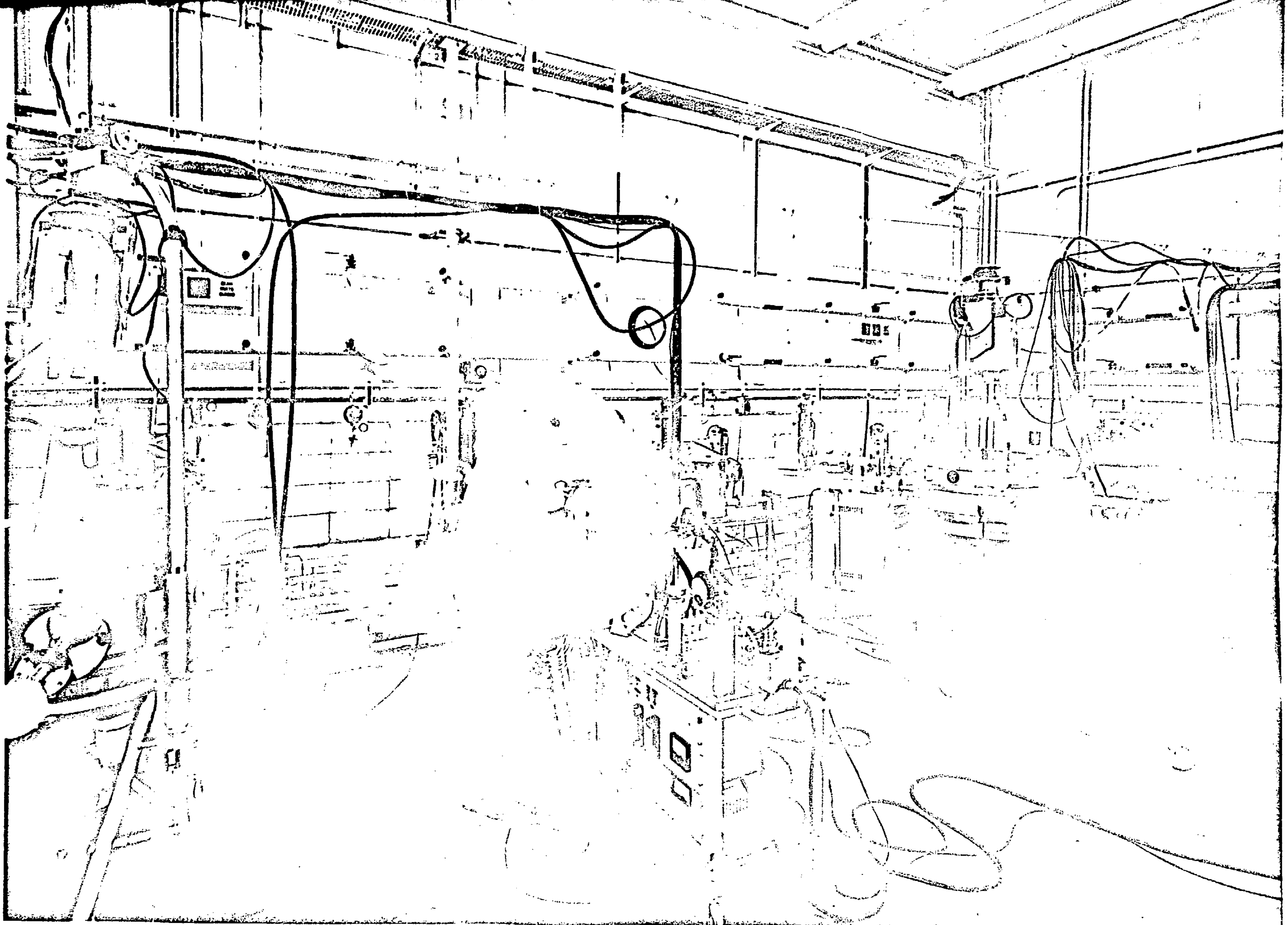

Fig. 2. Target Room Before Thin Shield Installed

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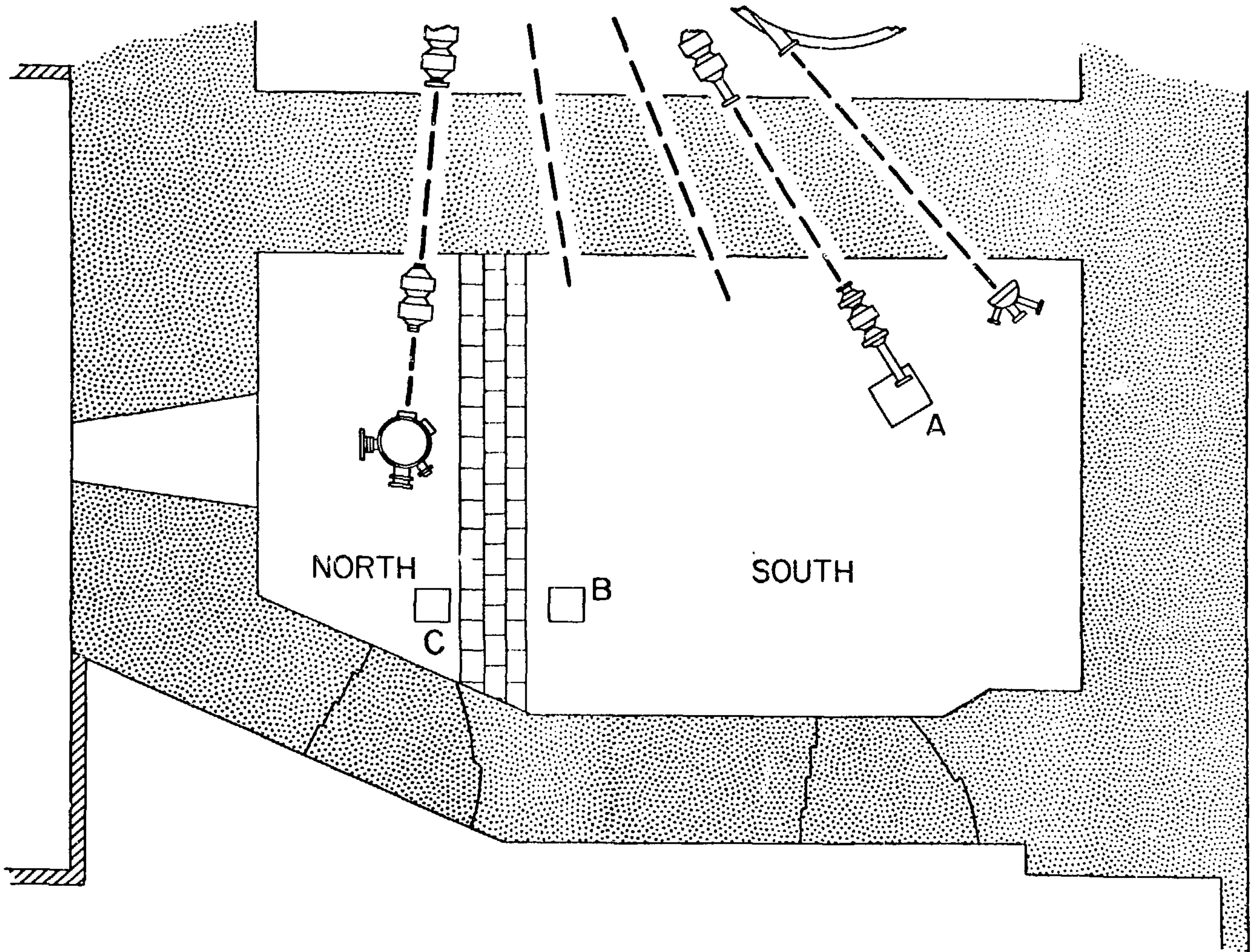

Fig. 3. Floor Plan of Target Room Showing Thin Shield Wall

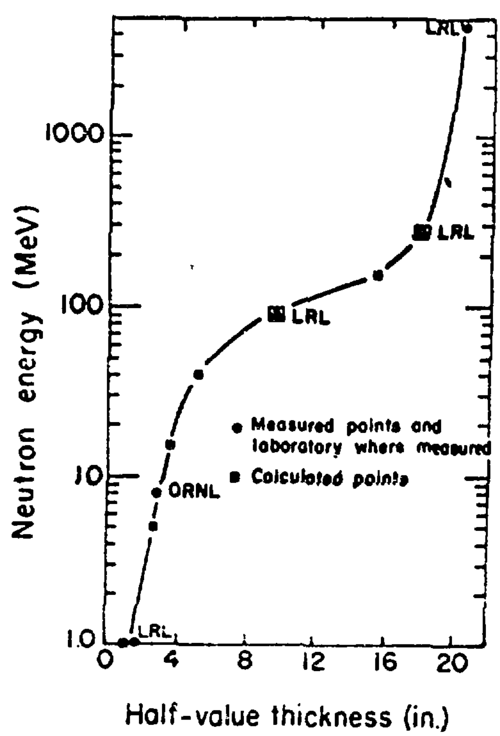

Fig. 4. Attenuation of neutrons in ordinary concrete. At 90 and 270 MeV, measurements were made at the 184-inch 340-MeV cyclotron. At 4.5 GeV the measurement was made at the Bevatron.

Table 1

HALF-VALUE THICKNESSES (CM) OF ORDINARY CONCRETE
FOR FAST NEUTRONS FROM CYCLOTRON BEAM TARGETS

TARGET MATERIAL	PARTICLE AND INCIDENT ENERGY								
	Protons				Deuterons		Alphas		Carbon Ions
	20 MeV	31 MeV	40 MeV	66 MeV	25 MeV	40 MeV	50 MeV	80 MeV	100 MeV
Carbon	--	9.7	10.1	10.5	10.2	10.2	10.3	10.2	10.4
Aluminum	9.7	10.0	10.3	10.5	9.6	10.4	9.4	9.4	9.6
Copper	9.4	9.7	9.7	10.2	9.7	9.9	9.4	9.4	9.7
Tantalum	9.7	9.3	10.0	10.0	9.4	10.2	9.3	9.4	9.0