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RADIATION LEAKAGE THROUGH THIN CYCLOTRON SHIELD WALLS†

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Thick targets of carbon, aluminum, copper, and tantalum were each bombarded with beams of protons, deuterons, α-particles, and carbon ions. The target station was 5.5 m from an 80 cm thick ordinary concrete shield wall. Measurements were made of radiation levels of fast neutrons, thermal neutrons, and γ-radiation on the shielded side of the wall for each target-beam combination. Total radiation levels due to leakage through the wall were thus determined as a function of beam intensity for targets of a wide range of atomic mass and for a variety of incident beam particles with energies in the range of 8–66 MeV/amu. Deuteron beams result in the highest radiation levels (for a given beam energy). Measurements on both sides of the wall indicate that neutrons are the principal radiation leakage through the wall. Neutron induced reactions in the wall, however, result in significant levels of γ-radiation on the shielded side of the wall which are $\sim$50 per cent of the total rem dose.

1. INTRODUCTION

The Oak Ridge Isochronous Cyclotron[1] (ORIC) is a variable energy accelerator for a variety of charged particles. The beams are 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. If the maximum requirements are provided in the fixed shielding it may be needlessly expensive both in installation cost and in valuable space occupied by the shield. It may be more practical in some situations to use more modest permanent shields that meet 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 of radiation leakage through a thin (80 cm) concrete block wall that was erected in one of the target rooms at ORIC. The wall was erected to divide the room into two target rooms (north and south) for different types of experiments. When beam is on target in one of the rooms it is often desirable for experimenters to have access to the other room. The north room will be used exclusively for experiments with low intensity beams of heavy ions and radiation leakage through the concrete block wall will be low. In the south room targets are bombarded with high intensity beams (up to 10 μA) 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.

The shield wall thickness requirements at accelerator installations are usually determined by neutron production rates, especially the higher energy neutrons. Estimates based on the data of Johnson and Ohnesorge[2] and of Wadman[3] and neutron attenuation data[4] indicated that a concrete wall 100–120 cm thick would provide adequate shielding for most situations. Because of space limitations it was decided to erect a wall 80 cm thick, make radiation leakage measurements, and to use these data to guide administrative control of access to the north room and in the design of a local shield at the target in the south room.

Measurements were made of the radiation dose rates of fast neutrons, thermal neutrons, and beta-gamma in the north room for beams of protons, deuterons, alpha particles and carbon ions on thick targets of carbon, aluminum, copper, and tantalum at target station *A*.

2. DESCRIPTION OF THE MEASUREMENTS

Figure 1 shows the plan of target room C111 at ORIC, with the stacked block wall that was recently erected. It is apparent that a significantly thicker wall would render inaccessible one of the beam lines that are directed to the room. In principle, material of more effective shielding properties

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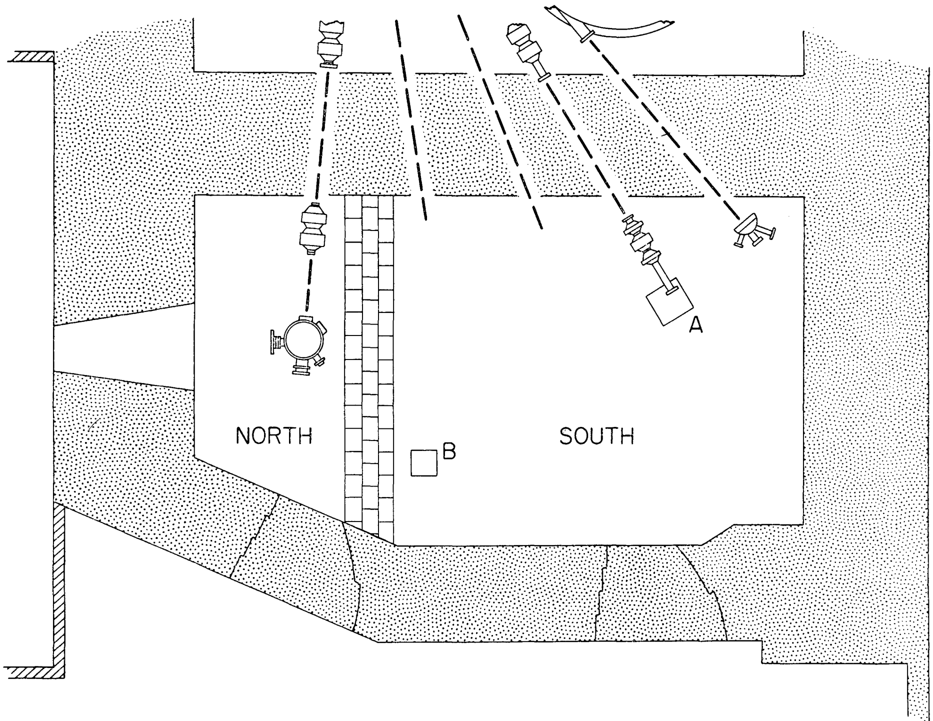

FIG. 1. Target room C111 at ORIC. The block wall divides the room into two target rooms. For the measurements reported in this paper targets were bombarded at *A* and a fast neutron monitor was located at *B*.

could have been used in the wall. Ordinary concrete blocks, however, were available from other building modifications and could be used to erect the wall at minimum cost.

For the measurements of radiation leakage through the wall the cyclotron beam was focused to an ~ 1 cm diameter spot at the target station labeled *A* in Fig. 1. For all of the measurements the targets were thick enough to stop the beam.

A portable fast neutron survey meter was positioned at location *B* on the target side of the wall 5.5 m from the target. This meter was observed via television and used by the cyclotron operators to determine the beam intensity needed on the target, which was electrically insulated from the beam line and served as a Faraday cup to monitor the incident beam intensity.

The radiation levels in the north room are due to radiation 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 at the top of Fig. .1 The latter do not significantly affect the measurements, however. About 25 per cent of the accelerated beam is extracted and delivered to the target at *A*. Fast neutrons resulting from beam losses in the cyclotron room and leaking into the north room of C111 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 on the fast neutron monitor at position *B*. Then with the beam intensity maintained, suitable health physics survey meters were used to obtain measurements of dose rates of fast neutrons, thermal neutrons and γ-radiation[5] in the north room on the shielded side of the wall. These measurements were made directly across the wall from *B* and at several other locations in the room. The variation of the measured dose rates in the room was usually less than 10 per cent.

The fast neutron measurements were used to determine half-value thicknesses[6] of ordinary concrete for the overall neutron spectra resulting from the various target-beam combinations. For the first two series of data runs measurements with the portable fast neutron meters were supplemented by data obtained with integrating monitors which employed tissue equivalent gas in the ionization chambers. The integration feature removed errors due to beam intensity fluctuations during the measurements. In all cases agreement was within 5 per cent and usually within 2 per cent. The fast neutron survey meters used in these measurements have a negligible response (less than 1 per cent) to background gamma radiation.[7]

The dose rate measured by the fast neutron monitor at location *B* is due to a combination of radiation directly from the target and from reflections 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* (see Fig. 1). 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 demonstrates that a modest shield around the target will significantly reduce the shield wall thickness requirements.

3. RESULTS AND DISCUSSION

Table I lists the beam currents needed on thick targets at station *A* (Fig. 1) to yield a fast neutron dose rate of 2.0 rem/hr at *B*. The uncertainty of these measurements is ± 10 per cent except for carbon ions where the low beam intensity available at the time of the measurements resulted in uncertainties of ± 20 per cent. For convenience of comparing results of the measurements for various incident particles beam intensities are expressed in particle microamperes, where 1 particle μA is 6.25×10^{12} particles/second.

The proton data cover the largest energy range and show a strong trend of increased neutron emission with bombarding energy. There is also a trend for neutron yield to increase with target atomic mass with the largest increase in the low mass region. The increase of neutron yield with bombarding energy is similar for all targets.

The measurements reported here were obtained by using health physics survey instruments. The increase of neutron yield with target mass thus measured for 66 MeV protons is very similar to the results (for 63 MeV protons) of Johnson and Ohnesorge[2] who used threshold detector techniques.

The neutron measurements from targets bombarded with deuterons and α-particles also show an increase of yield with incident particle energy. The rate of increase for both particle types, however, is larger than that of the proton data. The α-particle data show the principal increase of neutron yield with target mass in the low mass region. The 25-MeV deuteron data show a somewhat less systematic behavior of neutron yield with target mass while the 40-MeV data show an almost constant neutron yield over the wide range of mass.

For a number of target-beam combinations γ-radiation levels were also measured at *B* (Fig. 1) at the location of the fast neutron measurements on the target side of the shield wall. In all cases the γ-ray rad dose rate was 10 per cent as large as the fast neutron rem dose rate which is a rad dose rate times a quality factor. Thus the rad dose rates at *B* for fast neutrons and for γ-radiation are about equal.

Data were obtained with carbon ions at one bombarding energy. The neutron yields are significantly lower for all targets than when incident

TABLE I

Beam current needed on thick targets at station *A* to result in 2.00 rem/hr due to fast neutrons at location *B* 5.5 m from target. Beam currents are in particle μA.

Target	Protons				Deuterons		Alpha Particles		*Carbon Ions*
	20 MeV	31 MeV	40 MeV	66 MeV	25 MeV	40 MeV	50 MeV	80 MeV	100 MeV
Carbon		2.0	1.0	0.20	0.42	0.20	11	3.0	160
Aluminum	1.5	0.80	0.50	0.12	0.30	0.20	4.2	1.3	58
Copper	0.60	0.40	0.25	0.090	0.50	0.18	4.0	1.0	48
Tantalum	0.60	0.30	0.23	0.040	0.74	0.21	4.2	0.95	80

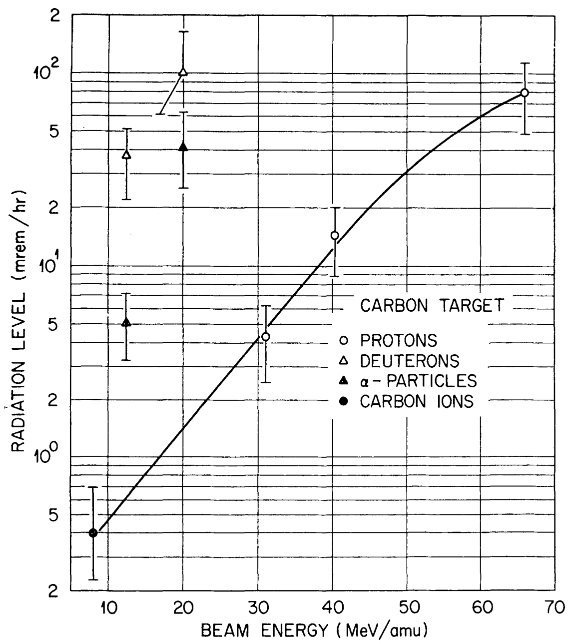

FIG. 2. Radiation levels in the north room with 1 particle μA of beam on a carbon target at A in the south room. The radiation levels are the sum of measured dose rates of fast neutrons, thermal neutrons, and $\beta-\gamma$.

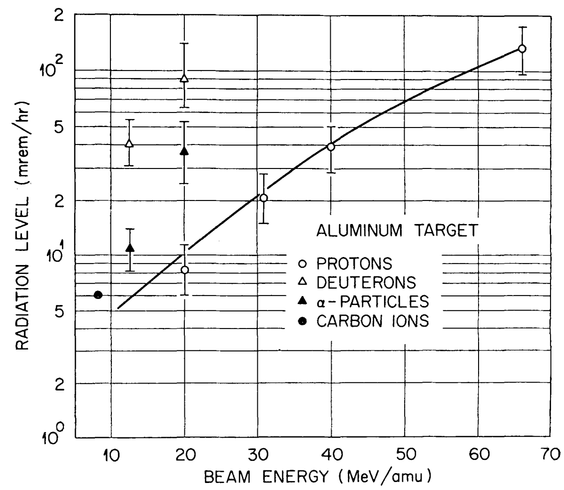

FIG. 3. Radiation levels in the north room with 1 particle μA of beam on an aluminum target at A in the south room. The radiation levels are the sum of measured dose rates of fast neutrons, thermal neutrons, and $\beta-\gamma$.

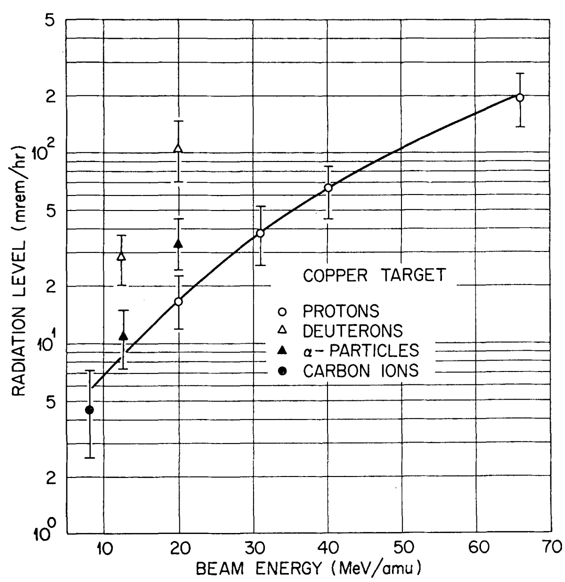

FIG. 4. Radiation levels in the north room with 1 particle μA of beam on a copper target at A in the south room. The radiation levels are the sum of measured dose rates of fast neutrons, thermal neutrons, and $\beta-\gamma$.

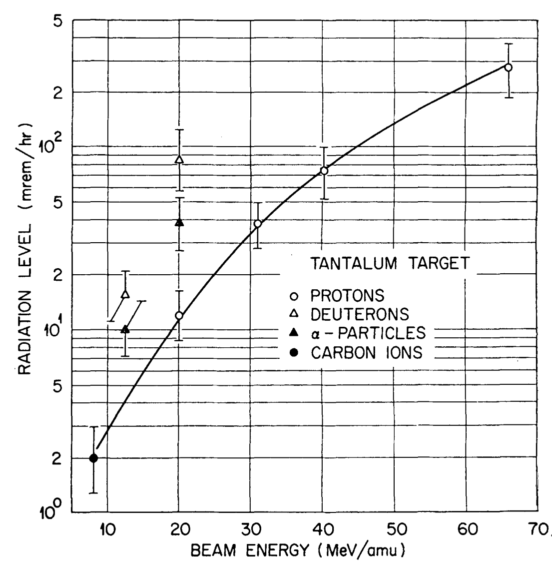

FIG. 5. Radiation levels in the north room with 1 particle μA of beam on a tantalum target at A in the south room. The radiation levels are the sum of measured dose rates of fast neutrons, thermal neutrons, and $\beta-\gamma$.

beams of protons, deuterons, and α-particles were used. Similar to the α-particle data the carbon ion data show the largest variation of neutron yield with target mass between carbon and aluminum.

The fast neutron dose rate measurements obtained at B (Fig. 1) and measurements in the north room directly across the 80-cm concrete wall were used to obtain neutron half-value thicknesses for the various target-beam combinations. The results, which are reported in Ref. 6, vary less than 10 per cent from the average value of 9.8 cm although the neutron yields vary appreciably over the range of beam-target combinations used.

Figures 2–5 show radiation levels in the north room for the various beam-target combinations used at station A in the south room. These data are the sums of measured dose rates of fast neutrons, thermal neutrons, and γ-radiation and are normalized to 1 particle μA of beam on the target. For each target the data for protons and carbon ions fit a smooth curve on the graph with the radiation levels for α-particle and deuteron beams above the smooth curve. Preliminary measurements with a beam of 160 MeV neon ions on an aluminum target also fit the smooth curve in Fig. 3. For all targets the radiation levels from deuteron bombardments are larger than from bombardments with the other beam particles used. The smooth curves for aluminum, copper, and tantalum overlap at low beam energies and diverge at higher beam energy with the highest radiation levels observed for the targets of highest atomic mass. Over the entire energy region radiation levels from carbon targets bombarded with protons or carbon ions are lower than those of aluminum, copper and tantalum.

The radiation levels from deuteron bombardments show the least systematic behavior. The most pronounced trend is the increase of radiation level with beam energy. The measured radiation levels for 40 MeV deuterons are almost the same for all target materials studied.

Our data did not include measurements of neutron angular distributions. For incident beams of deuterons direct reactions such as proton stripping would result in forward peaked neutron angular distributions. The neutron dose rate measurements at B (Fig. 1) were made at a direction of ~90 deg with respect to the incident particle beam. One may be inclined to attribute the less systematic behavior of radiation levels from deuteron bombardments to the forward peaked neutron angular distributions. We believe, however, that this is not a satisfactory explanation. One reason is that our measurements show that a large fraction of the measured neutron intensity at B is due to reflections. Another reason is that the neutron yield data of Johnson and Ohnesorge[2] for proton bombardments show a large variation of neutron energy and angular distributions with target mass. The radiation levels we observe show a more systematic behavior for proton bombardments than for deuteron bombardments.

The data shown in Figs. 2–5 were obtained by summing the measured dose rates of fast neutrons and other radiation in the north room. For all of the measurements the fast neutron component was 35–60 per cent of the total radiation level. For all targets bombarded with carbon ions the fast neutron component was 45 per cent or less while for 66 MeV protons it was more than 50 per cent. For the other target-beam combinations the fast neutron component of the total radiation level varied between 38 and 55 per cent. In all of the data the thermal neutron component was less than 20 per cent of the total radiation level.

5. CONCLUSIONS

The reasonably constant composition of the radiation in the north room is consistent with a much larger attenuation of γ-radiation than of fast neutrons by the 80 cm concrete wall. On the target side of the wall the rad dose rates were about equal for the two types of radiation. On the shielded side the rad dose rate of γ-radiation is a factor of ~10 larger than the rad dose rate of fast neutrons (the rem dose rates are about equal). The attenuation by the wall of the dose rates of fast neutrons ranges from 200–500 for the various beam-target combinations, while the attenuation of 80 cm of concrete for 3 MeV γ-rays is ~6000 and larger for lower energy γ-rays. Thus much of the γ-ray radiation level in the north room results from neutron induced reactions in the wall rather than γ-ray leakage through the wall. The principal radiation leakage through the wall is fast neutrons. One can thus use the data in Figs. 2–5 and the fast neutron half-thickness data of Ref. 6 to extrapolate radiation leakage from cyclotron targets through concrete walls of a range of thicknesses.

6. ACKNOWLEDGEMENTS

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