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HEAVY ION TARGET AREA FAST NEUTRON DOSE EQUIVALENT RATES

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Fast neutron dose equivalent rates were measured for targets bombarded with a variety of heavy ion beams over a wide range of energies. These data should be useful to those developing policies which allow personnel to enter accelerator areas during "beam on" periods.

Entry to accelerator areas during "beam on" periods can in some instances greatly simplify the performance of an experiment and make practicable some experiments which would not otherwise be performed. An example of such an experiment is the new heavy ion time-of-flight system (Fo77) at the Oak Ridge Isochronous Cyclotron which uses "state-of the art" electronics to achieve one-meter flight time resolution of 0.15 ns. Achieving this resolution requires that electronic modules be near the target station. Fine tuning of the timing signals requires personnel access to the system while a beam is on target.

Figure 1 shows the experimental layout as well as locations where radiation measurements were made. Results from some of these measurements are tabulated in Table 1. The beam passes through a thin target at the center of the scattering chamber and then into a Faraday cup which monitors the beam current and stops the beam. The target foil strips the electrons from the ion beam so that the charge on the ions at the cup is approximately that of the heavy ion nuclei. Points C and D are locations that the experimenters occupied while making adjustments. Beam currents were limited to less than one nA while experimenters were present. Radiation surveys were made with higher beam currents when no experimenters were present. The Faraday cup where the beam stopped was the source of most of the radiation. During the initial surveys beta-gamma measurements were taken in addition to the neutron measurements which are the primary subject of this paper; the beta-gamma readings accounted for only 5 to 10% of the combined dose equivalent rates.

The neutron dose equivalent rates were measured with ORNL fast neutron survey meters. The survey meters were calibrated with a ^{238}Pu + Be source which provides neutrons to approximately 6 MeV. The response of these instruments is documented for neutrons up to 10 MeV (Gu78). At higher energies the response is not well known. In the forward direction from the target, neutron energy spectra extended to much higher energies (Ba78), but the high energy components decrease rapidly with angle. For example, recently reported measurements (Sy79) for 315 MeV ^{16}O ions on a gold target show the yield of high energy nucleons at 80° to be 2 to 3% of the yield at 20°. The large angle nucleons are therefore principally from evaporation with energies within the reliable range of the instrument used in measurements reported here. At forward angles, however, the measured dose equivalent rates were probably too low.

Additional similar surveys were made with beams of ^{12}C, ^{14}N, ^{16}O and ^{20}Ne from ORIC and 36 MeV ^{12}C ions from the ORNL EN Tandem Van de Graaff. Dose equivalent rates measured at 90 degrees from the incident beam direction are summarized in Figure 2. The ^{12}C points at 7.5 and 9.5 MeV/amu are from previous work (Bu76) and the 3 MeV/amu points were obtained using beams from the Van de Graaff accelerator. The ^{20}Ne points are from two separate data runs. Two points obtained with alpha particles in measurements reported in (Bu76) are included.

The data shown in Figure 2 are from runs utilizing thick targets* of copper, iron, or nickel. Other data (not shown) were taken with thick carbon beam stops. For E >5 MeV/amu ions on carbon, results indicated dose equivalent rates approximately ½ those shown for corresponding energies and particles in Figure 2. Measurements utilizing 3 MeV/amu particles from the Van de Graaff on thick carbon stops indicated dose equivelent rates that were a factor of about 3 greater than those in Figure 2.

*"Thick target" implies the target was thick enough to stop the incident particle beam.

The errors shown in Figure 2 are thought to be due primarily to uncertainties in beam current level as well as the inability to reproduce measurements accurately. As mentioned in (Bu76) approximately 25% of the fast neutron dose rate is due to neutrons which are scattered from material such as the floor and walls of the room.

Measurements taken in the forward direction of the targets always indicated higher dose equivelent rates than comparable readings at 90^{0}, but the forward direction readings were not reported because of uncertainty in the survey instrument response at higher energies.

The results of the measurements reported in Figure 2 indicate that the dose rate <u>vs</u> energy/amu curve varies in a fairly smooth manner and could be used to predict dose rates for unreported ion species and energies. The ^{16}O and ^{14}N data points near 13 MeV/amu are puzzling to us. They were obtained just after data runs by the experimenters. There is some uncertainty about whether the beam stop was iron or carbon. The data points for ^{14}N at 11.8 and 13.4 MeV/amu were subsequently measured in data runs made specifically to obtain fast neutron dose equivalent rates. Sixteen MeV/amu is the maximum energy currently available at ORIC for ^{12}C or heavier ions, but it might be useful to extend measurements of this type to higher energies.

The data presented in Figure 2 should be helpful in planning personnel access to target areas. Most such needs do not require people to be in areas forward of the target. In planning such access, however, it is important to insure that significant amounts of beam are not lost on collimators and other beam optics components upstream. Such losses may expose workers to the higher energy forward peaked component of the neutron spectrum for which neutron monitors are not calibrated.

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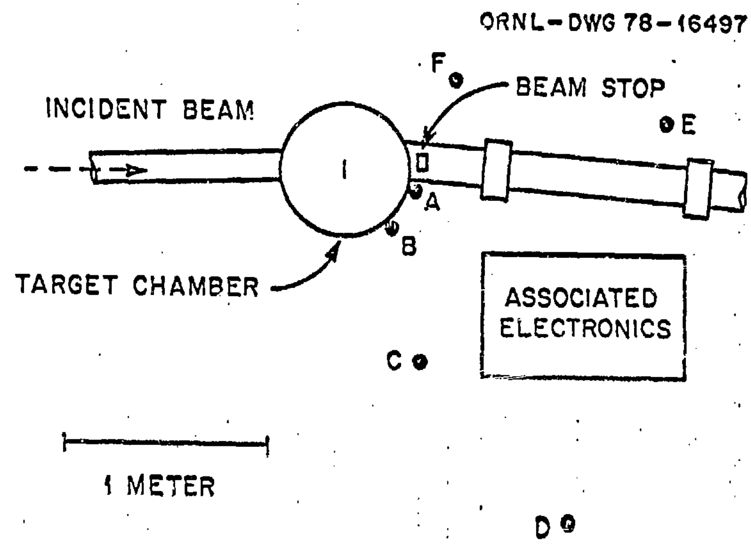

Figure 1. Experimental arrangement at ORIC's heavy ion time-of-flight target station. The approximate locations are indicated for the fast neutron dose rate readings listed in Table 1.

Table 1. Fast neutron equivalent dose rates in mrem/hr from 147.6 MeV ^{14}N ions on a stainless steel beam stop. The data in parenthesis are for $\beta\gamma$ measurements.

Location	Beam Intensity in Nanoamperes 4	10	30
A	100 - 130	550 - 600	1700 (150)
B	70	200 - 210	750 (35)
C	15 - 17	40 - 45	115
D	4 - 7	8 - 10	25 - 30
E	8 - 10	20 - 25	65 - 70
F	18 - 20	65 - 70	180 - 190 (20)

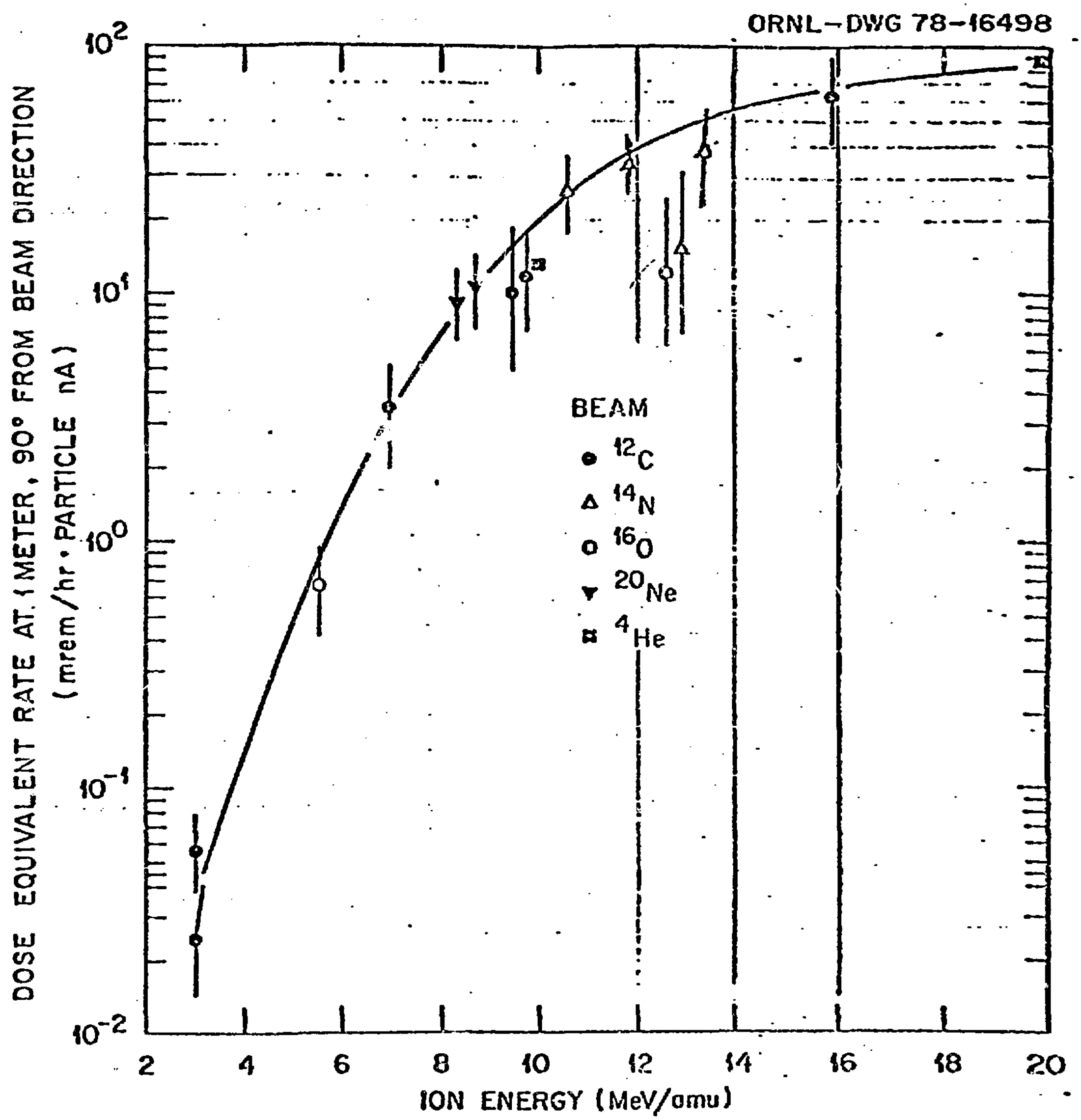

Figure 2. Fast neutron equivalent dose rates one meter from thick targets of iron, nickel or copper and 90 degrees from the incident heavy ion beam direction. One particle nanoampere is 6.25×10^9 particles/second.