FAST NEUTRON DOSE EQUIVALENT RATES IN HEAVY ION TARGET AREAS

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Abstract

At heavy ion accelerators, personnel access to areas near the target is sometimes important for successful performance of experiments. Radiation levels determine the amount of time that can be spent in these areas without exceeding maximum permissible exposures. Inasmuch as the fast neutrons contribute the major part of the Rem dose rates in these areas, knowledge of the fast neutron levels is important for planning permissive entry to target areas. We have measured fast neutron dose rates near thick medium mass targets bombarded with beams of C, N, O, and Ne ions. Beam energies ranged from 3 to 16 MeV/amu. Dose rates (mrem/h) 1 meter from the target 90 degrees from the beam direction range from ∿ 0.05 at 3 MeV/amu to ∿ 50 at 16 MeV/amu. These data should be helpful in planning permissive entry to heavy ion target areas.

The radiations from accelerator beams interacting with targets and associated target station components such as collimators and beam stops usually require shielding to protect personnel working nearby. Typically, the most penetrating radiations, and consequently the most difficult to shield, are the neutrons. Yields and energies of these determine the shielding requirements. In earlier work[1-3], we measured half-value thicknesses of concrete for neutrons from a range of light ions on a variety of thick targets. For these data, radiation levels without shielding were measured and the work reported in reference 3 included measurements at two energies for ^{12}C ions. In the present work, fast neutron levels were measured for targets bombarded with a variety of heavy ion beams at a wide range of beam energy. These data are useful in developing policies to allow personnel to enter radiation zones around target stations at heavy ion accelerators.

For thick targets, i.e. those that stop the beam, the neutron yield is given by $\int_0^R I(E)\sigma(E)dx$ where I is the beam intensity, R the range of the beam particles in the target material, and σ the cross section for neutron production. For low-energy, heavy ions the ranges are small and the neutron yields are low compared to those of targets bombarded with light ions of comparable energy. In many such cases, the neutron radiation levels are low enough so that access by personnel to areas near the targets is feasible providing that a suitable surveillance system employing active radiation detectors is in use. For example, a permissive entry system with accumulated dose monitoring has been used routinely for a number of years at the heavy ion target areas of the ORNL EN Tandem Van de Graaff accelerator. Here the beam energies for heavy ions are less than 4 MeV/amu.

At accelerators with higher beam energies, access to target areas is sometimes needed for successful performance of experiments. For example, the new heavy ion time-of-flight system[4] at the Oak Ridge Isochronous Cyclotron uses "state-of-the-art" electronics to achieve one meter flight time resolution of 0.15 ns. To achieve this, cable lengths for the time signals must be short and the electronic modules located near the target. Fine tuning of the timing signals requires personnel access to the system with a beam on the target. During the initial "shake down" data runs with the time-of-flight system access of the experimenters to the target area was arranged with continuous surveillance by health physics radiation survey personnel.

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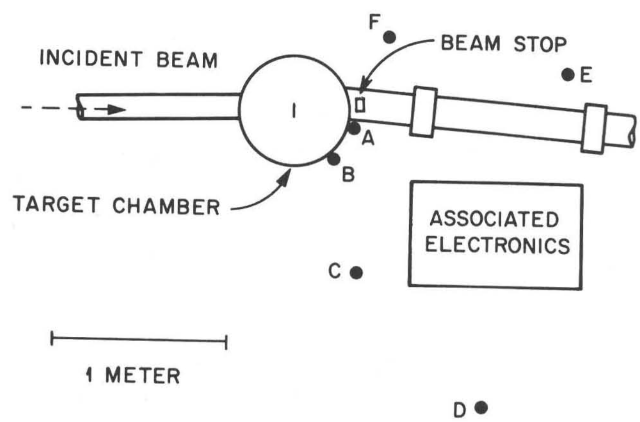

Figure 1. Experimental layout of heavy ion time-of-flight target station at ORIC. The approximate locations are indicated for the fast neutron dose rate readings listed in Table I.

Table I

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

Location	Beam Intensity in Nanoamperers 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)

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Figure 1 is a sketch of the ORIC heavy ion time-of-flight target station and Table I is a list of radiation levels measured with portable fast neutron survey meters. The most extensive access needed by experimenters was at locations C and D. Beam currents were limited to ∿ one nA while these people were in the target area, but radiation surveys were performed with higher beam intensities (as indicated in Table I) to yield more accurate fast neutron dose equivalent rate measurements. During the initial surveys β γ measurements were also made. These accounted for approximately 5 to 10% of the combined dose equivalent rates.

The beam passes through a thin target at the center of the scattering chamber (see Fig. 1) and then into a beam stop which serves as a Faraday cup to monitor the beam intensity. Almost all of the radiation is thus from the beam stop. The target foil serves as an electron stripper so the charge of ions entering the beam stop is approximately that of the heavy ion nucleus.

For each run, the fast neutron survey meters were calibrated with a ^{238}Pu + Be source. This source provides neutrons with energies ranging up to ∿ 6 MeV. The response of this type meter is documented for neutrons having energies extending to 14 MeV.[5] At higher energies, the response isn't well known. In forward directions, the neutron energy spectra extend to much higher energies,[6] but the angular distribution for the highest energy direct reaction neutrons falls off with angle such that at an angle of 80 degrees or larger, the neutrons are predominantly from evaporation and the survey meter measurements are reliable. At forward angles, the measured dose equivalent rates are obviously too low.

Radiation surveys like those shown in Figure 1 and Table I were performed for a number of data runs with the heavy ion time-of-flight target station. Beams of ^{12}C, ^{14}N, ^{16}O, and ^{20}Ne from ORIC were used. Additional measurements were made with a beam of 36 MeV ^{12}C ions provided by the ORNL EN Tandem Van de Graaff.

The measurements 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 the data of reference 3 and the 3 MeV/amu point were obtained with a beam from the Van de Graaff accelerator. The two ^{20}Ne points are from separate data runs. We have included in Figure 2 two points obtained with α-particles in the measurements reported in reference 3.

The data shown in Figure 2 were obtained with thick targets of iron, nickel, or copper and fit reasonably well on a smooth curve. A few measurements were also obtained with carbon beam stops. At all energies for beams from ORIC (i.e. E>5 MeV/amu) the measured neutron dose equivalent rates at 90 degrees from the beam direction were about half the corresponding dose rates in Figure 2. The 3 MeV/amu measurements at the Van de Graaff accelerator, with a carbon target, were a factor ∿ 3 larger than those values shown for Cu, Fe, and Ni targets. A few measurements were also obtained at ORIC with tantalum targets for beam energies above 8 MeV/amu. These dose rates were about 50% larger than those measured with iron or copper targets.

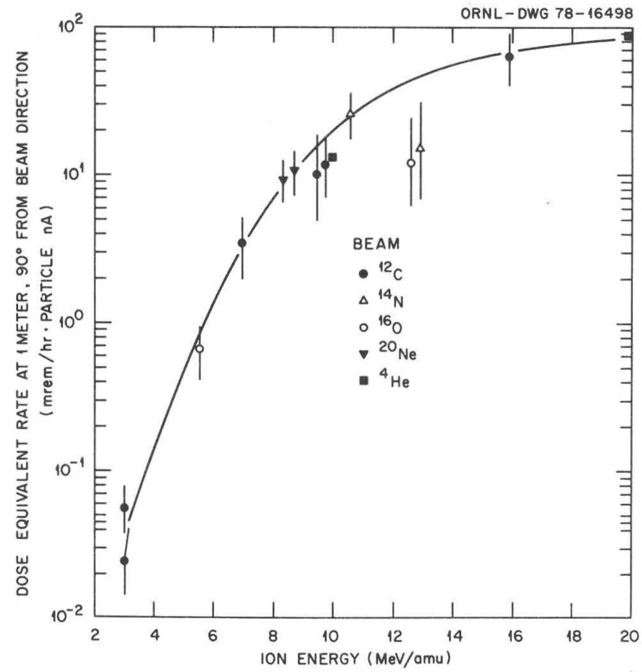

Figure 2. Fast neutron equivalent dose rates one meter from thick targets and 90 degrees from the incident heavy ion beam direction. The targets are iron, nickel, or copper. The curve is drawn to guide the eye. One particle nanoampere is 6.25 x 10^9 particles/second.

The errors shown in Figure 2 represent uncertainties in beam current and reproducibility of measurements. For some of the measurements, available beam currents were so low that integrated counts over periods of a few minutes were needed, and some variation of beam current occurred during the measurement. As was pointed out in reference 3, about 25% of the fast neutron dose rate is due to reflections from the walls, floor, and ceiling of the room.

In all of the radiation surveys performed in this work, the fast neutron dose rates at forward angles were larger than at 90 degrees for the same distance from the target. We are reluctant, however, to report any of those measurements because the high-energy, direct-reaction neutrons are emitted in the forward direction. Both the response of the survey meter as well as the uncertainty about the quality factor for high-energy neutrons make accurate determination of dose equivalent rates difficult in this region.

The data shown in Figure 2 agree reasonably well with the smooth curve that is drawn to guide the eye with no apparent variation for incident particle type. Even the two points for ^{4}He are in good comportment with the other data. For energies below ∿ 10 MeV/amu, the fast neutron dose rate increases exponentially with particle energy. At 10 MeV/amu the dose rate is more than two orders of magnitude larger than at 3 MeV/amu. This emphasises that close surveillance will be required for permissive entry of personnel into high-energy, heavy-ion target areas.

The present data suggest a smaller increase of dose rate with particle energy at beam energies above ∿ 10 MeV/amu. Sixteen MeV/amu is the maximum energy now available at ORIC for ^{12}C or heavier ions. It is desirable to extend measurements of this type to include higher energy ions.

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. This would result in the workers being exposed to the higher energy forward peaked component of the neutron spectrum for which neutron monitors are not calibrated.

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