Neutron dose angular distributions from high-energy ^{12}C ions stopping in various absorbers

H. Iwase, D. Schardt, and F. Gutermuth
GSI, Darmstadt

Using the irradiation system of the medical treatment unit (Cave M) at GSI, pencil-like beams of ^{12}C ions in the energy range of 100-400 MeV/u were stopped in thick targets of water, graphite, iron and lead placed at the reference point 100 cm behind the vacuum exit window. The beam intensity was monitored with a calibrated ionization chamber. Two kinds of neutron dosemeters, WENDI-II, a ^{3}He counter with polyethylene + tungsten moderator and BIOREM, a BF_3 counter with polyethylene moderator, were employed for the neutron dose measurements. The conversion factors of 3.2×10^9 counts/Sv for WENDI-II and 1.7×10^9 counts/Sv for BIOREM were determined with an ^{241}AmBe source. The REM-counters were placed at angles of 0, 5, 10, 20, 30, 60, 90, and 135° with respect to the beam axis. The distance from target center was 290 cm (0-30°), 250 cm (60°), 240 cm (90°) and 160 cm (135°). All data were normalized to a distance of 300 cm.

The measured angular distributions for a 12.8 cm thick water target are shown in Fig.1. The neutron dose per incident ion decreases rapidly between 0 and 20° and is most forward peaked for the highest beam energies.

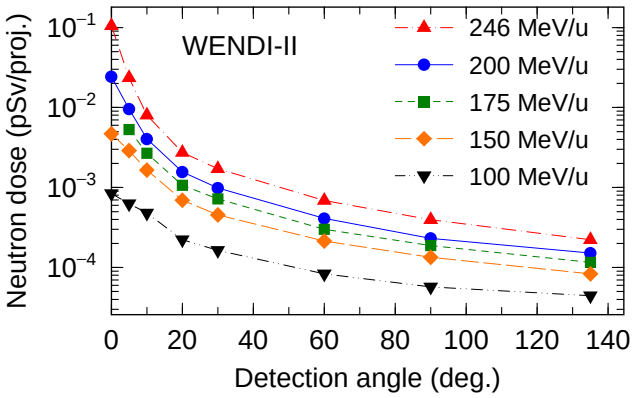

Figure 1: Neutron dose at 3m distance from a 12.8 cm thick water target (^{12}C primary beams)

Figure 2 shows a comparison of neutron doses measured with the REM-counters WENDI-II and BIOREM, and the neutron dose inferred from fluence measurements [1] with a BaF_2 scintillation detector for 200 MeV/u ^{12}C ions stopping in a 12.8 cm thick water target. The lower response of the BIOREM counter as compared to WENDI-II can be explained by the small sensitivity of BIOREM for neutrons above ~50 MeV, whereas WENDI-II has an improved energy response up to 5 GeV [2]. On the other hand, high-energy charged particles may increase the dose values of BIOREM at small angles. The BaF_2 fluence data, with a lower detection limit of 20 MeV, were converted into dose by convolution with the ambient dose equivalent h*(10) [3, 4]. The resulting dose angular distribution is in fair agreement with the WENDI-II data.

The neutron dose measured for various stopping materials (25.6 cm water, 20 cm graphite, 5 cm iron, and 5 cm lead) as a function of the incident ^{12}C energy is presented in Fig.3. The target thickness corresponds roughly to the range of 200 MeV/u ^{12}C ions in each material. At the highest energy the dose observed at 0° behind the water target is much higher than the dose behind the lead target. This is explained by the fact that the neutron production scales approximately with the mean number of nuclear interactions along the stopping path. Target dependences of neutron productions by 400 MeV/u ^{12}C were also investigated by Kurosawa et al. [5] and it gives similar tendency as the present results.

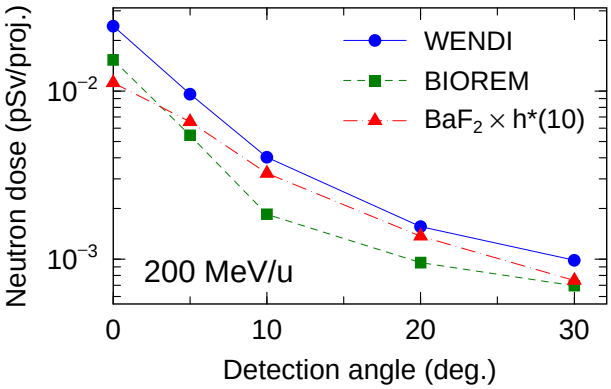

Figure 2: Comparison of neutron doses obtained from WENDI-II, BIOREM, and fluence measurements [1]

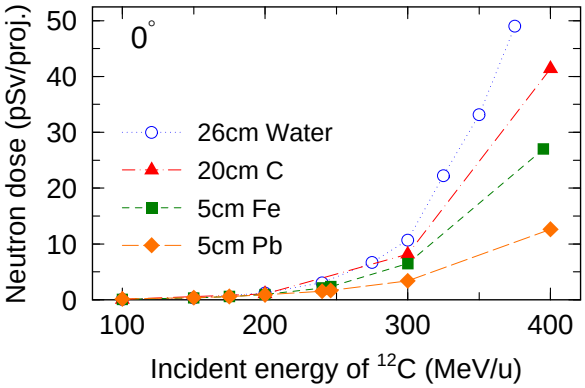

Figure 3: Neutron dose measured by WENDI-II at 0° from ^{12}C ions on various target

References

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