Nuclear Data for Science and Technology (1988 MITO), 1161-1164, Copyright © 1988 JAERI.

NEUTRON YIELD DATA DUE TO BOMBARDMENT OF THICK TARGETS OF Be, C, Ta AND Au BY 40 TO 60 MeV ALPHA PARTICLES

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Abstract: A knowledge of the energy distribution of the neutrons, from bombardment of thick targets by charged particles is necessary for accurate estimation of shield thicknesses. With increasing cost of shield materials and with the possibility of increasing the quality factor by a factor of about two resulting in the reduction of the values of the maximum permissible fluxes of neutrons, a knowledge of neutron energy distribution is very essential. Data on neutron production from thick targets is sparse. To generate such data, we have measured neutron energy distribution due to the bombardment of alpha particles in the energy range of 40-60 MeV on thick targets of Be, C, Ta and Au. NE-213 liquid scintillator system with the associated n-γ discriminator circuit was used for this purpose. The data have been analysed in the framework of the exciton model incorporating both multistep direct and multistep compound processes and the compound nuclear evaporation process.

(neutron spectrum, thick target, (α,xn) reactions, exiton model)

Introduction

With increasing applications of medium energy accelerators in various diverse fields, radiation dosimetry and radiation shielding are assuming greater importance. For this purpose, one has to have precise knowledge of the spectral distribution of secondary neutrons produced due to the bombardment of ions on thick targets. This need has been enhanced by the recent recommendations of the International Commission on Radiological Protection[1], whereby the annual dose equivalent limit for the members of the public is sought to be reduced by a factor of 5 at the same time increasing the quality factor of neutrons by a factor of 2. The net effect is to reduce the annual dose equivalent limit by a factor of 10.

The earliest measurement was made to determine the neutron spectrum produced due to the bombardment of 40 and 80 MeV alphas on a thick Ta target[2], using threshold detectors. Recently, there have been several spectral distribution studies[3-6], using various projectiles and various targets. This group has also studied the attenuation properties of some of the accelerator produced neutron sources to various shield materials[4].

In order to augment the existing data and to provide data, where not available, we have undertaken measurements of neutron energy distribution at various angles from different thick targets due to the bombardment of α particles in the energy range of 40 to 70 MeV. The target materials considered here are Be, C, Ta, and Au. NE-213 liquid scintillator, in conjunction with n-γ discriminator circuit, is used for such measurements.

Experimental details

Accelerated α particle beams from the Variable Energy Cyclotron are allowed to be incident on the thick target. The projectile energies and the targets used are given in Table 1.

Table 1. List of targets and projectile energies

Target	Energy (MeV)
Be	50
C	50
Ta	50,60
Au	40,50

A collimator in front of the target restricts the beam size to about 10mm. The collimator is electrically insulated from the target side. The beam current is minimised on the collimator and maximised on the target, thus reducing the background neutron contribution from the collimator. Beam currents used are of the order of 100 to 150 nA, except in the case of Be target, where the beam current used is of the order of 20 nA.

In order to estimate the number of α particles incident on the target, the current output of the target is fed to a scaler through a current integrator and a current digitiser. The data is collected for a fixed number of counts, thus taking into account the fluctuations in the beam current. Two gain settings in the ratio of 1:10 are used to span the entire neutron spectrum. In order to estimate the contribution from the room scattered neutrons, a shadow bar is interposed between the detector and the target. The perspex shadowbar of length 100 cm, stops the neutrons produced from the target. This scattered neutron spectrum is subtracted from the original spectrum. It was observed that the background neutrons contribute between 5% and 10% to the neutrons measured without shadowbar. The spectra reported here are corrected for this scattered component.

The spectrometer consists of a NE-213 organic liquid scintillator system of size 52.4 mm ϕ X 52.4mm, in conjunction with the n-γ discriminator circuit. The recoil proton spectra are measured at angles of 0°, 30°, 60° and 90° to the beam axis and the detector is kept at a distance of 1.4 M from the target.The lowest neutron energy that can be discriminated against gamma rays in the accelerator environment is about 1 MeV.

The resultant pulse height distributions were unfolded to obtain neutron energy spectra using the FERDOR-U code[7] with the aid of response functions calculated by the Monte Carlo technique. The FERDOR-U code gives the unfolded spectra along with the estimated error. The error consists of three components, namely, the statistical error of the observed counts; the error caused by the unfolding calculations truncated by the finite dimensions of the vectors and the response matrix; and the statistical error due the Monte Carlo estimation of the response matrix.

Analysis of the Data

Similar thick target neutron spectra have been analysed by Shin et.al[3] by the intranuclear cascade and evaporation model and by Nakamura and Uwamino[8] by the phenomenological hybrid model.

Shin et.al[3] analysed their data by the LHI code programmed by Armstrong and Colborn[9]. The code predicts radiation fields and effects produced in thick targets by light-heavy-ion (LHI) beams by Monte Carlo method. The lower projectile energy limit of the validity of the LHI code is given as 88.3 MeV (22.1 MeV/nucleon) for alphas. Shin et.al analysed the data of 65 MeV alphas with the code and found appreciable differences in the measured and calculated distributions. They have attributed the discrepancy mainly to the assumption of the Fermi free gas model in the MECC-7[10] code which neglects the nucleon-nucleon coupling and treats non-elastic nucleon-nucleon interactions as a series of independent hadron-hadron collisions. It is therefore expected that in the present case where the projectile energy is still lower (40-60 MeV), the LHI calculations will not be useful.

Nakamura and Uwamino[8] analysed the same data of Shin et.al by adopting a phenomenological hybrid model of equilibrium and pre-equilibrium emissions. Both the spectrum components of equilibrium and pre-equilibrium were fitted with two Maxwellian type functions having two different nuclear temperatures. The equilibrium temperature values are only a function of the excited energy of the compound nucleus and are independent of the neutron emission angle. According to Nakamura and Uwamino on the other hand, the pre-equilibrium temperature values are dependent on the excitation energy of the composite nucleus as well as on emission angle. It is presumed that the emission from the hotter pre-equilibrium state occurs in a more forward direction. However, neutron spectra calculated using this concept donot fit the experimentally observed data for light target nuclei e.g. carbon.

We have used the exciton model formalism[11] as modified by Kalbach[12] to analyse our data for pre-equilibrium and compound nuclear neutron emissions. The formalism extracts multistep direct and multistep compound components of the pre-equilibrium corss-sections. In the former process atleast one of the excited paritcles is in the continuum at each stage of the relaxation process. In the multistep compound process all excited particles are bound below the continuum and emissions take place through statistical fluctuations. Kalbach obtains the pre-equilibrium angular distribution through Legendre polynomials whose co-efficients have been determined by studying a large number of experimental angular distribution. The code PRECO-D2 written by Kalbach[13] incorporating the above formalism was used in the present study after modifying it to calculate thick target neutron yield.

Results and Discussions

Figures 1 to 6 give the measured neutron energy distribution per MeV per steradian for 40-60 MeV alphas on thick targets of Be, C, Ta and Au at 0°, 30°, 60° and 90°. It is observed that with the increase in angle the spectra in general becomes softer and softer with respect to energy. This is understandable because the direct processes are forward peaked and therefore high energy neutrons will be more in the forward direction.

Figure 7 compares our calculations based on Kalbach's formalism with the experiment for 50 MeV alphas on ^{181}Ta at 0°, 30°, 60° and 90°. At each angle the lower energy part of the spectrum is satisfactorily reproduced. The fit in the higher energy part is satisfactory only for 90°, but gradually worsens with decreasing angle. This would indicate that while the formalism reproduces the compound nuclear (lower energy and higher angles) part of the spectrum quite well, the pre-equilibrium angular distributions are underpredicted.

Acknowledgements

The authors thank Prof.B.Mitra and Prof.B.B.Baliga for their help during the collection of data for Be and C targets. Thanks are also due to the operation staff of the VECC for their cooperation.

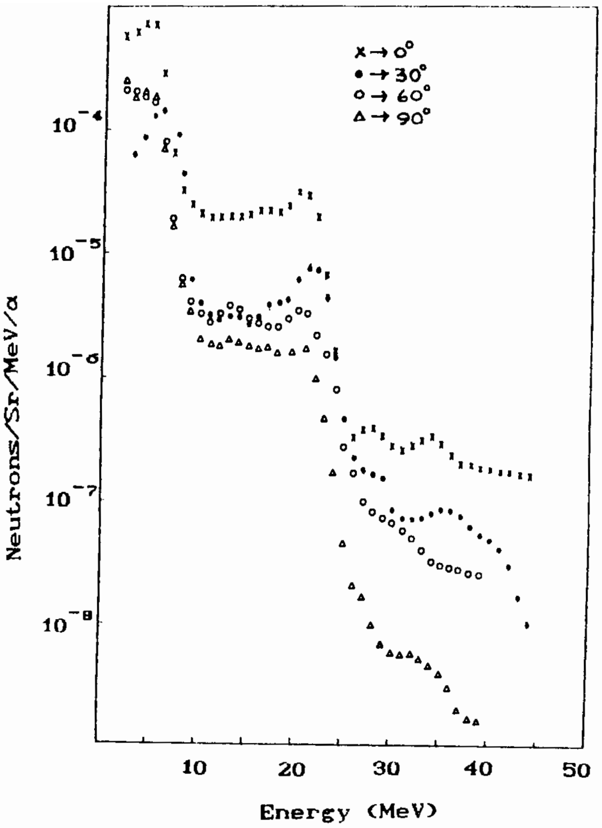

Figure 1. 50 MeV alphas on Be.

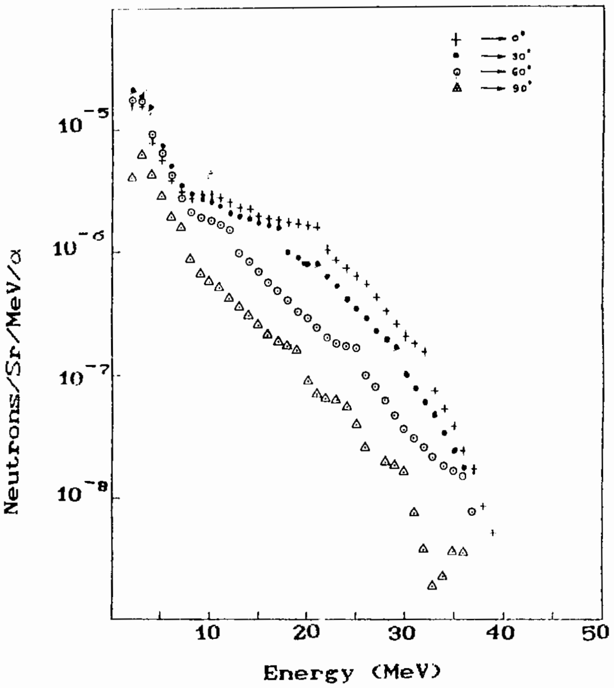

Figure 3. 50 MeV alphas on Ta.

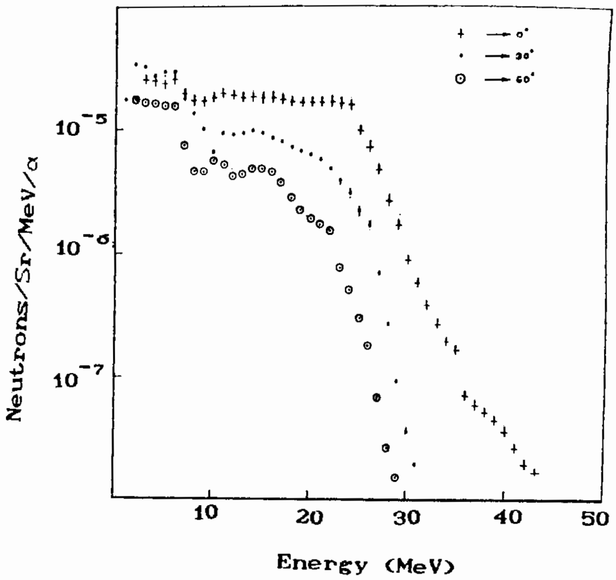

Figure 2. 50 MeV alphas on C.

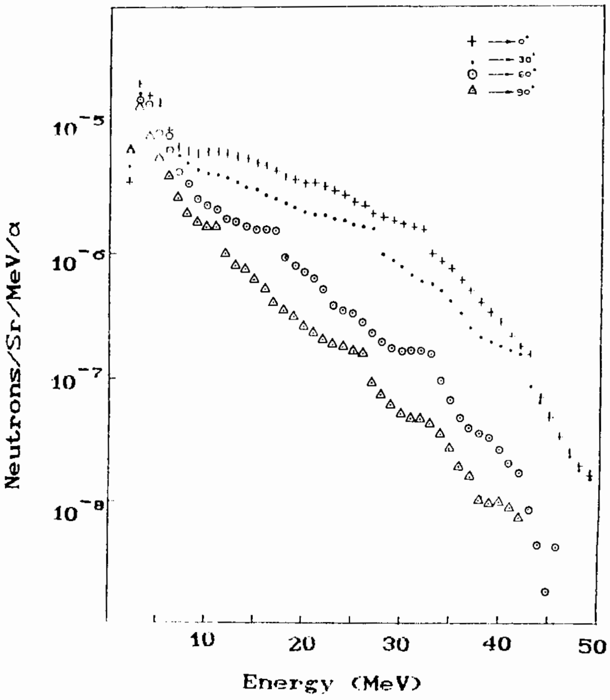

Figure 4. 60 MeV alphas on Ta.

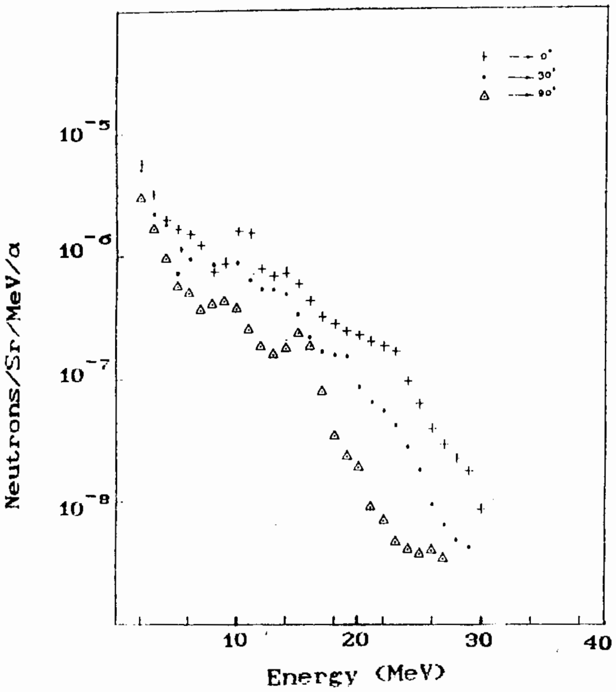

Figure 5. 40 MeV alphas on Au.

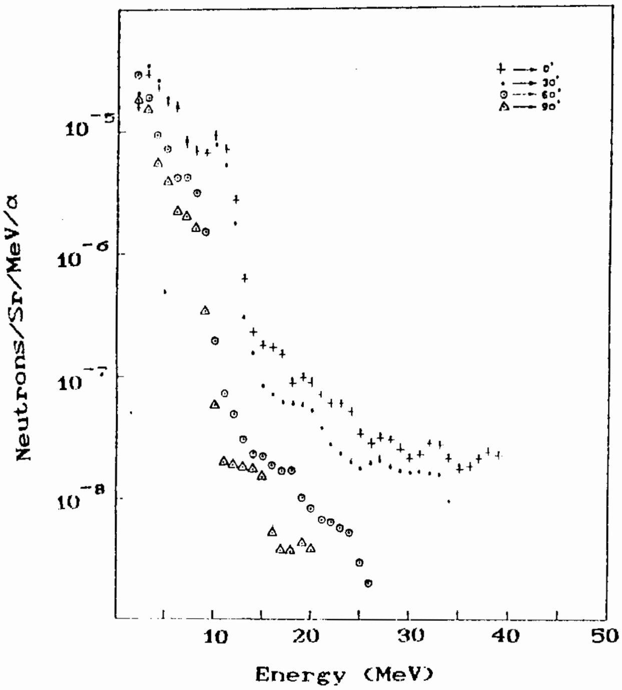

Figure 6. 50 MeV alphas on Au.

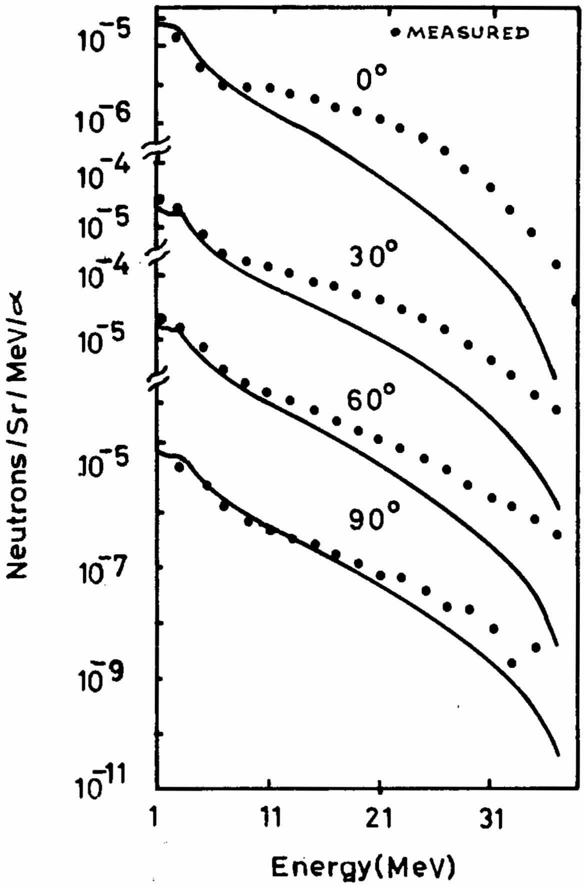

Figure 7. Comparison of calculated and measured neutron spectra due to 50 MeV alphas on Ta.

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