ANALYSIS AND EVALUATION OF GAMMA AND NEUTRON DOSIMETRY FROM 48MeV 7Li ON NATURAL Cu AND ITS DOSE SIMULATION WITH MCNP

R. G. Sonkawade, Birender Singh, Pankaj. Kumar, S.P. Lochab, Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi-110 067, India
R. V. Kolekar, Radiation Safety System Division, Bhabha Atomic Research Centre, Mumbai-400 085, India

Abstract

Neutron and gamma radiation dose as a function of angle was measured from 48MeV, $^{7}Li^{3+}$ ion beam incident on thick natural copper target. The experiment is simulated keeping in view the health physics importance for monitoring the radiation environment in charged particle accelerator. The neutron dose observed in the forward direction is slightly higher compared to the lateral direction. Gamma energy of the same reaction is also monitored in the experimental setup with the HPGe-detector. The experimental results are compared with the calculated dose from empirical formulations. From the observed gamma spectrum, and PACE calculation, possible reactions were identified and correlated with the observed spectrum.

INTRODUCTION

In an accelerator, prompt secondary radiations such as gamma and neutrons are produced during the acceleration of ions, due to the interaction of the projectiles with the beam line materials. In a medium energy heavy ion accelerator, neutrons are the dominant prompt radiation. There are a number of low to medium energy accelerators utilized for research in various fields. In a heavy ion accelerator facility, neutron emission from thick targets are important, as they constitute the major component of prompt radiation environment owing to beam loss during normal operations or accidental situations. In this connection, energy and angular distribution of neutron and gamma dose distribution from thick targets are important for radiation protection point of view. The neutron dose in any direction is a function of the energy and angular distribution of neutrons, which in an accelerator environment vary depending upon the projectile, target and incident energy. Such measurements have been reported in the literature for protons and alpha particles but in the case of heavy ions, the experimental data are very few [1-5]. Moreover, most of the neutron yield data from heavy ion projectiles are in the energy region of 20MeV amu^{-1} and above. There are only few experimental measurements in the region of 10MeV amu^{-1} and below [6-7].

EXPERIMENTAL ARRANGEMENT

The experiment was performed at 15 UD Pelletron Accelerator Facility at the Inter University Accelerator Center (IUAC), New Delhi. The neutron energy spectrum and the radiation dosimetry were measured for $^{7}Li^{3+}$ ion beam accelerated through the Pelletron accelerator to 48MeV energy, stopped on thick Cu target of 1mm. Projectile ^{7}Li of 48MeV, has a range of 0.1026mm in Cu as calculated by SRIM [8]. The experiment is performed in the General Purpose Scattering Chamber (GPSC), which has the specially designed flanges of very small wall thickness to allow neutrons to emerge without much energy degradation . Spherical NDE meters are kept around 1.0m distance from the target at 0, 30, 60 and 90 degrees with respect to the beam direction. The neutron survey meter of make "Meridian" model 5085 is also used for monitoring the neutron dose level around the chamber. The gamma dose measurement is done with the gamma survey meter at one location at an angle of 90^{0}. The calibrated CR-39 sheet of thickness 500um procured from Pershore Moulding Ltd., UK and Lithium Borate radiators (Kodak, CA80-15 type B) of thickness 9.4$mgcm^{-2}$ were used in the experiment. CR-39 with 1mm polyethylene radiator and with Lithium Borate external radiator are used for discrimination of fast and thermal neutrons respectively. PACE is used to cross check the possible formation of compound nuclei from this reaction and to correlate with the observed gamma spectrum. MCNP simulation code is used for the simulation of gamma and neutron dose in the experiment. The high purity germanium detector from M/S EG&G, ORTEC, Oak Ridge, USA, Model MPX20P4 is used for gamma spectrum analysis from the Li projectile on Cu target. The detector has a resolution of 2.0 KeV at 1332 KeV and relative efficiency of 20%. A BC501 liquid scintillation detector of 5cm(ϕ)x5cm (thick) was kept at distance of 1.0m from the target at 30^{0} with respect to the beam. Time of Flight set up is used for the discrimination of neutron and gamma. This detector is shielded with the 9cm wax to minimize the contribution of the scattered neutrons during the experiment.

UNCERTAINTIES IN THE MEASUREMENT

Error or uncertainties in the measurement arises due to different factors including the uncertainty in overall beam current normalization which is estimated ~2%. For rem meters major contribution to error is from the pulsed nature of radiation fields, pile up (a random overlapping of pulses due to multiple events within a spill) can lead to large systematic errors [9]. The overall effect is due to possible underestimation of dose. Another source of error is due to pick up of radiofrequency (RF) pulses generated in accelerator. This is likely to add spurious pulses to the rem meter. Further because of the large size of the rem meter it covers a relatively larger solid angle with respect to beam spot on the target and there can be uncertainty in the positioning of the detector. Divergent and anisotropic nature of the radiation field also adds to the uncertainty in the detector response[10], another possible non-negligible contribution to error is from the background scattered radiation.

RESULTS AND DISCUSSION

In the present work experimentally measured neutron ambient dose equivalents at the specified angles are compared with those calculated by Guo and Sunil [11,6]. Several researchers have developed empirical formalisms to estimate the total neutron dose, angular distribution of neutron dose equivalent and the yield [11-12]. Results shown by other researcher [6] using Clapier empirical relations are underestimated, which is quite un justified in the radiation dosimetry. Hence in the present study the Guo empirical relations are used, which are given as follows.

Formulations of Guo et. al.

Guo et al. has given an empirical relation for the neutron angular dose distribution (μSvh^{-1} PμA^{-1}) at 1 m) as follows :

$$D(\theta) = 2D_{AV}\left[\frac{(1+S)^2}{1+\exp^{S}}\right]\exp(-S\theta) \tag{1}$$

Where θ is defined in radians and S is defined as average center of mass (c.m.) velocity of the projectile while slowing down in the target as follows.

$$S = 0.5 \times \frac{A_b}{(A_b + A_t)} \times \sqrt{\frac{E_b}{A_b}} \tag{2}$$

and D_{AV} is defined in (μSvh^{-1} pμA^{-1} at 1 m for P>0 i.e if the reaction is above Coulomb barrier).

$$D_{AV} = (33.4\,\bar{R}_b\,\bar{R}_t)^2(P+0.35)^2 \tag{3}$$

Values of the parameters $\bar{R}_b$ *and* $\bar{R}_t$ are defined by Guo et al for different Projectile and Target combinations and P is defined as follows.

$$P = \frac{E_b - CB}{A_b} \tag{4}$$

Where E_b is the projectile energy and CB is the coulomb barrier for a specific beam- target combination given by:

$$CB = 1.44 \times \frac{A_t + A_b}{A_t} \times \frac{Z_b Z_t}{\left[1.9 + 1.209\left(A_b^{1/3} + A_t^{1/3}\right)\right]} MeV \tag{5}$$

A_b, Z_b, A_t, Z_t are the mass and atomic numbers of projectile and target respectively.

Guo et al have given a conversion factor to estimate total neutron yield which can by expressed as follows :

$$Y = 1.41 \times 10^{-8}\, D_{AV}\,(\text{proj})^{-1}$$

The neutron dose measured by using Neutron Radiation Detectors (NRD), rem detectors at 0, 30, 60, 90,120 degrees, are given in table.1 along with the calculated empirical relation of Guo [11]. All the results are given as dose rates in units of μSvh^{-1} per particle-nanoampere (pnA), the figures inside parentheses give (C/E) the ratio of calculated and experimental results. The results quoted by Sunil [6], with present work follows the same trend. No empirical relations are used for gamma dose equivalent. The values quoted for gamma dose equivalents are only experimental values and measured at an angle of 90 degree. The total neutron yield per projectile calculated by using the empirical formulae given by Guo is 2.89×10^{-3}, the same value is cross checked with the earlier published results for this projectile and target combination, the present results are in very good agreement with the earlier work [6]. The neutron energy input for the MCNP code is taken from the observed neutron spectrum from the BC501 detector. The observed neutron spectrum measured at angle 30^0 with respect to beam direction is shown in fig.1 and the time of flight spectrum is shown in fig.2. The neutron cumulative dose (mSv) measured by using CR-39 is shown in fig.3, the measured angular distribution is also following the same the trend, with the results of the empirical relations and the REM meters data. The observed gamma spectrum is shown in fig.4, the same is used for the MCNP simulation.

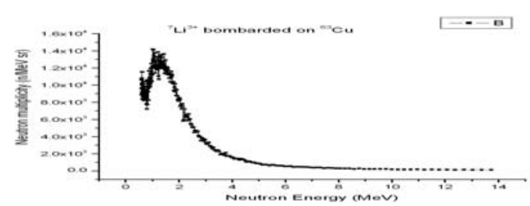

Figure 1 Neutron spectrum obtained with BC501A

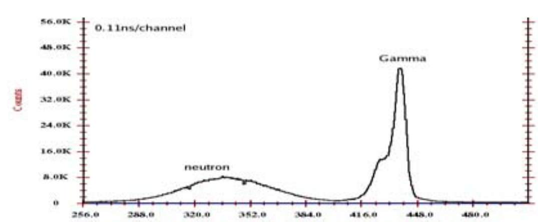

Figure 2 Time of flight spectrum

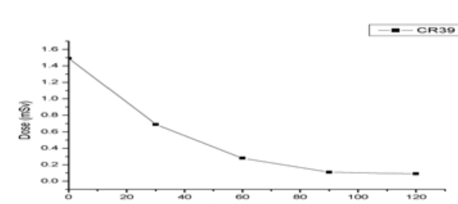

Figure 3 Dose response obtained by using CR-39

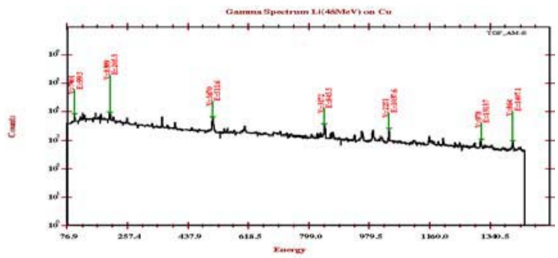

Figure 4 Gamma spectrum obtained by HPGe

MCNP and PACE simulation analysis:

MCNP simulation code is used to simulate the overall surface neutron and gamma dose equivalent, in the same the distributed energy of neutrons is taken assuming neutron as a isotropic source. PACE simulation code is used to cross check the possible cross sections of the nuclear reaction and the same is verified with the obtained gamma spectrum using HPGe-detector. From the PACE reaction cross section and the observed gamma spectrum it is seen that there is a possibility of (2p, 2n), (1p, 3n) and (α) channel reactions. The observed gamma spectrum is also very much useful for the radiation protection point of view for calculating the shielding calculations, etc

Table 1 Neutron Dose experimental values and with empirical relations of Guo at different angles

Lab Angle	**Dose Rate (μSv h^{-1} [pnA^{-1}])**		
	Gamma Expt.	Neutron Dose	
		Experimental REM meter	Calculated $D_{CAL}^{GUO}(\theta)$
0	-	290	245 (0.84)
30	-	242	229 (0.94)
60	-	220	214 (0.97)
90	9	207	199 (0.96)
120	-	193	186 (0.96)

CONCLUSIONS

The angular distribution of neutrons are very much important for the radiation shielding aspects of the accelerator as well it is very much useful to analyze the expected dose received by the radiation workers during the beam on condition in the beam area. Since, measurements are practically impossible for all targets and projectiles at various projectile energies, simple empirical relations are very useful tool for the purpose of first hand information for radiation protection. However, it is always better to have the experimental data as well so this study is done. The overall simulation codes used in this study are also very much useful for radiation protection aspects. This work presents the radiation environment around the heavy ion accelerator facility.

REFERENCES

[1]R. G. Sonkawade, S. P. Lochab, D. Sen, S. K. Datta, “Fast neutron dose equivalent rates for protons in 15UD Pelletron accelerator facility”Radiat. Prot. Dosi. , 1998, Vol 3 & 4, p.178-179.

[2]M. Nandy, T. Bandyopadhya and P. K. Sarkar, “Measurement and analysis of neutron spectra from thick Ta target bombarded by 7.2A MeV ^{16}O ions”, Physical Review C, 2001, 63, p.34610-34616.

[3]M. Nandy, S. Ghosh and P. K. Sarkar, “Angular distribution of preequilibium neutron emission from heavy ion reactions”, Physical Review C, 1999, 60, p.44607-44610.

[4]P. K. Sarkar, T. Bandyopadhya and G. Muthukrishnan, “Neutron production from thick targets bombarded by alpha particles: Experiment and theoretical analysis of neutron energy spectra”, Physical Review C, 1991, 43, p.1855-1860.

[5]B. B. Back, “Radiation Safety at low energy heavy ion accelerators”, Nuclear Instruments and Methods in Physics research B, 1993, 74, p.527-541.

[6] C. Sunil, M. Maiti, M. Nandy, P. K. Sarkar, “Thick target neutron dose evaluation for 19F+Al systems”, Radiat. Prot. Dosi., 2006, p.1-6.

[7] C. Sunil, A. Saxena, R. K. Choudhary, L. M. Pant, “Neutron yield and dose equivalent from heavy ion interactions on thick target”, Nuclear Instruments and Methods in Physics research A, 2004, 534, p.518-530.

[8] J. F. Ziegler, J. P. Biersack, U. Littmark, “The stopping and range of ions in solids” (NY:Pergamon press), 2000.

[9] S. Mayer, N. Golnik, J. KlloEnen, H.G.Menzel, Th. Otto, “Dose equivalent measurements in a strongly pulsed high energy radiation field”, Radiat. Prot. Dosim., 2004, 110, p.759-762.

[10] R. J. Tanner, D. T. Bartlett, L. G. Hager, L. N. Jones, C. Molinos, N. J. Roberts, G. C. Taylor and D. J. Thomas “Modelling of neutron survey instrument performance and experimental validation of those calculated response data”, Radiat. Prot. Dosim., 2005, 116, p.406-410.

[11] Z. Y. Guo, P. T. Allen, G. Doucas, H.R. Mck. Hyder, “Thick target fast neutron yields”, Nuclear Instruments and Methods in Physics research B, 1987, 29, p.500-507.

[12] F. Clapier, C. S. Zaidins, “Neutron dose equivalent rates due to heavy ion beams” Nuclear Instruments and Methods in Physics research, 1983, 217, p.489-494.C.