Measurement and simulation of neutron beam fluence spectra

**M Herbert1, R Nchodu2 and P Maleka3**

1Physics Department University of the Western Cape, Modderdam road, Bellville, 7535, South Africa

2Physics Department University of Cape Town, Rondebosch, Cape Town, 7700, South Africa

3iThemba LABS (Laboratory for Accelerator Based Sceince), PO Box 722, Somerset West 7129, South Africa

msherbert@uwc.ca.za

**Abstract.** This paper reports on work done at the neutron time-of-flight facility at the iThemba LABS in South Africa. Neutron beams of energy up to ~ 64 MeV were produced by bombarding a pulsed beam of 66 MeV protons from the iThemba LABS separated sector cyclotron onto either a Li (1.0 mm) metal target or a Be (10.0 mm) metal target or a graphite (10.0 mm) target. The Li, Be and C neutron beam fluence spectra were measured with an NE213 detector using the time-of-flight technique. The results from the time-of-flight measurements were compared with Monte Carlo simulations using the MCNPX code.

1. **Introduction**

Knowledge of fast neutron beam fluence spectra are of interest in various nuclear applications namely radiotherapy for the treatment of cancer [1]; radiobiology, studying the biological effectiveness of neutrons [2] and radiation protection at nuclear research facilities namely the iThemba LABS. The latter one is of importance because neutron fields encountered around high-energy accelerators like iThemba LABS are characterised by broad spectral distribution ranging from thermal energies to several hundred MeV. Monitoring these neutron fields and determining their fluence spectra pose a challenge for radiation protection [3]. In principle, these fluence spectra can either be calculated by Monte Carlo Methods or measured experimentally [4].

There are a number of difficulties that are involved in carrying out either the calculations or experiments, especially at energies above 20 MeV. One in particular, which limits the accuracy of the predictions of the calculations is the degree to which the required reaction cross-sections are known [5]. This applies particularly to the energy region above 20 MeV where the non-elastic contribution to the reaction cross-section is significant and have either not been measured or are not correctly calculated by present nuclear models. There are a variety of methods that can be used to measure neutron beam fluence spectra [5]. At energies above 20 MeV, the techniques include time-of-flight, recoil spectrometry, threshold (activation or fission) spectrometry and methods based on neutron moderation. Of these methods the time-of-flight is the most accurate and it is widely used for measuring neutron beam fluence spectra.

The purpose of this paper is to report on work done at the neutron time-of-flight facility at the iThemba LABS in South Africa. Neutron beams of energy up to ~ 64 MeV were produced by bombarding a pulsed beam of 66 MeV protons from the iThemba LABS separated sector cyclotron onto either a Li (1.0 mm) metal target or a Be (10.0 mm) metal target or a graphite (10.0 mm) target. The Li, Be and C neutron beam fluence spectra were measured with an NE213 detector using the time-of-flight technique. The results from the time-of-flight measurements and Monte Carlo simulations of the measurements using the MCNPX code are presented, compared and discussed [6].

1. **Experimental procedures and Data analysis**

Experiments were conducted at the neutron time of flight facility at the iThemba LABS in Faure, outside Cape Town, South Africa. Fig. 1 is a schematic diagram showing the details of the beam line in the neutron vault, the shielding in the experimental area and the positions of the detectors including the neutron monitor.



Fig.1: Schematic diagram showing the details of the beam line in the neutron vault. Note the borated blocks are not part of the current neutron vault.

[Type a quote from the document or the summary of an interesting point. You can position the text box anywhere in the document. Use the Text Box Tools tab to change the formatting of the pull quote text box.]

Neutrons were produced by bombarding either a Li metal target (thickness 1 mm) or a Be metal target (thickness 10 mm) or a graphite target (thickness 10 mm) with a pulsed beam of 66 MeV protons from the iThemba LABS separated sector cyclotron. A 2 m thick shielding wall (concrete and iron) separated the experimental area from the target. A circular aperture (25 mm diameter) in the wall provided a collimated neutron beam at angle 0º to the proton beam direction. The neutron beam profile measured at the end of the neutron flight path of 7.7 was found to be uniform within 5% over a circular area of diameter 50 mm. Measurements of the neutron beams were taken with an NE213 liquid scintillator of 25 mm diameter x 25 mm at a distance of 7.7 m away from the target. The NE213 scintillator was equipped with a LINK pulse shape discriminator to suppress gamma rays and to select only events such as n-p elastic scattering or all heavier particles resulting from neutron interaction in the scintillator [7].

The neutron energy spectra for the respective targets were obtained in the offline analysis from the measurements of time-of-flight, T and pulse height, L by the NE213 detector as follows. The neutron energy was determined from T. This information with T and L measurements were used to determine the neutron detection efficiency of the NE213 detector as a function of neutron energy with reference to the n-p elastic scattering cross-section as described by Brooks and Klein [5]. The neutron detection efficiency of the NE213 detector was determined for 31 equally spaced 2 MeV neutron energies ranging from 6 MeV to 66 MeV. The response functions of the NE 213 detector were determined at each one of the 31 neutron energies from the data from each target. From each one of response functions the number of n-p elastic scattering events corresponding to each one of the 31 neutron energies was determined. The ratio of the number n-p elastic scattering events at energy E to the neutron detection efficiency at E give the number of neutrons at E measured in the detector relative to the n-p elastic scattering cross-section at E. The number of neutrons incident on the detector for each one of the neutron energies was determined in this manner for each one of the experimental measurements. The neutron fleunce for the beam of each target is given by the ratios of numbers of neutrons measured at each one of the energies to the area of the NE213 detector.

The measurements carried out in this work were simulated using the Monte Carlo code MCNPX. The Monte Carlo code MCNPX is widely used in nuclear physics for simulating the transport of particles through matter. MCNPX describes the physics of the nuclear interactions that take place by using: (a) evaluated nuclear data libraries or (b) various physics models, including intranuclear cascade models [8] where libraries are not available [9]. In this work the simulations were carried out in two stages. First, the proton transport through the beam line onto the target was carried out and the neutrons produced were calculated at a position 10 cm along the 0 degree beam line from the target. In these simulations the proton beam was modelled as a pencil beam. In the second stage the neutrons produced were transported along the 0 degree line to the position of the NE213 detector in the vault at 7.7 m.

1. **Results and discussion**

The neutron fluence spectra measured are compared to the predictions of Monte Carlo calculations using the code. To facilitate comparison between the spectra, the integral fluence of each calculated spectra were normalised to the same integral fleunce as that of its corresponding measured spectra. The results obtained are display in Figure 2 (a) – (c). The solid line histograms indicate the measurements obtained from time-of-flight with the NE213 scintillator detector while the dotted line histograms are the results from the MCNPX Monte Carlo code.

Overall the Monte Carlo calculations reproduce all the main features in the measured spectra, namely the peaks in the measured spectra as well as the shape of the measured spectra. The agreement between the calculated and measured spectra of the Be- and C targets are better than the agreement between calculated and measured spectra of the Li-target. The disagreements observed between the calculated and measured spectra might be as a result of how the proton beam and the target thickness was modelled in the Monte Carlo calculations. The above will be investigated in future. However, overall the research indicates that the Monte Carlo calculations and measurements agree well. Hence, the Monte Carlo code MCNPX is a viable way to predict neutron fleunce of neutron fields encountered around high-energy accelerators like iThemba LABS.



1. **References**

[1] Herbert M 2009. *Determination of neutron energy spectra inside a water phantom irradiated by neutrons of energy up to 64 MeV*. PhD Thesis, Unpublished, University of Cape Town.

[2] Nolte R, Mhlbradt K, Meulders J, Stephan G, Haney M and Schmid E. *RBE of Quasi-monoenergetic 60 MeV Neutron Radiation for the Induction of Dicentric Chromosomes in Human Lymphocytes.* Radiation and environmental biophysics, **44**(3), 201-209.

[3] Taniguchi S, Nakamura T, Nunomiya T, Iwase H, Yonai S, Sasaki S, Rokni S, Liu, J, Kase K and Roesler S 2003. ........ Nuc.Instru. and Meth **A503**, 595

[4] Bohm T, Deluca P, Cox L, Maughan R, Jones D and Lennox A 1999. *Monte Carlo calculations to characterize the source for neutron therapy facilities*. Med. Phys. **26,** 783-792.

 [5] Brooks F and Klein H 2002, *Neutron spectrometry- historical review and present status*, Nucl. Instr. Meth. **A476,** 1-1.

[6] Hughes H, Prael R and Little R 1997. *MCNPX- The LAHET/MCNP code merge*. X- Division research note XTM-RN(U) 97-012, LA-UR- 97- 4891, Los Alamos National Laboratory.

[7] Adams J and White G 1978. *A versatile pulse shapes discriminator for charge particle separation and its application to fast neutron time of flight spectroscopy*. Nucl. Instr. and Meth, **156,** 459-476.

[8] Bertini H 1969, *Intranuclear-cascade calculation of the secondary nucleon spectra from nucleon-nucleus interactions in the energy range 340 to 2900 MeV and comparison with experiment*. Phys. Rev **188**, 1711-1730.

[9] Rose P 1991, *ENDF-201: ENDF/B-VI Summary Documantation.* Report BNL-NCS-17541, Brookhaven National Laboratory.