Calibration of TOF Detectors Using Short Laser Pulse Generated Neutron Source

Contact: *s.kar@qub.ac.uk

S. R. Mirfayzi, S. Kar*, H. Ahmed, A. Green, A. Alejo, D. Jung, M. Zepf, M. Borghesi
Centre for Plasma Physics,
Queen's University Belfast,
BT7 1NN, United Kingdom

A.G. Krygier, R.R. Freeman
Department of Physics,
The Ohio State University,
Columbus, Ohio 43210, USA

R. Clarke, J.S. Green, P. Norreys, M. Notley
Central Laser Facility,
Rutherford Appleton Laboratory,
Didcot, Oxfordshire, OX11 0QX, UK

J. Fuchs, L. Vassura
LULI, Ecole Polytechnique, CNRS,
Route de Saclay, 91128 Palaiseau Cedex,France

A. Kleinschmidt, M. Roth
Institut für Kernphysik,
Technische Universität Darmstadt,
Schloßgartenstrasse 9, D-64289 Darmstadt, Germany

J.T. Morrison
Propulsion Systems Directorate,
Air Force Research Lab,
Wright Patterson Air Force Base, Ohio 45433, USA

Z. Najmudin, H. Nakamura
Blackett Laboratory, Department of Physics,
Imperial College,
London SW7 2AZ, UK

M. Oliver
Department of Physics,
University of Oxford,
Oxford, OX1 3PU, UK

1 Introduction

In a fusion experiment, whether inertially or magnetically confined, measurement of the yield and the energy spectrum of the neutrons are the crucial steps to estimate the fusion power and plasma temperature [1, 2]. Since laser-driven neutron sources are primarily based on beam-fusion or spallation reactions, measurement of absolute neutron spectrum is crucial not only for the development and optimisation of the neutron sources, but also for the study of the parent ions involved in neutron generation process.

Among commonly used neutron diagnostics, those based on time-of-flight (TOF) arrangement are probably the most widely used for characterising the neutron spectra. Depending on the distance between the source and the detector, a TOF spectrometer can in principle resolve neutron energies ranging from sub-MeV to hundreds of MeV. However, the most unique feature of a TOF scintillator detector lies in the capability to provide an absolute spectral measurements of fast neutrons. Here we report on the calibration of TOF detectors using an ultra-short burst of neutrons, which enables energy resolved calibration of the detector by deploying in a TOF mode. The burst of neutrons was produced by DD reactions driven by ultraintense laser pulse. The calibration of the TOF detectors were obtained against an absolutely calibrated bubble detector spectrometers (BDS) fielded in the same shots.

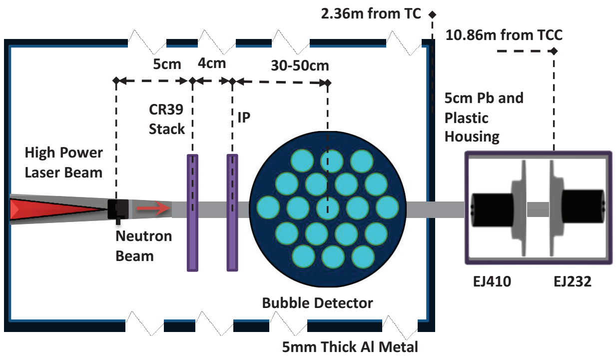

Figure 1: Schematic of experimental setup. The neutron beam generated by the laser-target interaction propagates through various diagnostics before reaching the scintillator detectors placed outside the interaction chamber.

2 Experimental Setup

Calibration of the scintillator detectors was carried out using a laser driven neutron beam generated at the VULCAN Petawatt target area. The 750fs FWHM laser pulse of Vulcan, with energy of 600J, was focused on the target by a f/3 off-axis parabola delivering intensity in excess of $10^{20} W cm^2$. Energetic neutrons were produced by irradiating the laser on to deuterated plastic foils of various thickness. A suite of diagnostics, such as scintillator TOF, bubble detector, activation and CR39 stacks, were employed around the target in order to characterize the neutron beam parameters. Schematic of a typical experimental setup used for cross-calibrating the scintillator detectors with the bubble detectors is shown in Fig. 1. The bubble detectors, manufactured and calibrated by BTI Bubble technology industries[3] were placed inside the interaction chamber at various distances (30-50 cm) from the neutron source in order to ensure sufficient bubble formation. The scintillator detectors were placed outside the interaction chamber at a significantly larger distance from the neutron source in order to achieve high energy resolution by the TOF technique. The scintillators were shielded appropriately by lead and plastic blocks in order to reduce the noise level due to gamma rays and thermal neutrons hitting the scintillators. Two one-meter long plastic collimators were used along the line of sight of the scintillators in order to reduce stray neutrons hitting the detector.

The three plastic scintillaors discussed in this paper are EJ232Q[4], BC422Q[8] and EJ410[4]. Where EJ232Q and BC422Q have fast rise and decay times (sub ns and a few ns respectively), EJ410 has a significantly slower decay of 200 ns. Each scintillator was coupled with fast PMT tubes for converting the light output from the scintillator into electrical signal as well as to amplify the signal for detection. The gain of PMT was controlled by varying the biasing voltage shot to shot in order to avoid signal saturation. The detectors were attached to fast (6GHz) oscilloscopes for recording the output from the PMTs.

3 Results

Scintillators used in TOF diagnostic mode are used with fast photo-multiplier tubes in order to convert the optical photons from the scintillator into electrical signal with a gain commensurate to the applied bias voltage. The gain characteristics of the PMTs are calibrated precisely by the manufacturers, and these can be used together with the neutron detection efficiency of the scintillator to obtain a neutron spectrum from the raw data recorded by the oscilloscope.

Fast neutron detection efficiency of a plastic scintillator depends on several factors. The dominant mechanism for production of secondary ionising radiation for incident neutron energy upto a few 10s of MeV is the proton recoil based on elastic n-p scattering. As neutrons of a given energy pass through the scintillator, they produce a spectrum of recoiled protons by direct elastic scattering with hydrogen atoms present inside the material. Each recoiled protons then produce scintillation while traveling inside the scintillator, which can be calculated by using Chou's[6] and Wright's[7] semi-empirical formulae. Since the neutron detection efficiency of the EJ232Q and BC422Q detectors was not provided by the manufacturers, we used a simple model based on the scintillation mechanism mentioned above to estimate the detector efficiency curve. First the energy spectrum of recoiled protons produced by neutrons in scintillator plastic was obtained by employing FLUKA[8] simulations. The next step of calculation involves finding the energy deposition profile of each recoiled protons in the scintillation material, and calculating scintillation light output from each recoiled protons using Chou's and Wright's semi-empirical formulae. Finally, the detection efficiency of the scintillator for a given neutron energy is obtained numerically by convolving the spectrum of the recoiled protons.

In order to cross-calibrate the scintillator detectors against the data obtained in the BDS, it is also important to assess the transmission and scattering of neutrons by the various objects they encounter, along the scintillators' line of sight including the BDS. Since the scintillators are placed at a significantly large distance ($\sim$ 10 meter) from the BDS, any small angle scattering of neutrons by the intermediate objects would prohibit the scattered neutron from reaching the scintillator detector. On this basis, the neutron propagation through the system was simulated using FLUKA in order to estimate transmission to the detector as a function of neutron energy.

A typical data set is shown in fig. 2(a) where the neutron spectra obtained from EJ232Q and EJ410 scintillators are shown in comparison with the spectrum obtained by BDS, after applying a constant factor in order to match the neutron flux with that measured by the BDS. One can see a good agreement between the spectra, not only in terms of integrated neutron numbers, but also in terms of the spectral shape, which remains fairly consistent.

The comparison between neutron flux obtained in different scintillators with the one measured absolutely by the BDS over a number of shots taken in the experiment is shown in figure 2(b). In this case we have chosen the high energy range (2.5-20 MeV) for flux comparison in order to avoid discrepancies due to the down-scattered (lower energy) neutrons detected by the BDS, which is a time integrated spectrometer. As can be seen from the fig. 2(b), the data points follow a linear trend over a range of neutron fluxes, the slope of which can be used as the final calibration factor for the scintillators.

4 Conclusion

Employing a sub-ns neutron source driven by high power laser and absolutely calibrated, gamma-insensitive bubble detector spectrometers, we have carried out the systematic calibration of three types of plastic scintillators namely EJ232Q, BC422Q and EJ410. Over a number of shots, spanning over a wide range of neutron fluxes between $10^8 - 10^{10}$ n/Sr for 2.5-20 MeV neutrons, the comparison between the results obtained from the TOF data analysis and the BDS data follows a linear fit, which provides the final calibration factor for the scintillators.

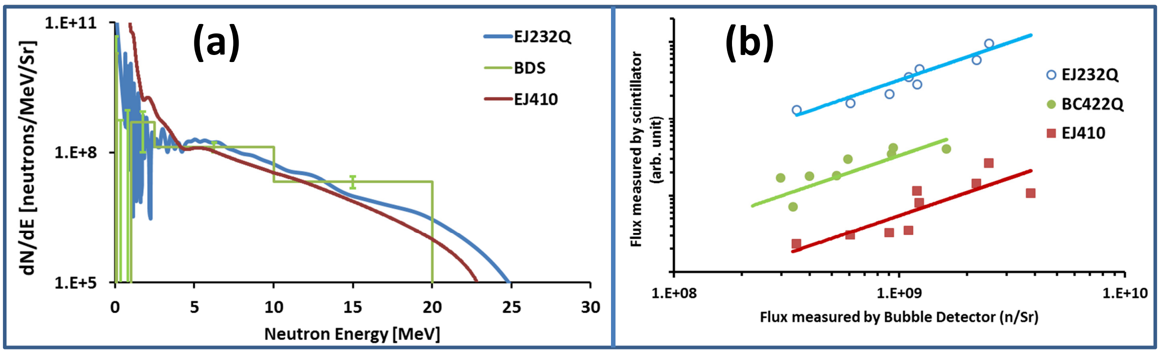

Figure 2: **(a)** Calibrated neutron spectra obtained from EJ232Q and EJ410 detectors compared with spectrum obtained by BDS in the same shot. **(b)** Comparison between neutron flux obtained from different scintillator detectors and the BDS for neutron energy in the range 2.5-20 MeV. The graph plots the comparison for three different scintillator detectors, EJ232Q, BC422Q and EJ410, obtained over a number of shots. The solid lines show linear fits to the data points.

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