Development progress of Tagged Neutron System with multiple γ-detectors

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Introduction

Tagged neutron method (TNM) is an advanced and sophisticated nuclear technique having wide applications in the field of basic and applied nuclear research. For example, studies of nuclear physics reactions (n, n), (n, n' γ), (n, 2n), (n, f) induced by 14.1 MeV neutrons, cross-section measurement, soil carbon measurement, illicit material detection based on elemental signatures, etc. [1]. TNM is based on inelastic scattering of fast neutrons on interaction with nuclei of the inspected sample and registering the accompanied characteristic gamma radiation. The emitted neutrons (^{2}D + ^{3}T = α + n) from the D-T neutron generator (D-T NG), incident on an object, are "tagged" by means of a coincidence measurement of the associated alpha particle. The neutrons are tagged in their emission time and direction. The emitted characteristic gamma rays are utilized to analyze the elemental composition of the inspected object. Carbon, oxygen, and nitrogen elements are mainly of interest, as these are the major elements constituting explosives or narcotics. Discrimination between threat and commonly used benign materials is consequently made by measuring relevant elemental ratios such as C/O, N/O. This interrogation technique has been realized at lab scale, and a prototype TNM system has been developed. Proof of concept and methodology has been demonstrated via experiments [1]. Further, development of a full-fledged experimental facility or an inspection system for field application demands more challenging requirements. One of them is the multiple gamma detectors to have sufficient counting statistics in short data acquisition duration. In this direction, a set of 12 BGO gamma detectors, each of size 3-inch x 3-inch, were installed with proper shielding. This paper highlights the development progress of the tagged neutron system with 12 gamma detectors. It includes characterization of gamma detector shielding, tagged neutron beam profile, etc. Also initial experimental results demonstrating analysis of different regions of 3D volume via time window selection has been performed.

Experimental Setup

The TNM system mainly consists of a multi-pixel (8 x 8) alpha detector incorporated inside D-T NG for alpha detection, a gamma detector set placed in backscattered geometry for gamma detection, a VME-based data acquisition (DAQ), etc. More details are available in [1].

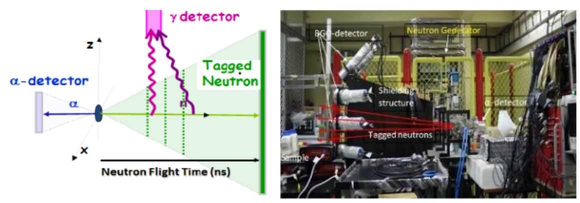

Fig. 1 (Left) Schematic of TNM and (right) Lab-based TNM system with multiple γ-detectors

Energy and Time Resolution of γ-detectors

Energy resolution is a crucial parameter in all kinds of spectroscopic measurements. It becomes even more important if the detection energy region is ~ 200 KeV to 10 MeV. It is because in high-energy gamma, energy spectra get spoiled by escape peaks and result in a complex spectrum. Energy resolutions of the BGO's were measured over a wide energy range up to 4.44 MeV using gamma sources (Na^{22}, Cs^{137}) and an Am-Be source. Measured energy resolutions are presented in Fig. 2. All detectors except one (BGO30) have shown the resolution ~7.7 - 8.0% at 1173 KeV and 5.3-5.5% at 4.44 MeV. BGO30 has resolution 12% lower w.r.t. others.

Timing resolution of the detection setup is vital for the time-of-flight technique applied in the TNM system, which enables defining the position of the inspected volume. Time resolutions of BGO's were measured using a 2-inch x 2-inch plastic scintillator as a reference detector. It was placed at a distance of 16 cm from the BGO, and the time spectrum of n-γ coincidences in the Am-Be was measured. The time peak was Gaussian fitted, and the time resolution (FWHM) evaluated (Fig. 2.) was of ~ 3.54 - 3.84 ns.

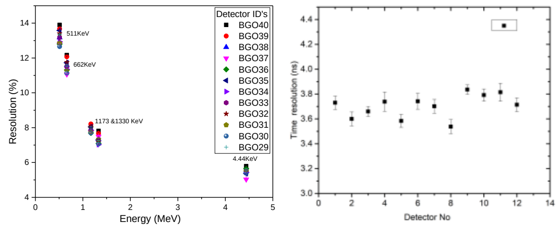

Fig. 2 (Left) Energy and (right) Time resolution at different energies for different detectors

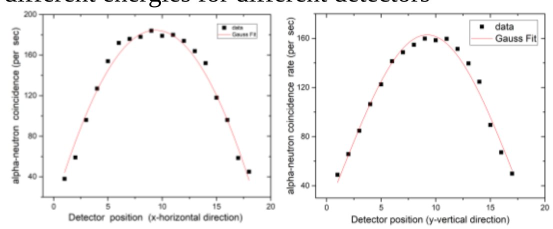

Fig. 3 Tagged neutron beam profile in (left) horizontal and (right) vertical directions

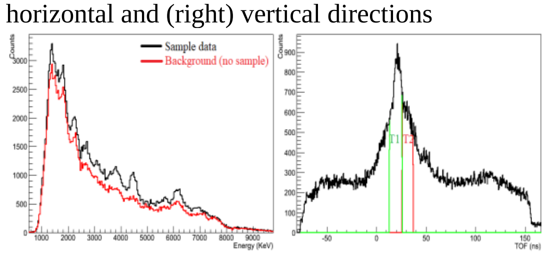

Fig. 4 (Left) Energy and (right) time spectra of sample ('water + graphite') with background (red)

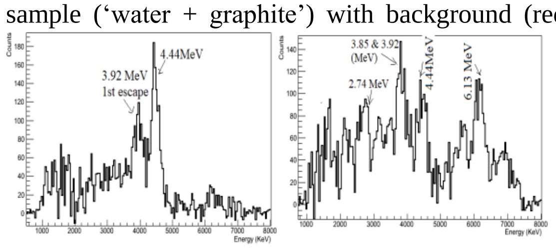

Fig. 5 Correlated energy spectra of carbon and oxygen corresponding to window 'T1' and 'T2'

Detectors and Tagged neutron profile

In order to protect gamma detectors from direct or scattered neutrons, a shielding structure of trapezoidal shape was designed. It is 70 cm long with walls of 3 inches thick, and at the end detectors are mounted on an iron frame arranged in a square way, oriented at a 45-degree angle (Fig. 1). It is made up of iron, borated high-density polyethylene, and lead blocks, placed close to the neutron source at 90º w.r.t. the d^+ ion beam and opposite to the alpha detector. Now, to ensure that detectors are positioned outside the tagged neutron beam, the profile of the tagged neutron beam was scanned by the n-α coincidence experiment. A neutron detector placed at 140 cm from the neutron source and α-γ coincidence rate was recorded, varying the neutron detector's position in horizontal as well as vertical directions in steps of 5 cm (Fig. 3). At an alpha count rate of ~ 200 kHz, the maximum coincidence rate was around ~ 180 Hz. From the plot (Fig. 3) of coincidence rate vs. detector positions, the tagged beam size (FWHM) obtained was ~ 62 cm ± 2 cm, and detectors were positioned accordingly.

Sample spectra

After a series of tests and identifying tagged neutron beam location, experiments with samples were performed for testing of system performance. Elemental responses of carbon and oxygen with 14 MeV neutrons were obtained using graphite and water samples respectively. Energy and time spectra were acquired via α-γ coincidence with and without samples. The time spectrum was used to identify the components of background, sample, and scattered neutron contribution. Finally, a sample configuration of water plus graphite was studied. In this, water and graphite sample were placed together inline at a separation of 45 cm. Energy and time spectra of this configuration are shown in Fig. 4. Data analysis performed via different time window (T1, T2) selection and then respective background subtraction. The resulted correlated energy spectra are shown in Fig. 5. The energy spectra corresponding to the time windows "T1" and "T2" indicate clearly the gamma signatures [2] of carbon and oxygen elements separately, confirming the presence of water and graphite samples in different regions (Fig. 5).

Conclusions

Development progress of the lab-based tagged neutron system with a set of gamma detectors presented. Energy and time characterization of the gamma detector set was carried out. Elemental responses of C and O were acquired for system performance. In addition to that, tagged neutron beam profile measurement, shielding design, and position determination of the inspected volume using energy and time spectra were performed.

References

[1] Bishnoi S et al., Modeling of tagged neutron method for explosive detection using GEANT4, Nuclear Inst. and Methods in Phy. Res., A 923 (2019) 26-33.

[2] Eleon C et. al., Experimental and simulated gamma ray spectra for the UNCOSS neutron based explosive detector, Nucl. Inst. Methods in Phys Res A 629 (2011) 220-229.