Feasibility studies of doing NRTA measurements using an AmBe neutron source

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I. ABSTRACT

In this work a new approach for Neutron Resonance Transmission Analysis (NRTA) experiments is explored which forgoes a pulsed source for neutron generation and instead uses an isotopic neutron source such as americium beryllium (AmBe) or ^{252}Cf. This would make the experimental setup compact and mobile and would allow for on-site material identification having applications in the field of nuclear safeguards and security. In other NRTA experiments a pulsed neutron beam is required for providing a time reference to calculate the time-of-flight of neutrons. Instead, the setup proposed in this study uses an active moderator-detector for providing the reference time signal. A liquid scintillator detector acts as a moderator with hydrogenous material to reduce the energy of the neutrons emitted while also providing the start time of the time-of-flight. Energy of the transmitted epithermal neutrons is provided by the time-of-flight measurement between the moderator-detector and a ^{6}Li-doped GS20 disk. Experimental geometry and first set of experimental results obtained for a Ag target are presented in this report. These results provide a proof-of-concept, and will inform future experimental measurements.

II. INTRODUCTION

The Incident and Trafficking Database (ITDB) [1] of the International Atomic Energy Agency (IAEA) is an essential component of its Nuclear Security Plan [2], established with the aim of preventing the malicious use of special nuclear material. According to the recent report, out of 3928 total reported incidents, 320 were aimed at the illicit use of sensitive nuclear isotopes, which could be dangerous if not detected and prevented. IAEA states that "effective border control measures help to detect illicit trafficking, even though effective controls are not uniformly implemented at all international border points. A part of the problem is the availability of techniques/equipment capable of material identification and the financial burden of deploying them at border areas". In order to facilitate better border control measures, a recent study demonstrated how a well-established Neutron Resonance Transmission Analysis (NRTA) method could be done using a portable, commercially available Deuterium-Tritium (DT) neutron generator [3]. NRTA is a non-destructive and isotope sensitive technique that relies on unique neutron-capture resonance signatures for differentiating between isotopes of an element [4–14]. Therefore, this method is an effective approach for identification and enrichment analysis of the fissionable isotopes of uranium and plutonium all having capture resonances in the epithermal energy range of 1-100 eV [15]. A mobile and portable NRTA setup studied in Ref. [3] having capability of performing isotope identification is highly attractive for applications in the field of nuclear safeguards and security. Such experimental innovations ensure the widespread use of a powerful technique that was otherwise limited by the availability of beam times at large neutron facilities dedicated for neutron time-of-flight (TOF) measurements. The present work aims at building and testing a similar neutron TOF setup for doing NRTA with an isotopic neutron source. This experimental concept explores the possibility of replacing pulsed generators with sources such as americium-beryllium (AmBe) or ^{252}Cf for neutron generation. The major impact would be on the portability and price

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of the final setup. Since isotropic neutron sources are easily available at nuclear laboratories, this setup can be adopted at multiple places for enhanced accessibility and it greatly reduces the footprint of such experiments.

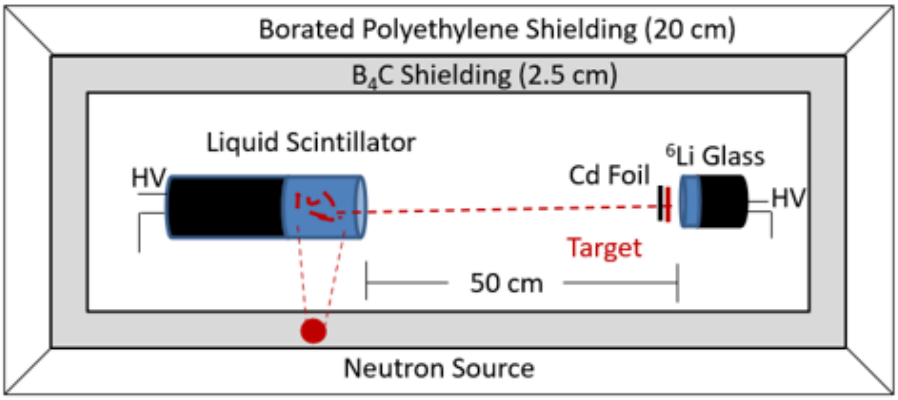

FIG. 1. A schematic of the experimental setup taken from Ref. [16]. The AmBe neutron source is embedded in a layer of 20-cm thick borated polyethylene followed by a 2.5-cm thick B_4C layer. The fast neutrons are incident on a liquid scintillator also used as a moderator to reduce the energy of the neutrons. Moderated beam is incident on a target and detected in a 1-cm thick ^{6}Li-enriched GS20 glass scintillator coupled to a photomultiplier tube. The detector is shielded from off-axis epithermal neutrons by boron carbide. Thermal neutrons are filtered by 3.0 mm cadmium foil placed in front of the GS20 detector. Time-of-flight distance between the liquid scintillator and GS20 glass detector is 50 cm.

III. EXPERIMENTAL SETUP

The NRTA experimental concept involves measuring TOF of epithermal neutrons transmitted through a target or material being investigated. The TOF information is then used to extract the kinetic energy of neutrons. Since, most of the isotopic neutron sources emit fast neutrons and the discrete capture resonances in the fissionable isotopes are in epithermal energy range, the first step in the present experiment is to moderate the neutrons. These slowed-down neutrons are captured by the nuclei in the target and the transmitted neutron energy spectrum consists of characteristic dips at energies corresponding to resonances in different isotopes. Analyzing the resonance patterns provide isotopic composition of the target.

In the current setup, coincidences are measured between two neutron-sensitive detectors to provide TOF. Start of the time-of-flight is provided by a 10.5" X 4" X 10.5" liquid scintillator and the stop is given by a 1-cm thick, 12.7-cm wide, ^{6}Li-doped GS20 detector. Distance between the two detectors is 50 cm resulting in a time-of-flight $\sim$ 100 μs for a 1 eV neutron travelling on axis. Therefore, observing a true correlation of neutron signals in two detectors enforces a limit on the activity of the source that can be used without significantly introducing the false neutron coincidences in TOF spectra. The AmBe source faces the liquid scintillator which also acts as a moderator to reduce the energy of $\sim$ 3 MeV neutrons down to $\sim$ eV range. The epithermal neutrons travelling on axis pass through a 3-mm thick Cd foil and the target to be investigated before getting detected in the GS20 detector. Cd foil acts as a thermal neutron filter and the off-axis epithermal neutrons are absorbed by B_4C shielding surrounding the GS20 detector. Both thermal and off-axis neutrons show up as background contributions in NRTA spectra. The whole setup was placed inside an aluminium box shielded by a 2.5-cm thick boron carbide layer and 20-cm thick borated polyethylene slabs. The outer layer ensures that the fast neutrons scattered by surroundings get moderated by polyethylene and absorbed by boron thus reducing the interference from room returns considerably. In a previous report [16], studies of this experimental concept were discussed through GEANT4 based grasshopper simulations of the full setup [17]. NRTA spectra for W and Ag targets were simulated for different AmBe source activities to understand the effect of false coincidences on background contributions. Preliminary results presented confidence on feasibility of the experiments. This study

focuses on the results obtained from the first set of experiments done using the setup discussed above and shown in Fig. 1.

IV. RESULTS

The TOF spectrum obtained for a 0.25-mm thick Ag target is presented in Fig. 2. For comparison, an open-beam (no-target) spectrum is overlayed on Ag curve. Data was collected for 40 hours. A shallow dip is observed at 17.8 µs corresponding to 5.19-eV resonance line in ^{109}Ag. This confirms that the experimental concept works however, for unambiguous identification of different isotopes the resonance dips should be more pronounced and the signal to background ratio should be improved.

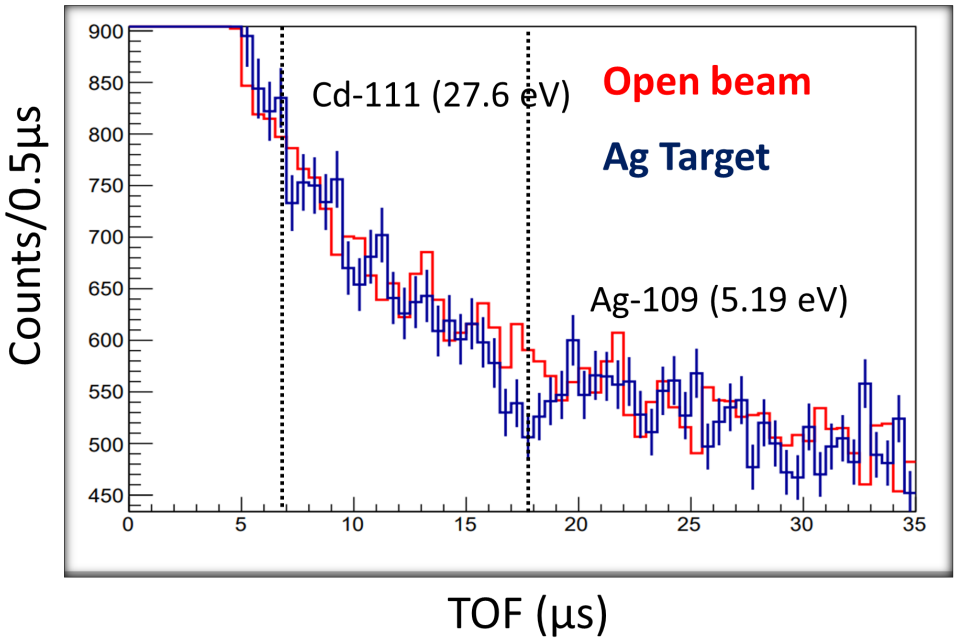

FIG. 2. Neutron transmission for a 0.25-mm thick Ag target with an AmBe neutron source. An open-beam run with no target in front of GS20 detector is also shown for comparison. Data was collected for 40 hours. The shallow dip at 17.8 μs is from the 5.19-eV resonance line in ^{109}Ag. A 3-mm thick Cd foil is also placed along with the Ag target to absorb thermal neutrons and a small resonance dip at 27.6 eV can be observed from ^{111}Cd.

The AmBe neutron source emits both neutrons and gammas and the liquid scintillator and GS20 detector are also detecting gamma radiations along with the neutrons. Therefore, to understand the background in the TOF spectrum, pulse shape discrimination data from liquid scintillator and energy data from GS20 detector were further analyzed.

There are 4 different types of coincidences measured in our setup, these are: n_0-n_1, n_0-γ_1, γ_0-n_1, and γ_0-γ_1. The subscript here denotes the detector in which the event is detected, with n_0 being a neutron detected in liquid scintillator and n_1 being a neutron signal in GS20 detector. Pulse shape analysis methods for liquid scintillators are pretty well established and gamma rays can be very well distinguished from fast neutrons. Therefore, selecting only the fast neutrons in liquid scintillator helps in removing 3rd and 4th components that are false coincidences. For reducing the false neutron-neutron coincidences in first component, a weaker source can be used but that also results in longer measurement times. So a detailed experimental study is planned for finding a balance between acceptable rate of false coincidences for identifying the resonances unambiguously and obtaining fast measurement times. After investigating

the room background spectrum in GS20 detector we came to the conclusion that the main background contribution in TOF data comes from the unwanted n_0-γ_1 coincidences. Gammas radiations detected in GS20 detector come from the room environment and get falsely correlated with neutron signals in liquid scintillator. Since these are long measurements, the n_0-γ_1 component shows up as the majority background contributor. The GS20 disk has some neutron-gamma discrimination capability for gamma energies below 1.6 MeV but above that gammas contaminate the neutron signal significantly [18]. In Fig. 3, the room background data taken for 40 hours without any source in the vicinity of the GS20 detector is compared with a similar spectrum taken with an AmBe source placed in front of the moderator thus producing epithermal neutrons. It is evident that the small epithermal neutron peak sits on top of a huge gamma continuum from room environment. Using a thinner GS20 detector might result in a better discrimination on the basis of light collection and interaction mechanism of the photons and neutrons.

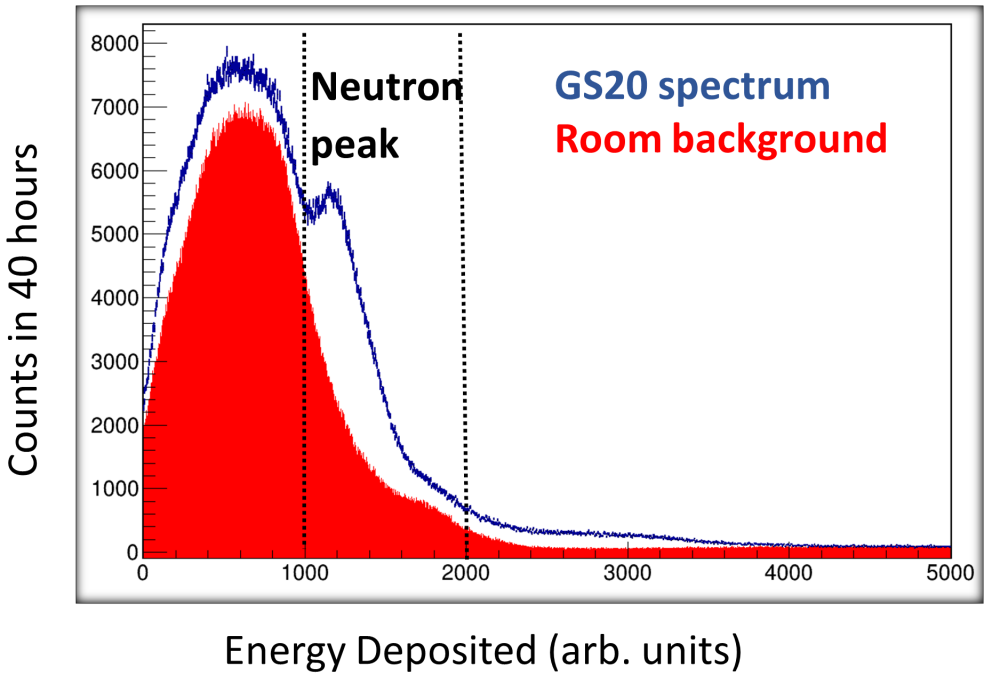

FIG. 3. The energy spectrum collected for 40 hours from GS20 detector. Curve shown in blue is with an AmBe source producing neutrons whereas the red solid curve is room background. The epithermal neutron peak sits on top of a huge gamma continuum that forms the majority background contributor in the resulting TOF spectrum.

V. CONCLUSION

In conclusion, a new concept for NRTA, time-of-flight measurements using an isotopic neutron source for identification of materials was tested experimentally. The preliminary results for a Ag target indicate the presence of a shallow dip at the right resonance energy. Improvements in the signal to background ratio are required for a clear isotope identification analysis. Experimental results presented in this report corroborate the idea that a compact and mobile NRTA setup could be built to do table-top experiments for material identification which would allow for practical applications in the field of nuclear security and safeguards.

Future work will focus on doing the experiments with a thinner GS20 detector to achieve a better neutron-gamma discrimination important for reducing the false neutron-gamma coincidences contaminating the NRTA TOF spectrum.

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