



Performance of the Versatile Array of Neutron Detectors at Low Energy (VANDLE)



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ABSTRACT

The Versatile Array of Neutron Detectors at Low Energy (VANDLE) is a new, highly efficient plastic-scintillator array constructed for decay and transfer reaction experimental setups that require neutron detection. The versatile and modular design allows for customizable experimental setups including beta-delayed neutron spectroscopy and (d,n) transfer reactions in normal and inverse kinematics. The neutron energy and prompt-photon discrimination is determined through the time of flight technique. Fully digital data acquisition electronics and integrated triggering logic enables some VANDLE modules to achieve an intrinsic efficiency over 70% for 300-keV neutrons, measured through two different methods. A custom GEANT4 simulation models aspects of the detector array and the experimental setups to determine efficiency and detector response. A low detection threshold, due to the trigger logic and digitizing data acquisition, allowed us to measure the light-yield response curve from elastically scattered carbon nuclei inside the scintillating plastic from incident neutrons with kinetic energies below 2 MeV.

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1. Introduction

Neutron detection is increasingly necessary in modern nuclear physics experiments. Advancements in radioactive beams have made available for studying more neutron-rich nuclei, where delayed neutron emission will increasingly dominate beta decay [1]. Furthermore, inverse-kinematic transfer reactions such as (d,n) can probe structure that are not easily studied otherwise. The Versatile Array of Neutron Detectors at Low Energy, VANDLE, facilitates such experiments.

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VANDLE [2,3] has similarities to other existing detector arrays such as: TONneau pour NEutrons RETardes (TONNERRE) [4] at the Grand Accélérateur National d'Ions Lourds (GANIL) in France; the Modular Neutron Array (MoNA) [5,6], the beta decay neutron detector [7], and the Low Energy Neutron Detector Array (LENDA) [8,9] at the National Superconducting Cyclotron Laboratory in Michigan; the Large Area Neutron Detector [10] at GSI in Germany; the neutron wall at the Institute of Physical and Chemical Research (RIKEN) in Japan [11]; and the neutron wall [12] at the University of Notre Dame. Improvements are achieved by optimizing materials and design, and by using digital signal processing. VANDLE incorporates three sizes of detector modules so that an experimental setup can be customized and tailored to meet geometric and efficiency requirements.

Some neutron reactions within detectors such as these are considered “dark” and do not induce a detectable amount of light.

These may be followed by an event that induces a measurable amount of light within the detector (or in a different detector), thereby creating false position and timing for those events. For many scintillator detectors, neutron scattering off carbon nuclei is a strong source of dark reactions. While it is nearly impossible to eliminate false triggering following dark reactions, by running with the lowest possible threshold they are minimized because fewer events are missed. Section 3 discusses how we get VANDLE's detection threshold as low as possible. Section 6 details VANDLE's sensitivity to these carbon-scattering events, reducing the amount of dark events in our data. We also present the light-yield response curve for recoil carbon nuclei within the bulk scintillator material. The design motivations and capabilities of VANDLE are discussed in Sections 2–5. Results from efficiency and resolution measurements as well as comparisons with a custom Monte Carlo simulation are reported in Sections 7 and 8. Section 9 outlines various experimental programs for which VANDLE is used.

2. Design

Arrays of neutron detectors must have good timing characteristics when used in experiments where the neutron energy is determined via time-of-flight (TOF). Typically scintillators are coupled to photo-multiplier tubes (PMTs). To achieve higher intrinsic efficiency, the detector should be thick to expose each neutron to more material with which to interact. Unfortunately, thicker materials degrade the resolution of the path length and reduce the resolution of the measured energy (see Eq. 10 of [13]). The resolution of the flight path is mostly due to the thickness of the bar surface facing the target. This is the first value listed when quoting the dimensions of a VANDLE bar. The full resolution of the flight path also includes the longitudinal position resolution along the bar's axis, which is dependent on the TOF resolution, and is discussed in more detail in Section 4.1.

VANDLE is comprised of three different sized scintillating detector modules with scintillator material dimensions of, $3 \times 3 \times 60 \text{ cm}^3$, $3 \times 6 \times 120 \text{ cm}^3$, and $5 \times 5 \times 200 \text{ cm}^3$; labeled “small”, “medium”, and “large”, respectively. This allows for custom experimental layouts to optimize the energy resolution for the energy range of neutrons important to each particular experiment. The medium size modules are a recent addition to the VANDLE suite of detector modules. Therefore, much of the characterization and analysis in this document was performed with the small or large modules.

The small modules are designed to be as sensitive as possible to low-energy neutrons. The medium modules are designed to have the same angular coverage as the small modules, mounted further away for a longer TOF and better resolution for higher neutron energies (2–7 MeV). The large modules are designed to detect neutrons up to about 20 MeV. The VANDLE collaboration has assembled over 100 small modules, 60 large modules, and 45 medium modules.

Fig. 1 illustrates the VANDLE module design. Scintillating plastic bars made of Eljen EJ-200 [14] or Bicron BC408 [15] are coupled to photo-multiplier tubes (PMTs) made by Hamamatsu [16] using an optical epoxy (Eljen brand EJ-500). Because the PMTs are approximately the same size as the scintillator's cross section, there is less light loss than using a light-guide. The Hamamatsu model R580 PMTs on the smaller VANDLE modules has a diameter of 3.8 cm that nearly matches the diagonal of the square cross section for the small bars. For the large and medium VANDLE modules, the Hamamatsu PMT model R7724 with a diameter of 5.2 cm is used because it is nearly equal to the width of the bars. The medium bars have a 1.5 cm long taper at their ends bringing the width of 6 cm down to 5 cm to more closely match the diameter of the R7724 PMTs. These PMTs were also chosen because of

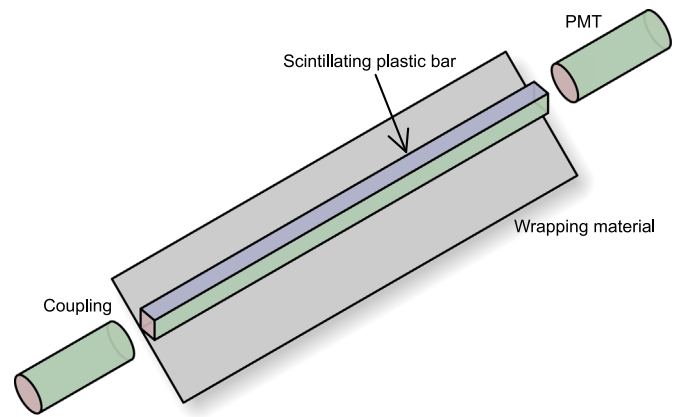


Fig. 1. VANDLE components. Typical of time-of-flight neutron detectors. The specific geometry, PMT, and wrapping used for each of the three VANDLE modules are detailed in the text.

their timing resolution and a photomultiplier gain factor of at least 10^7 .

Ideally, scintillation light is internally reflected and guided to the ends, but for extended geometries such as the VANDLE bars, reflective wrapping improves the light collection and reduces attenuation. Different wrapping materials were tested by placing a standard γ -ray source at the center of a VANDLE bar and recording the light-yield spectrum transmitted to the ends while keeping the voltage on the PMT constant. Nitrocellulose (rolls of Cole-Palmer nitrocellulose membranes) transported more light to the ends, leading to a light-yield spectrum 20% higher than Teflon tape, which was 15% better than aluminized Mylar foil wrapping. Since nitrocellulose or Teflon tape wrapping material are expensive, and considering the large number of modules, the nitrocellulose wrapping is only used for the inside layer on the small VANDLE modules that are designed to optimize sensitivity to low-energy events. To reduce costs, the larger sized VANDLE modules had their bars wrapped with SunFilm brand (2 mil gauge) aluminized Mylar. All VANDLE bars have a second layer consisting of Mylar that is aluminized on the inner surface and coated with an opaque white film on the outer surface (Easygrow brand 'Lightite' film).

Optical epoxy from Eljen (EJ-500) was used to couple the PMT to the VANDLE bars to provide a rigid coupling joint. The epoxy was mixed and then placed in an evacuated chamber for 5 min to remove bubbles that formed during the mixing process. Epoxy was applied to the ends of vertically mounted VANDLE bars that had been sanded to increase adhesion. The weight of the PMTs squeeze the epoxy to fill in the rough surface and results in a thin (less than 0.1 mm) layer of rigid epoxy when cured. The final assembly included a layer of shrink-wrap tubing around the ends to protect the epoxy joint and electrically insulate the PMT and its base.

3. Digital data acquisition

A common problem with detectors that rely on PMTs are random pulses generated by the PMT itself that can overwhelm the data acquisition (DAQ) when trigger thresholds are low. The most common unwanted pulses come from thermionic emission (electrons), that create dark current, arising from the semi-conductor photocathode [17]. Other background pulses caused by stray ions or photons typically have shorter time widths or less amplitude than a normal scintillation event in the PMT. Their frequency is random but decays after any strong PMT signal in a few hundred nanoseconds.

To deal with these background pulses, the VANDLE DAQ system takes full advantage of the digitizing electronics and integrated,

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