


NEUTRON ENERGY ESTIMATION
USING ^3He COUNTERS*

RAJAT ROY ^{a,b}, D. CHOUDHURY^{a,b}, D.A. TESTOV^b
D.L. BALABANSKI^b, G.L. GUARDO^c, A. KANOUE^a, M. KAUR^a
A. KUŞOĞLU^{b,d}, G. LORUSSO^{e,f,g}, S. SINGH^a, P.-A. SÖDERSTRÖM^b
Y. XU^b, S. AOGAKI^b, S.-R. BAN^b, M. BREZEANU^b, I. BURDUCEA^h
R. CORBU^b, M. CUCIUC^b, A. DHAL^b, N. DJOURELOV^b, N. FLOREA^h
A. GAVRILESCU^b, C.C. GHEORGHIU^b, D. IANCU^h, V. LELASSEUX^b
C.V. NEDELICU^b, H. PAI^b, P. PARLEA^b, T. PETRUSE^b, A. ROTARU^b
A.N. STATE^b, M. STRATICIUC^h, T. TOZAR^b

^aDepartment of Physics, Indian Institute of Technology Ropar
Rupnagar, Punjab 140001, India

^bExtreme Light Infrastructure — Nuclear Physics (ELI-NP)
Horia Hulubei National Institute for R&D in Physics and Nuclear
Engineering (IFIN-HH), 30 Reactorului St., Bucharest-Măgurele 077125, Romania

^cLaboratori Nazionali del Sud INFN, Catania 95125, Italy

^dDepartment of Physics, Faculty of Science, Istanbul University
Vezneciler/Fatih, 34134 Istanbul, Turkey

^eNational Physical Laboratory, Teddington-TW11 0LW, UK

^fDepartment of Physics, University of Surrey, Guildford GU2 7XH, UK

^gRIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

^hApplied Nuclear Physics Department

Horia Hulubei National Institute for R&D in Physics and Nuclear
Engineering (IFIN-HH), 30 Reactorului St., Bucharest-Măgurele 077125, Romania

*Received 12 November 2025, accepted 18 January 2026,
published online 31 March 2026*

Neutron energy determination is crucial in (α, n) reaction studies, where emitted neutrons span a broad energy range influenced by reaction kinematics and target properties. This work presents an experimental method using an array of moderated ^3He proportional counters to determine neutron energies. Optimized moderator configurations and Monte Carlo-supported spectral unfolding enable reliable reconstruction of neutron spectra without time-of-flight measurements. The system offers a practical and efficient approach for neutron energy characterization, applicable to nuclear data validation and shielding design.

DOI:10.5506/APhysPolBSupp.19.1-A31

* Presented at the XXXVIII Mazurian Lakes Conference on Physics, Piaski, Poland, August 31–September 6, 2025.

1. Introduction

Determination of neutron energies is fundamental in nuclear reaction studies, as it underpins accurate cross-section evaluation, model benchmarking [1, 2], and understanding of nuclear reaction mechanisms. In (α, n) reactions, emitted neutrons exhibit a broad energy spectrum determined by factors such as the incident α -particle energy, reaction Q -value, excitation of the residual nucleus, and emission angle. Accurate spectral characterization is therefore vital for both fundamental and applied nuclear research.

From a physics standpoint, neutron energy measurements provide insight into reaction kinematics and help identify discrete neutron groups corresponding to transitions to specific nuclear states. Such information is crucial for validating reaction models, refining nuclear data libraries, and improving predictive codes such as TALYS [1] and EMPIRE [2]. Detailed neutron spectra also contribute to a deeper understanding of nuclear structure and decay pathways. In applied contexts, (α, n) neutron spectra are essential for reactor design, shielding, radiation protection [3], dosimetry, activation analysis, medical isotope production [4], and neutron detector calibration. Since neutron interactions are strongly energy-dependent, reliable spectral determination is indispensable across these applications.

Among available detectors, ^3He proportional counters are highly sensitive to thermal neutrons, exhibit low gamma sensitivity, and provide long-term stability. Although they do not directly detect fast neutrons, coupling them with moderating materials such as polyethylene or paraffin extends their usability to higher energies [5]. Embedding multiple moderated ^3He detectors in optimized configurations allows for reconstruction of incident neutron spectra through response-matrix or spectral unfolding methods supported by Monte Carlo simulations (*e.g.*, MCNP [6], Geant4 [7]).

In this work, we present the methodology and experimental approach for neutron energy determination using a moderated array of ^3He proportional counters in $^{27}\text{Al}(\alpha, n)$ reaction studies. The detector design, calibration, response modeling, and unfolding analysis are discussed, demonstrating the system's capability to deliver reliable neutron energy information over a wide range of neutron fields.

2. Experimental details

Neutron detection in ^3He proportional counters is based on the neutron capture reaction



which has a large thermal capture cross section of about 5330 barns. The reaction releases 764 keV, shared between a 573 keV proton and a 191 keV

triton, whose energy deposition produces an ionization pulse in the detector gas. Owing to their high sensitivity to thermal neutrons and low gamma response, ^3He counters are widely used for neutron measurements.

The measurements were carried out using the ELIGANT-TN detector array [8, 9], which was constructed at ELI-NP. The detector assembly consists of three concentric rings of ^3He proportional counters positioned at radial distances of 5.9, 13.0, and 15.5 cm from the target position, as shown in Fig. 1. The counters are embedded in a high-density polyethylene moderator block with dimensions of 46 cm (width) \times 46 cm (height) \times 54 cm (length). This configuration ensures spatially distributed sensitivity and uniform efficiency over a wide energy range. Since these detectors primarily respond to thermal neutrons, fast neutrons from (α, n) reactions must be moderated to lower energies. In this work, the counters were embedded in a polyethylene moderator that efficiently thermalizes neutrons across a broad energy range while maintaining low gamma sensitivity. Neutrons emitted with thermal energies have a higher probability of being detected in the innermost ring (R1), as shown in Fig. 1, as it is located closest to the target position. In contrast, higher-energy neutrons require longer moderation and are therefore more likely to be detected in the outer rings.

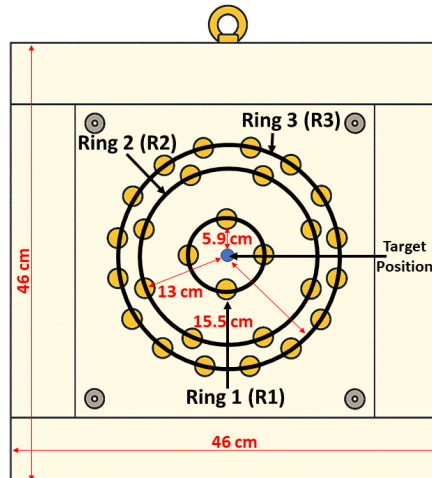


Fig. 1. Schematic representation of the ELIGANT-TN experimental setup.

The ELIGANT-TN was used for $^{27}\text{Al}(\alpha, n)$ cross-section measurements employing a $20 \mu\text{g}/\text{cm}^2$ ^{27}Al target [5], and α -beam was delivered by 3 MV Tandatron accelerator of IFIN-HH, Romania. The array was characterized using a ^{252}Cf spontaneous fission neutron source with an activity of about 28 kBq at the time of measurement to verify the overall efficiency, spatial uniformity, and stability of the setup.

2.1. Ring-ratios: neutron energy estimation

Thermal neutron detectors such as ^3He proportional counters are insensitive to the initial energies of incident neutrons, as they only record the count rate of thermalized neutrons from the $n + ^3\text{He} \rightarrow ^3\text{H} + p$ reaction. To extract energy-related information, the Ring-Ratio Method [10] was employed in this study. In this technique, we use the individual detection efficiencies of the 3 rings as shown in Fig. 1. As incident neutrons undergo multiple elastic scatterings before thermalization, the count ratio between the outer and inner detector rings,

$$R_{\text{ring}} = \frac{\text{Count rate in outer ring}}{\text{Count rate in inner ring}}, \quad (2)$$

serves as a monotonic indicator of the average incident neutron energy. Higher-energy neutrons penetrate deeper and are more likely to be detected by outer rings, while lower-energy neutrons are moderated earlier and captured near the surface. Thus, spatial variations in count rates encode information on neutron spectral hardness.

Calibration of R_{ring} as a function of neutron energy — using standard sources or Monte Carlo simulations (*e.g.*, Geant4, MCNP) — allows for conversion of measured ratios into average neutron energies. In the present work, this approach was applied to neutrons from (α, n) reactions. Count rates in the rings were corrected for background and analyzed using energy-dependent multiplicity relationships to determine ring count ratios, multiplication factors, and average neutron energies.

3. Data analysis and results

The detection efficiency of each concentric ring of ^3He detectors varies with neutron energy [9]. Simulations show that the inner ring is most sensitive to thermal and epithermal neutrons, while the middle and outer rings respond more effectively to higher-energy neutrons. Specifically, Ring 1 (see Fig. 1) exhibits maximum efficiency for low-energy neutrons, decreasing with energy; Ring 2 peaks around 1–3 MeV; and Ring 3, with minimal low-energy sensitivity, becomes increasingly efficient at higher energies. The overall efficiency remains nearly constant (37–39%) from 10 keV to 3 MeV, as the reduced inner-ring response is compensated by enhanced outer-ring detection, ensuring minimal energy bias. This distinct energy dependence enables the definition of detector count-rate ratios, or ring-ratios, which act as sensitive indicators of neutron energy. Simulations using the experimental geometry yielded the variations of ring-ratios with neutron energy, as shown in Fig. 2. The R1/R2 ratio is high at low energies and decreases rapidly with energy, reflecting the dominance of Ring 1 in the thermal region. The

R2/R3 ratio remains nearly constant ($\approx 3\text{--}4$) over a broad range, indicating comparable responses of the middle and outer rings. The R1/R3 ratio shows strong energy sensitivity, dropping from about 40 at low energies to ≈ 1 at higher energies, making it particularly suitable for energy estimation.

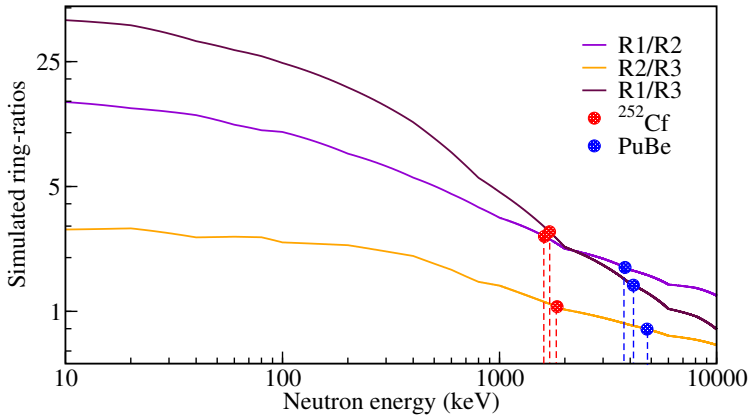


Fig. 2. Neutron energy dependence of simulated ring-ratios for the experimental geometry, with validation using ^{252}Cf and PuBe neutron sources.

The Ring-Ratio Method was verified using well-characterized neutron sources, such as ^{252}Cf and PuBe sources, as shown in Fig. 2. For each source, three vertical dashed lines indicate the neutron energies independently deduced from the measured R1/R2, R2/R3, and R1/R3 ratios using the simulated response curves. The extracted mean neutron energies are consistent with the approximately Maxwellian spectrum of ^{252}Cf (mean energy ≈ 2.1 MeV) and the broad 1–10 MeV energy distribution of PuBe [11], while the observed spread reflects both the intrinsic width of the neutron energy distributions and the differing sensitivities of the individual ring ratios.

The experimentally measured ring-ratios (R1/R2, R2/R3, R1/R3) for various α -beam energies were interpolated on the simulated curve of ring-ratios *versus* neutron energy. A direct relation between the α -beam and neutron energies was established for the α -energy range from 4 to 5.2 MeV, as shown in Fig. 3. The neutron energy structures observed in Fig. 3 for the $^{27}\text{Al}(\alpha, n)$ reaction arise from the reaction kinematics and the energy-dependent cross section, with enhancements reflecting resonant states in the compound nucleus ^{31}P that lead to increased neutron yield at specific energies.

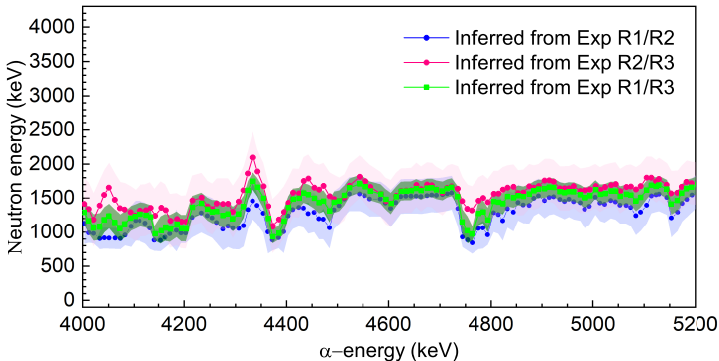


Fig. 3. Extracted neutron energies from the ring-ratio technique, corresponding to each α -energy at the middle of the target. The shaded bands correspond to the uncertainty of each ring-ratio when used independently for neutron energy determination.

The ring-ratio method is not a spectroscopic technique but provides an approximate determination of the mean neutron energy, with improved accuracy for narrower energy distributions. For non-monoenergetic neutrons, variations in the extracted mean energy arising from different ring combinations are unavoidable and constitute an intrinsic systematic uncertainty of the method [9]. However, this spread also offers qualitative information on the width and shape of the neutron energy distribution, as illustrated in Fig. 2. Such insight is accessible in the three-ring ELIGANT-TN geometry rather than the conventional two-ring thermal neutron counter designs. The ring-ratio approach therefore provides a practical alternative to time-of-flight (TOF) methods for estimating neutron energies in (α, n) reactions producing continuous spectra.

4. Summary

This work demonstrates a neutron energy measurement technique using an array of twenty-eight moderated ^3He detectors for the $^{27}\text{Al}(\alpha, n)$ reaction. Although ^3He counters do not directly measure neutron energy, the Ring-Ratio Technique enabled reliable energy reconstruction through simulation-calibrated count-rate ratios. The extracted neutron energies serve as crucial inputs for cross-section evaluation and model validation, providing an effective alternative in situations where time-of-flight measurements are impractical.

Future improvements, including TOF-capable configurations, optimized moderator geometries, and advanced analysis methods such as Bayesian or machine-learning-based unfolding, could further enhance the precision and

extend the applicability of moderated ^3He arrays in low- and intermediate-energy nuclear reaction studies. A follow-up experiment will be conducted to determine the neutron energy through direct experimental measurement.

We thank the target laboratories of ELI-NP and IFIN-HH for preparing the targets used in this work. This work was supported by the Romanian Ministry of Research, Innovation, and Digitalization under contract No. 10N/PN 23 21 01 06. R.R. acknowledges financial support from the Council of Scientific & Industrial Research (CSIR), Government of India, for carrying out this research work. D.C. acknowledges the financial support from the SERB-DST India under CRG (grant No. CRG/2022/005439). D.L.B. acknowledges partial financial support from the Institute of Atomic Physics, Romania, contract number ELI-RO/RDI/2024-007 ELITE.

REFERENCES

- [1] W. Hauser, H. Feshbach, *Phys. Rev.* **87**, 366 (1952).
- [2] M. Herman *et al.*, *Nucl. Data Sheets* **108**, 2655 (2007).
- [3] S.P. Simakov, Q.Y. van den Berg, *Nucl. Data Sheets* **139**, 190 (2017).
- [4] F. Tárkányi *et al.*, *Nucl. Instrum. Methods Phys. Res. B* **351**, 6 (2015).
- [5] R. Roy *et al.*, *Phys. Rev. C* **112**, 044613 (2025).
- [6] M.E. Rising *et al.*, MCNP® Code Version 6.3.1 Release Notes, Los Alamos National Laboratory Tech. Rep. LA-UR-25-23548, Rev. 1, Los Alamos, NM, USA, April 2025, [10.2172/2563101](https://doi.org/10.2172/2563101).
- [7] S. Agostinelli *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **506**, 250 (2003).
- [8] C. Clisu *et al.*, *EPJ Web Conf.* **284**, 01015 (2023).
- [9] P.-A. Söderström *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **1084**, 171229 (2026).
- [10] I. Gheorghe *et al.*, *Phys. Rev. C* **110**, 014619 (2024).
- [11] P.-A. Söderström *et al.*, *Appl. Radiat. Isot.* **167**, 109441 (2021).