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Measurement of flux distribution of an AmBe neutron source and estimation of two group integral capture cross-sections

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A R T I C L E I N F O

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A B S T R A C T

Neutron capture cross sections of elements are of utmost importance in reactor physics, dosimetry applications and stellar nucleosynthesis studies. Manipal Centre for Natural Sciences (MCNS) possesses a 16Ci AmBe neutron source, which is housed inside a concrete structure. The neutrons undergo multiple scattering events in the concrete structure and surrounding materials; therefore, the neutron flux profile is unique to this source and structural material, which differs from the standard ISO spectrum. Using this AmBe source, experiments are being conducted to understand the neutron energy distribution in two groups to measure capture cross sections of various isotopes. In the present work, gold has been used as a flux monitor, and the indium cross-section has been measured in two groups. These foils (Gold and Indium) are irradiated with and without cadmium cover to understand the neutron spectra in two spectral regions as cadmium cutoffs neutrons of energy below 0.5 eV. Irradiated samples were counted in High-Pure Germanium (HPGe) detector, and the γ-spectra obtained were used to get the epi-cadmium (0.5 eV and above) to total ratio of $\langle \sigma(E)\phi(E) \rangle$. The neutron flux is estimated in two groups corresponding to thermal (thermal energy neutron extended up to 0.5 eV) and epi-cadmium regions, and also the flux-weighted capture cross sections of 115In are determined.

1. Introduction

Americium-Beryllium (AmBe) neutron sources are commonly used in a variety of applications such as in activation analysis, radiography, well logging and nuclear power plant instrumentation. Understanding the neutron flux distribution from an AmBe neutron source is of utmost importance as the energy-wise flux data is essential for further experimental measurements of the capture cross-sections of several other isotopes. AmBe neutron spectra in any experimental facility differs from the standard ISO [1] spectra due to the scattering events by the structural materials present around the source. In continuation to the flux measurement works [2] for the 16Ci AmBe neutron source at Manipal Centre for Natural Sciences (MCNS), it is essential to understand the spectral energy distribution of neutrons. Neutron activation analysis [3] was performed using indium and gold samples with and without cadmium covers. Cadmium has a very high capture cross section below 0.5 eV; therefore, by the activity produced in the cadmium-covered gold sample and bare gold sample, the nature of neutron spectra in two energy groups can be determined. With the help of Neutron flux calculated in two groups, Indium capture cross-sections were estimated below and above the cadmium threshold. By the neutron activation studies, using gold as a flux monitor, indium cross sections and the epi-cadmium to total (without Cadmium cover) $\langle \sigma(E)\phi(E) \rangle$ ratio of the source are calculated.

2. Material and methods

The division of neutron spectra into two energy groups can be obtained through the resonance absorption property possessed by cadmium. The cross-section of cadmium is large at lower neutron energies

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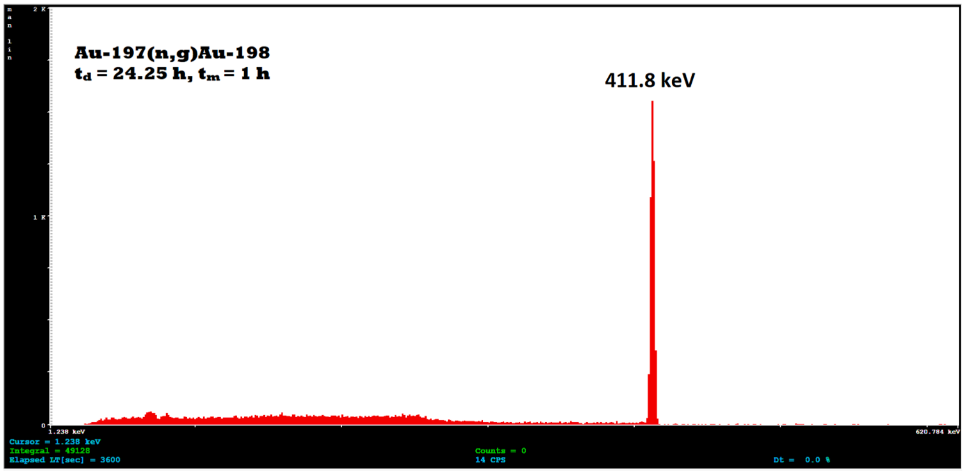

Fig. 1. Measured γ-spectra of Gold.

and decreases drastically as the energy of neutrons increases above 0.5 eV. This means that cadmium absorbs all thermal neutrons up to 0.5 eV while allowing the epi-cadmium neutrons to pass through and irradiate cadmium-covered samples. By comparing the activities produced in bare foils to those produced in cadmium-covered foils, the activities resulting from neutrons of both energy groups can be determined. Absolute activities are obtained from the measured γ-spectra of gold and indium using an HPGe detector. From these measured spectra, the epi-cadmium to total $\langle\sigma(E)\phi(E)\rangle$ ratio is obtained. The capture cross sections vs neutron energy data for indium and gold were taken from ENDF VIII.0 [4]. The experimental epi-cadmium to thermal (up to 0.5 eV) flux-weighted capture cross-sections of indium and gold can be obtained by folding the neutron energy flux distribution with the cross-sections. The neutron flux profile of our experimental is shown in references [2, 5]. In the present work, we determined the flux in two groups, namely thermal (up to 0.5 eV) and epi-cadmium neutrons. The neutron activation analysis formulas are taken from [3]. The measured counts using the HPGe detector are given in terms of flux-weighted cross-sections and other parameters as given in the activation equation 1 below

$$C = \varphi_{th}\sigma_{th}\frac{N_{Av}\theta m_x}{M_a}\left(1-e^{-\lambda t_i}\right)e^{-\lambda t_d}\frac{\left(1-e^{-\lambda t_m}\right)}{\lambda}\Gamma\epsilon \tag{1}$$

Where,

σ_{th} Thermal neutron cross section

ϕ_{th} Thermal neutron Flux

C net counts in the γ-ray peak area at energy E_γ

N_{Av} Avogadro's number, mol^{-1}

θ isotopic abundance of the target isotope considered for capture reaction

m_x mass of the irradiated sample, g

M_a atomic mass, $g.mol^{-1}$

Γ the γ-ray abundance ϵ the full energy photopeak efficiency of the detector at energy E_γ in the measured spectrum

t_i Irradiation time

t_d Cooling (decay) time

t_m Counting (measurement) time.

3. Experimental setup

The AmBe neutron facility at MCNS is a 16Ci 22 cm long, 5 cm diameter cylindrical source housed inside a concrete bunker. The indium and gold activation foils, with and without cadmium covers, are placed at 3 cm from the source. Gold foils having a weight of 0.1246 g (with Cd cover) and 0.1254 g (without Cd cover) are used. Indium foils having a weight of 0.1216 g (with Cd cover) and 0.1234 g (without Cd cover) are used. The foils were irradiated for a period of 142.5 h. γ-spectra of the irradiated samples are counted using the HPGe detector, and the sample spectra of gold and indium are shown in Figs. 1 and 2. The efficiency of the HPGe detector is obtained by 152Eu count spectra of known activity, which is 6.65 kBq, kept at a distance of 5 mm from the

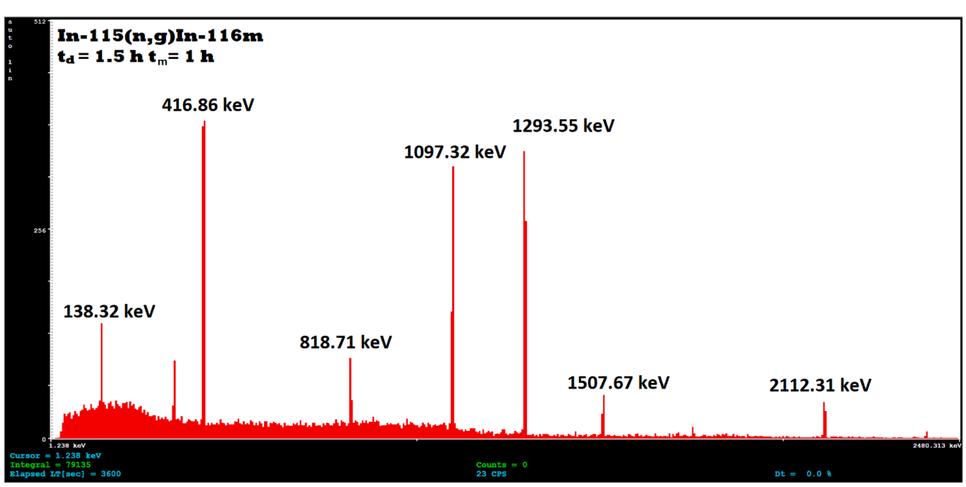

Fig. 2. Measured γ-spectra of Indium.

Table 1
Ratio of ⟨σ(E)ϕ(E)⟩ result with γ-lines used.

Flux monitors	Gamma line used (keV)	epi-cadmium to total ratio of ⟨σ(E)ϕ(E)⟩
^{197}Au (n, g) ^{198}Au	411.8	0.416
^{115}In (n,g) ^{116m} In	138.29, 416.86, 818.71, 1097.32, 1293.55, 1507.67, 2112.31	0.322

Table 2
Fluxes as measured by gold and estimated indium cross section.

Flux monitors ^{197}Au (n,g) ^{198}Au	Extended thermal group (upto 0.5 eV) flux = $2.33 \times 10^3 \pm 1.71 \times 10^2$ n/cm^2/s	epi-cadmium (0.5 eV and above) flux = $1.72 \times 10^3 \pm 1.26 \times 10^2$ n/cm^2/s
Sample ^{115}In (n, g) ^{116m} In	Extended thermal group (upto 0.5 eV) σ = 152.9 ± 14.8 barns	epi-cadmium (0.5 eV and above) group σ = 92.1 ± 8.93 barns

detector from where all the remaining spectra are obtained for the activation analysis. The efficiency determination has been carried out using the coincidence summing effect with EFFTRAN program [6].

4. Results and discussion

The ratio of ⟨σ(E)ϕ(E)⟩ of the extended thermal group (upto 0.5 eV) and epi-cadmium group is computed by dividing the photo-peak areas of the cadmium-covered sample by that of the bare sample. All other factors of Eq. (1) will be cancelled by the ratio. The Table 1 shows the γ lines of gold and indium which are used for the calculation. The photopeak values corresponding to these gamma line are obtained from the spectra. The difference in the ratio of gold and indium foils can be attributed to the difference in the flux-weighted capture cross-section of ^{197}Au and ^{115}In.

Using the ⟨σ(E)ϕ(E)⟩ of gold with and without cadmium cover, and their difference, the extended thermal group ⟨σ(E)ϕ(E)⟩ (upto 0.5 eV) is estimated. Using these values and by taking the gold average cross-section of 120 barns from thermal to 0.5 eV, flux of this region is calculated with the standard activation formula. This value is shown in the Table 2. Therefore, we focus on the two group values, i.e., extended thermal and epi-cadmium flux values using gold as monitor. Using these two group flux values, we determined the corresponding two group cross sections for Indium.

There are total seven γ-lines of indium as shown in Table 1. In the present work most prominent 3 gamma lines (416.86 keV, 1097.32 keV, 1293.55 keV.) of higher abundances have been considered. The indium two-group capture cross sections are determined by using these estimated two-group flux data, and are shown in Table 2. Without cadmium, we get a total flux-weighted cross-section, and with cadmium, we get an epi-cadmium cross-section. Subtracting the epi-cadmium group from the total cross-section gives the thermal group cross-section up to 0.5 eV. The total (extended thermal + *epi* cadmium) flux estimated in this work is 4.1×10^7 which is consistent with the flux measured in previous work [2]

In any gamma spectroscopic measurements, uncertainties araise in measurement due to various quantities such as, sample mass, efficiency calibration of the detector, photopeak area and Nuclear data. The errors associated with the experiments comes from the Counting statistics (<5 %)

Detector Efficiency (<5 %) and assuming all the other errors (<5 %) The total uncertainties associated with the final values is around 8.6 %. Rigorous error analysis from all sources is not performed in this work.

5. Conclusion

The neutron flux from the AmBe source at MCNS has been estimated by employing activation method followed by offline gamma ray spectrometry. Using the activation technique with gold and indium foils, with and without cadmium covers, the average flux of the AmBe source is estimated in two energy groups viz., epi-cadmium (0.5 eV above) and extended thermal (thermal and upto 0.5 eV). Total flux (extended thermal + *epi* cadmium) estimated by us is around 4×10^3 n/cm^2 /s which is consistant with the ealier measurements [2]. Indium capture cross sections in the two energy groups are estimated using these two group flux values.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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