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An alternative method for the measurement of neutron flux

RUPA SARKAR[1,*], PRASANNA KUMAR MONDAL[1,2] and BARUN KUMAR CHATTERJEE[1]

[1]Department of Physics, Bose Institute, 93/1 APC Road, Kolkata 700 009, India
[2]Present address: Department of Chemical, Biological & Macromolecular Sciences, S.N. Bose National Centre for Basic Sciences, Block JD, Sector-III, Salt Lake, Kolkata 700 098, India
*Corresponding author. E-mail: sarkar_rupa2003@yahoo.com

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Abstract. A simple and easy method for measuring the neutron flux is presented. This paper deals with the experimental verification of neutron dose rate–flux relationship for a non-dissipative medium. Though the neutron flux cannot be obtained from the dose rate in a dissipative medium, experimental result shows that for non-dissipative medium one can obtain the neutron flux from dose rate. We have used a ^{241}AmBe neutron source for neutron irradiation, and the neutron dose rate and count rate were measured using a NM2B neutron monitor and R-12 superheated droplet detector (SDD), respectively. Here, the neutron flux inferred from the neutron count rate obtained with R-12 SDD shows an excellent agreement with the flux inferred from the neutron dose rate in a non-dissipative medium.

Keywords. Neutron dose; neutron flux; superheated droplet detector; bubble nucleation.

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1. Introduction

A proper estimation of the neutron flux is essential in different fields of research involving neutron sources, e.g., for the characterization of superheated droplet detectors (SDD) [1–6]. The SDD is a well-known detector for neutrons and are widely used because of its advantages over other conventional neutron detectors [7–9]. The SDD contains micron-size droplets of superheated liquid suspended in a host medium [10–12]. The superheated droplet vapourizes explosively when sufficient amount of energy is deposited by energetic radiations within a localized region of the active liquid [11]. For the characterization of SDD, a quantitative measurement of different parameters is required [1–6]. For this, an accurate estimation of the neutron flux is essential. A simple and easy method for measuring the neutron flux is hence worth exploring, which will not only be useful for the characterization of SDD but can also be extended to other fields of work where a proper

estimation of the neutron flux is required [13–15]. In this paper, a simple and easy method for measuring the neutron flux is presented.

It is well known that the neutrons, while passing through a medium, deposit energy by elastic or inelastic scattering with the atomic nuclei present in the medium. The amount of energy deposited by the neutron depends on the rate of scattering events and the average energy lost by the particle during the scattering events. The energy deposited per unit mass of the absorber, i.e., the absorbed dose rate, is proportional to the neutron flux. The dose rate–flux relationship was experimentally verified for a non-dissipative medium using NM2B neutron dosimeter and R-12 SDD. For neutron irradiation a ^{241}AmBe neutron source was used. The neutron flux inferred from the count rate as observed in R-12 SDD shows an excellent agreement with the flux obtained from the dose rate in a non-dissipative medium. This enables one to infer the neutron flux accurately from the neutron dose rate.

2. Theory

For neutrons the absorbed dose rate (D) can be written as

$$D = \psi \sum_i n_i \sum_j \sigma_{ij} \left\langle \Delta E_{ij} \right\rangle / M, \tag{1}$$

where ψ is the neutron flux, n_i is the number of target nuclei of ith species of the material, σ_{ij} is the cross-section of the ith nuclei for the jth scattering process, ΔE_{ij} is the energy lost by the neutron in that event and M is the mass of the absorber. Here it can be seen that the dose rate (D) is proportional to the neutron flux (ψ). The neutron flux not only depends on the geometric factor, for which the integral over any closed surface enclosing the source would be a constant, but also on the disintegration of unstable particles and the attenuation of the number of particles due to the reactive scattering. The cross-section and the deposited energy also depend on the energy of the incident neutrons, which diminishes with collisions and hence with the distance. Interpretation of neutron flux from the neutron dose rate is hence non-trivial. For neutrons in a non-dissipative medium, the energy and the number of neutrons remain unaffected in transit, and hence the neutron dose rate will be proportional to the incident neutron flux in non-dissipative medium. In this paper we have considered air as a non-dissipative medium [16] and that the transit time is much shorter than the free neutron mean lifetime.

The absorbed dose rate can also be expressed in terms of the energy absorbed per unit mass of the absorber for each neutron and neutron flux. The absorbed dose rate $D(r)$, at a distance r from the source, is related to the neutron flux $\psi(r)$ at r as

$$D(r) = AE(r)\psi(r), \tag{2}$$

where $E(r)$ is the average energy deposited per unit mass by a neutron in the area A of the detector at a distance r. In a non-dissipative medium, the energy of the particles and hence the deposited energy per particle are constant, i.e., $E(r)$ is independent of the distance. Hence, the dose rate and flux will maintain a proportional relationship

$$\frac{\psi(r)}{\psi(r')} = \frac{D(r)}{D(r')}, \tag{3}$$

where $D(r)$, $D(r')$ are the dose rates and $\psi(r)$, $\psi(r')$ are the neutron flux at positions r and r', respectively.

It can also be shown that the neutron count rate in a detector maintains a proportional relationship with the neutron flux, and can be expressed as

$$\frac{N(r)}{N(r')} = \frac{\psi(r)}{\psi(r')}, \tag{4}$$

where $N(r)$ and $N(r')$ are the count rates at positions r and r', respectively. The quantitative value of the neutron flux at a distance R from a neutron source of activity S_{act} can be written as

$$\psi_{\text{th}}(R) = \frac{S_{\text{act}}}{4\pi R^2}. \tag{5}$$

If $\psi_{\text{th}}(R)$ is the theoretical flux at a sufficiently large distance R from the source, then using eq. (4) the flux at any other point may be expressed as

$$\psi(r) = \frac{N(r)}{N(R)}\psi_{\text{th}}(R), \tag{6}$$

where $N(R)$ is the count rate at a distance R from the source. It should be noted that in the absence of background counts, such a calibration does not depend on the geometry of the source. The reference neutron flux can be calculated from eq. (5) and the neutron flux at any other position can be calculated using eq. (6).

This method is also applicable for obtaining the neutron flux from neutron dose rate, if and only if one can prove a proportional relationship between the neutron dose rate and count rate, i.e.,

$$\frac{N(r)}{N(r')} = \frac{D(r)}{D(r')}. \tag{7}$$

If the above relation holds, then this in turn will give a measurement of neutron flux by measuring the dose rate using eq. (3) as

$$\psi(r) = \frac{D(r)}{D(R)}\psi_{\text{th}}(R). \tag{8}$$

To study the proportional relationship between the neutron flux and dose rate in a non-dissipative medium and to accurately measure the neutron flux from the dose rate, experiments were performed using a 3 Ci ^{241}AmBe neutron source. A R-12 (CCl_2F_2, b.p. -29.8°C) based SDD, which is insensitive to γ-rays at room temperature [2,17,18] was used for measuring the count rate and a NM2B neutron monitor (NE Technology Limited, UK) was used for measuring the neutron dose rate.

3. Experiment

The R-12 SDD consists of a large number of micron-size droplets of superheated R-12 dispersed in a viscoelastic gel matrix. When R-12 SDD is exposed to the neutrons, the superheated droplets evaporate explosively into bubbles if sufficient amount of energy is deposited in the liquid droplet [7]. During such a bubble nucleation, an acoustic pulse

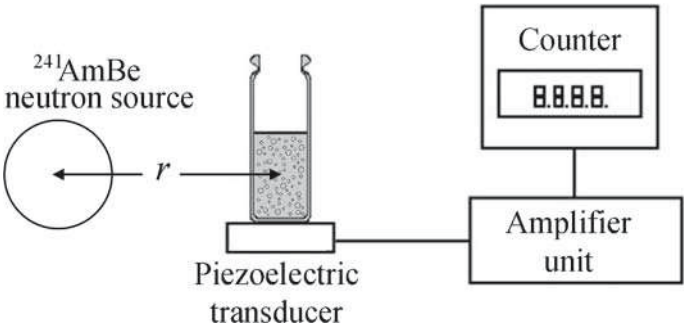

Figure 1. Schematic diagram of the experimental setup using superheated droplet detector (SDD).

is produced [19–21] which can be detected electronically [11,22]. To obtain the neutron flux at any distance from the neutron source the dose rate and the bubble nucleation rate were measured at different distances from the source.

The experiments were performed in two steps. In step 1, the count rate in R-12 SDD was measured as a function of the distance between the ^{241}AmBe neutron source and the detector. The count rate in SDD is proportional to the neutron flux, and this allows one to obtain neutron flux as a function of distance from the neutron source. The experimental arrangement using R-12 SDD and ^{241}AmBe neutron source is schematically presented in figure 1. The SDD was placed on top of a $BaTiO_3$ piezoelectric transducer and was irradiated with neutrons from a ^{241}AmBe neutron source. The bubble nucleations were detected electronically and the accumulated counts were measured using a counter. This experiment provides the count rate $N(r)$ as a function of detector-to-source distance r.

In step 2 of the experiment, a NM2B neutron dosimeter (dose rate sensitivity $= 0.01$ μSv/h) was used for measuring the neutron dose rate $D(r)$ at different distances from the neutron source. The NM2B dosimeter is a cylindrical-shaped polyethylene-moderated BF_3 gas detector with an external diameter of 21.5 cm and a length of 24 cm.

4. Result and discussion

The variation of the normalized neutron dose rate $D(r)/D(R)$ and normalized count rate $N(r)/N(R)$ with the distance from the neutron source are shown in figure 2. Here $D(R)$ and $N(R)$ are, respectively the neutron dose rate and count rate at a sufficiently large distance R from the source. From figure 2 one can observe that in non-dissipative medium the variation of the dose rate and count rate with the distance from the neutron source is similar to each other. This proves the proportional relationship between the neutron flux and dose rate in non-dissipative medium, as expected from eq. (7). Hence one can obtain the neutron flux by measuring only the neutron dose rate. From the measured dose rates the neutron flux was estimated at different distances from the source by using eq. (8). We have also calculated the neutron flux from the count rate data by using eq. (6). The variation of the neutron flux obtained from the two measurements are shown in figure 3, which shows that the two results are in good agreement with each other in non-dissipative media.

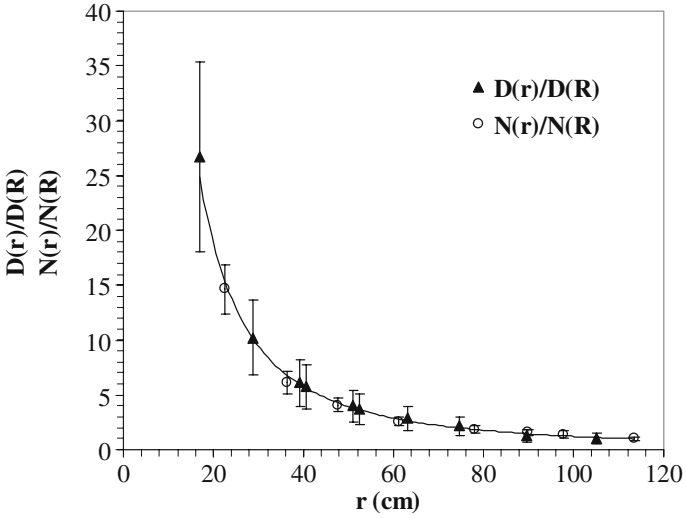

Figure 2. Variation of the normalized neutron dose rate $D(r)/D(\mathrm{R})$ and normalized count rate $N(r)/N(\mathrm{R})$ with the distance from a 3 Ci ^{241}AmBe neutron source.

This method implicitly assumes the constancy of the neutron energy spectrum as a function of distance and can be used for obtaining neutron flux by measuring only the neutron dose rate. This method could be used for any finite geometry of the source, because a finite source at large distance behaves as a point source and hence can be used for calibration purposes. The present method enables one to compute neutron flux from the neutron dose rate in a non-dissipative medium, provided that the background counts

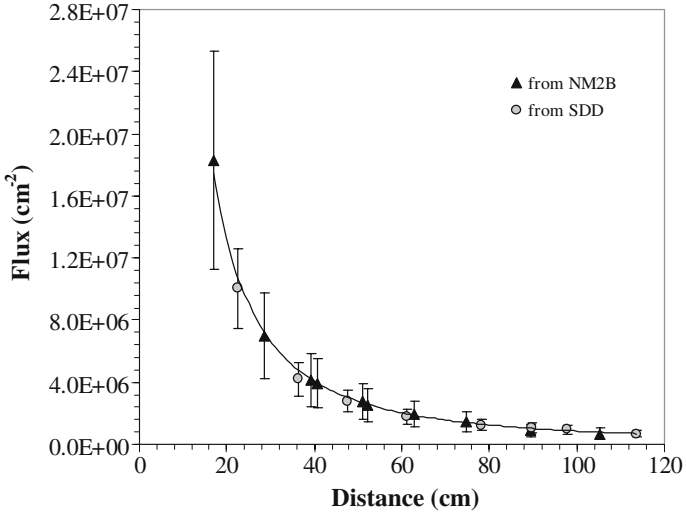

Figure 3. Variation of the neutron flux with the distance from a 3 Ci ^{241}AmBe neutron source.

are negligible and the time-scale of the experiment is much shorter than the mean lifetime of the incident particles. In this study we have used R-12 SDD, because it is insensitive to γ-rays at room temperature and has a negligible background count and hence suitable for measuring neutron flux.

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