Neutron Flux Measurements at the CFDF using Different Detectors

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ABSTRACT

The present work deals with neutron flux measurements performed at the Cairo Fourier Diffractometer Facility (CFDF); which has been installed at the ET-RR-1 Reactor. The CFDF applies two neutron guides for transmitting the neutron beam from the reactor to the sample position. The measurements were carried out at the exit of the straight neutron guide of the CFDF using $^3$He and BF$_3$ detectors. The neutron flux, at different points of the neutron guide, was also measured using both the calibrated $^3$He and BF$_3$ detectors; as well as gold foil activation method. It has been found from the present measurements that the $^3$He detectors are superior, for the CFDF neutron beam monitoring, to the BF$_3$ ones.

Key Words: Cairo Fourier Diffractometer Facility (CFDF) / Calibration detector.

INTRODUCTION

The BF$_3$ and $^3$He proportional counters are the most widely used for slow neutron detection. Boron trifluoride, in the BF$_3$ detectors, serves both as target, for slow neutron conversion into secondary particles, and as a proportional gas. The BF$_3$ is the near- universal choice, out of other boron-containing gases, because of its superior properties, as a proportional gas, and its high concentration of boron. The gas is highly enriched with $^{10}$B, nearly in all commercial detectors, leading to an efficiency ~ five times greater than that when the gas is containing natural boron. Because the performance of BF$_3$, as a proportional gas is poor when operating at higher pressures, its absolute pressure in typical tubes is limited to about 0.5-1.0 atm$^{(1)}$.

The reaction $^3$He (n,p) $^3$He is an attractive alternative for slow neutron detection and has a cross section even higher than that of the boron reaction . Unfortunately, because $^3$ He is a noble gas, no solid compounds can be fabricated and it has to be used in gaseous form for neutron detection; and detectors based on this approach have come into common use$^{(2)}$.

The present work deals with neutron flux measurements performed at the Cairo Fourier diffractometer facility (CFDF) using both gold foil activation method and $^3$He and BF$_3$ detectors. The detectors efficiencies were determined using neutron sources and the neutron activation method applying gold and indium foils.

EXPERIMENTAL DETAILS

1. Detector Efficiencies

The BF$_3$ and $^3$He detectors efficiencies were first determined using the irradiation channel of an irradiation cell which accommodates a Californium - 252 neutron source of 100 $\mu$g ($1.486 \times 10^8$ n/s). The thermal neutron flux was determined using the gold foils activation technique which is used for
measuring both the thermal and epithermal neutron flux distributions inside the irradiation channel of the source. The gold foils were fixed on a small wooden rod, to avoid flux disturbance, at distances 3 cm apart from each other (see Fig.1). Measurements were performed both with bare and cadmium covered gold foils in order to distinguish between the thermal and epithermal neutron fluxes.

Thus, the foils were irradiated for 69 hours, through the reaction: \(^{197}\text{Au} + n \rightarrow ^{198}\text{Au}\). While cadmium absorbs most of all neutrons with energy lower than 0.4eV, it is almost transparent to neutrons of higher energy. The difference between the neutron flux measured with and without cadmium yields the thermal flux. Both the thermal flux \(\phi_{th}\) and the epithermal one \(\phi_{epth}\) were calculated from the following formulae (3):

\[
\phi_{th} = \frac{P_{th}}{N_A f I_\gamma \varepsilon \sigma} \tag{1}
\]

\[
\phi_{epth} = \frac{P_{cd}}{N_A f I_\gamma \varepsilon \sigma} \tag{2}
\]

where,

\[
P_{th} = P_{bar} - P_{cd} \tag{3}
\]

\[
P_{bar} = \frac{\Lambda / t_m}{W e^{-\lambda t_d} (1 - e^{-\lambda T}) (1 - e^{-\lambda t_m}) / \lambda t_m} \tag{4}
\]

\[
P_{cd} = \frac{\Lambda_{cd} / t_m}{W_{cd} e^{-\lambda t_d} (1 - e^{-\lambda T}) (1 - e^{-\lambda t_m}) / \lambda t_m} \tag{5}
\]

\(N_A\): Avogadro’s number,
\(F\): fractional isotopic abundance of the target nuclide,
\(I_\gamma\): absolute value of the \(\gamma\)-ray line at energy \(E_\gamma\),
\(\lambda\): 
\(\lambda_{t_m}\): 

Fig. (1): The \(^{252}\text{Cf}\) experimental arrangement.
ε: efficiency of the detection system,
σ: effective neutron activation cross-section,
I: resonance integral.
A: net area under the peak of the concerned gamma-ray line (Eγ),
tm: live measurement time,
W: mass of target nuclide,
λ: decay constant of product nuclide,
td: transporting or cooling time,
T: irradiation time,
tm: real measurement time.

The induced activities of the irradiated foils were counted for a period of 100 sec by NaI (TI) detector, and both thermal and epithermal fluxes were determined.

The Monte Carlo Neutron Particle Transport Code (MCNP) (4) was used to calculate both the flux and the depth dose distributions for neutrons and gamma-rays of different energies at different positions along the vertical axis of the irradiation channel. Both, experimentally determined and theoretically calculated, distributions of thermal and epithermal neutron fluxes are respectively represented in Fig. 2.

![Fig. (2): The neutron flux distributions.](image)

a- Thermal distribution.  
b- Epithermal distribution.
The average value $4.56 \times 10^4$ n/cm$^2$.s of thermal neutron flux, determined using gold foils, at 20 cm distance from the bottom of the irradiation channel, is consistent with the value $4.98 \times 10^4$ n/cm$^2$.s calculated by the MCNP code.

The efficiencies of $^3$He and BF$_3$ detectors have been determined using the average value $4.56 \times 10^4$ n/cm$^2$.s, which has been previously determined, and the corresponding counts obtained by exposing each detector to the neutron beam in the vertical channel of $^{252}$Cf source at 20 cm distance with and without cadmium. The efficiencies of the detectors were determined from the following equation \(^{(5)}\):

$$\varepsilon = \frac{R_0}{\phi_0 A}$$  \hspace{1cm} (6)

where $R_0$ is the recorded average count rate of the detector, being in the source’s neutron beam, $A$ is the area of the detector exposed to the neutron beam. $\phi_0$ is the thermal neutron flux of the source, determined using the activation method.

The efficiencies of $^3$He and BF$_3$ detectors were also determined using activation method with indium foils and Pu-Be neutron source at different positions (see Fig.3).

![](image)

Fig. (3): Pu-Be neutron source arrangement.

2. Flux Measurements at the (CFDF)

2.1. Measurements using activation method

The Cairo Fourier diffractometer facility (CFDF) is installed in front of one of the ET-RR-1 reactor horizontal channels and is based on the reverse time of flight (RTOF) concept. It consists of the main curved neutron guide (22 m. length) followed by a Fourier chopper of 1024 slits and a straight neutron guide (3 m. length) for the collimation of the neutron beam (Fig. 4). Neutrons after that are incident on the sample and then diffracted at scattering angle $2\theta = 90^\circ$. The scattered neutrons are then detected by the CFDF detector system. More details about the CFDF are given elsewhere \(^{(6,7,8)}\).
The thermal neutron flux at the exit of both curved and straight neutron guides was measured using thin gold foils, being exposed to the neutron beam for ~45 hours. The thermal neutron flux was then determined using the following formula (9):

\[
\phi_{th} = \frac{N_A \delta I_\gamma \sigma \varepsilon m e^{-\lambda t} (1 - e^{-\lambda t}) (1 - e^{-\lambda m})}{Ac M}
\]

Where;

- \(M\) : is the atomic weight of the element,
- \(m\) : is the mass of the foil in gm,
- \(Ac\) : is the activity,
- \(I_\gamma\) : is the intensity of the gamma ray line at observed spectra,
- \(\delta\) : is the isotopic abundance of the target nuclide.

The induced activity was determined using (HPGe) detector.

Fig. (4): A schematic diagram of the CFDF at the ET-RR-1 Reactor

2.2. Measurements using \(^3\)He and BF\(_3\) detectors

The thermal neutron flux of the CFDF at the exit of the straight neutron guide was measured using the calibrated \(^3\)He and BF\(_3\) detectors, where each of them was placed in the way of the middle of the beam which passed through a cadmium slit. The value of the neutron flux at the exit of the straight neutron guide was calculated using equation (6).

RESULTS AND DISCUSSION

The efficiencies of three different \(^3\)He and BF\(_3\) detectors, determined applying the activation method using gold and indium foils, are given in Table 1. It is noticeable that both values are consistent except for the BF\(_3\) detector. This could be due to the low flux emitted from the Pu-Be source, compared with that of the Cf source.
Table (1): The efficiencies of $^3$He and BF$_3$ detectors using neutron sources and activation method.

<table>
<thead>
<tr>
<th>Detector type</th>
<th>Efficiency Using indium foils</th>
<th>Efficiency Using gold foils</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$He (251)</td>
<td>$3.5 \times 10^{-3}$</td>
<td>$3.68 \times 10^{-3}$</td>
</tr>
<tr>
<td>$^3$He (25111)</td>
<td>$4.98 \times 10^{-3}$</td>
<td>$5.65 \times 10^{-3}$</td>
</tr>
<tr>
<td>BF$_3$ (20130)</td>
<td>$3.1 \times 10^{-4}$</td>
<td>$7.9 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Each of the three calibrated detectors has been used for determining the neutron flux intensity at the exit of the straight neutron guide tube (SNGT) of the (CFDF) as in Table 2.

Table 2: The values of thermal flux at the (SNGT) using calibrated detectors.

<table>
<thead>
<tr>
<th>Detector type</th>
<th>Thermal neutron flux ($n/cm^2.s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$He (251)</td>
<td>$1.08 \times 10^6$</td>
</tr>
<tr>
<td>$^3$He (25111)</td>
<td>$1.23 \times 10^6$</td>
</tr>
<tr>
<td>BF$_3$ (20130)</td>
<td>$1.13 \times 10^6$</td>
</tr>
</tbody>
</table>

The integral neutron flux was also determined at the exit of both curved and straight neutron guides using the gold foil activation method. While the value of the thermal neutron flux at the exit of the curved neutron guide was found to be $6.66 \times 10^6 n/cm^2.s$, the value at the exit of the straight neutron guide was $1.15 \times 10^6 n/cm^2.s$. Such difference is due to the Fourier chopper (8). It is concluded that the thermal neutron flux obtained using calibrated detectors and activation method are very close to each other. The $^3$He detectors are superior for the CFDF neutron beam monitoring, to the BF$_3$ detector.

REFERENCES