Determination of the Thermal Neutron Flux of a Pu-Be Neutron Source

Objectives: This experiment will demonstrate how to measure the thermal neutron flux of a neutron source by foil activation. A gamma-ray counting efficiency calibration and absolute disintegration rate determination are involved.

References: Ehmann & Vance: pp. 85-98.

Nuclear reactors and isotope sources, like the Pu-Be source used in this experiment, do not supply monoenergetic neutrons. Neutron energies characteristic of such sources may range from tens of MeV to values corresponding to neutrons in thermal equilibrium with their surroundings (typically 0.025 eV), with the average neutron energy from a Pu-Be source being around 4.5 MeV. Moderation (slowing down) of the emitted neutrons will also dramatically affect the available energy spectrum.

Since the neutron is electrically neutral, there is no Coulomb barrier to its absorption by a nucleus, and neutrons of even thermal energies are readily absorbed to form a "compound nucleus". In fact, the probability of reaction (called the cross section) between a nucleus and a neutron for an (n,γ) reaction is largest for thermal neutrons and decreases approximately as 1/v with increasing neutron velocity (v). Such a plot of reaction cross section versus neutron energy is called an excitation function. The (n,γ) excitation function for indium, an almost perfect 1/v absorber, is shown in Fig. VI.1. Occasionally, peaks in the excitation function (resonances) do exist (see Fig. VI.1) and represent large probabilities for neutron absorption at higher-than-thermal neutron energies.

For a monoenergetic source of neutrons with velocity v, the neutron flux φ can be defined as

$$\varphi = n\,v \qquad \text{(VI.1)}$$

where n is the neutron density of the beam. The units of φ are n/cm^2-sec. The neutron flux is related to the activity induced in a sample by the activation equation

$$A_0 = N\,\varphi\,\sigma\,S \qquad \text{(VI.2)}$$

where A_0 is the induced activity, in dps, at the end of the irradiation;

N is the number of target nuclei, and can be calculated from the mass of element in sample (m), the abundance of target isotope (a), Avogadro's number (N_a) and the target element atomic weight (AW) according to $m \cdot a \cdot N_a / AW$;

φ is the neutron flux (n/cm^2-sec) used to irradiate the sample;

σ is the cross section of the neutron absorption reaction, in units of cm^2;

S is called the saturation term and accounts for decay of any induced activity during the irradiation. S equals 1-exp (-0.693 $t_i/t_{½}$), where t_i is the irradiation time and $t_{½}$ is the half life of the induced radioactivity.

Since the neutron flux is not monoenergetic, and since the target nuclide's (n,γ) cross section may not follow exactly the 1/v law, a correction in the cross section is required. One can substitute for σ in eq. VI.2 the effective reaction cross section (σ_{eff}), given by

$$\sigma_{eff} = (g + rs)\sigma \qquad \text{(VI.3)}$$

where g is a measure of the departure of the reaction cross section from 1/v in the thermal region of the neutron spectrum;

r is a measure of the fraction of epithermal neutrons (neutrons with slightly higher-than-thermal energies) in the total spectrum;

s is a measure of the departure of the reaction cross section from 1/v in the epithermal region.

Values for g and s for a number of nuclides have been determined and tabulated. For the ^{115}In target used in this experiment g = 1.019 and s = 19.8. The value for r depends on the shape of the neutron energy spectrum of the neutron source, and can be calculated from a measure of the cadmium ratio (R_{Cd}) using

$$R_{Cd} = \frac{g + rs}{r}\left[s + \frac{1}{K}\left(\frac{T}{T_0}\right)^{½}\right]^{-1} \qquad \text{(VI.4)}$$

where R_{Cd} is the ratio of induced activities in a target foil without and with a cadmium cover;

K is a constant, the exact value depending upon the thickness of the cadmium cover used (in this experiment K = 1.8161);

T is the neutron temperature (in this experiment T is assumed to be equal to T_0);

T_0 is equal to 293.6 K, the temperature at which the neutron velocity equals 2200 m/s.

Pre-weighed indium foils will be irradiated with and without a cadmium cover in the Pu-Be neutron source. The induced $^{116m1}In$ activity ($t_{½}$ = 54.2 min) will be measured using a HPGe semiconductor detector, and the counting efficiency of the system will be determined by counting ^{60}Co and ^{22}Na gamma standards. Rearrangement of eq. VI.2 and appropriate substitution will allow for the calculation of the thermal neutron flux.

PROCEDURE

A. Sample Preparation, Irradiation and Counting

Weigh two indium foils as accurately as possible and place one foil between two sheets of cadmium. Position the foils side-by-side in one of the side-port irradiation positions and irradiate for approximately one hour. Remove the foils and place each in a small plastic bag for counting. Count each foil for approximately 15 minutes by reproducibly positioning the samples on top of the germanium detector. Determine the net photopeak counts and the photopeak count rate of the 1294-keV peak of ^{116m1}In for each sample. Divide each activity by the sample mass and calculate a cadmium ratio for your irradiation conditions. Determine the value of r using eq. VI.4, and the value of σ_{eff} using eq. VI.3. (Note: $\sigma = 162 \times 10^{-24}$ cm^2 for ^{115}In)

B. Counting Efficiency Determination

The photopeak counting efficiency for the 1294-keV peak for ^{116m1}In can be gotten by counting the calibrated ^{60}Co and ^{22}Na sources in exactly the same geometry used for the indium foils. Determine the net photopeak count rates of the 1173-keV and 1332-keV photopeaks of ^{60}Co and the 1275-keV photopeak of ^{22}Na. Use the source disintegration rate data to calculate the absolute photopeak counting efficiency (ε_{pp}) at each energy, plot log ε_{pp} versus log E_γ and fit with a straight line. Use the equation for this energy calibration plot to estimate the counting efficiency at 1294 keV and convert the measured ^{116m1}In photopeak count rate to disintegration rate for the <u>uncovered</u> sample. (Note: The 1294-keV gamma ray is emitted in 84.4% of the ^{116m1}In decays.) Calculate the thermal neutron flux of the Pu-Be neutron source by appropriate substitution into eq. VI.2.

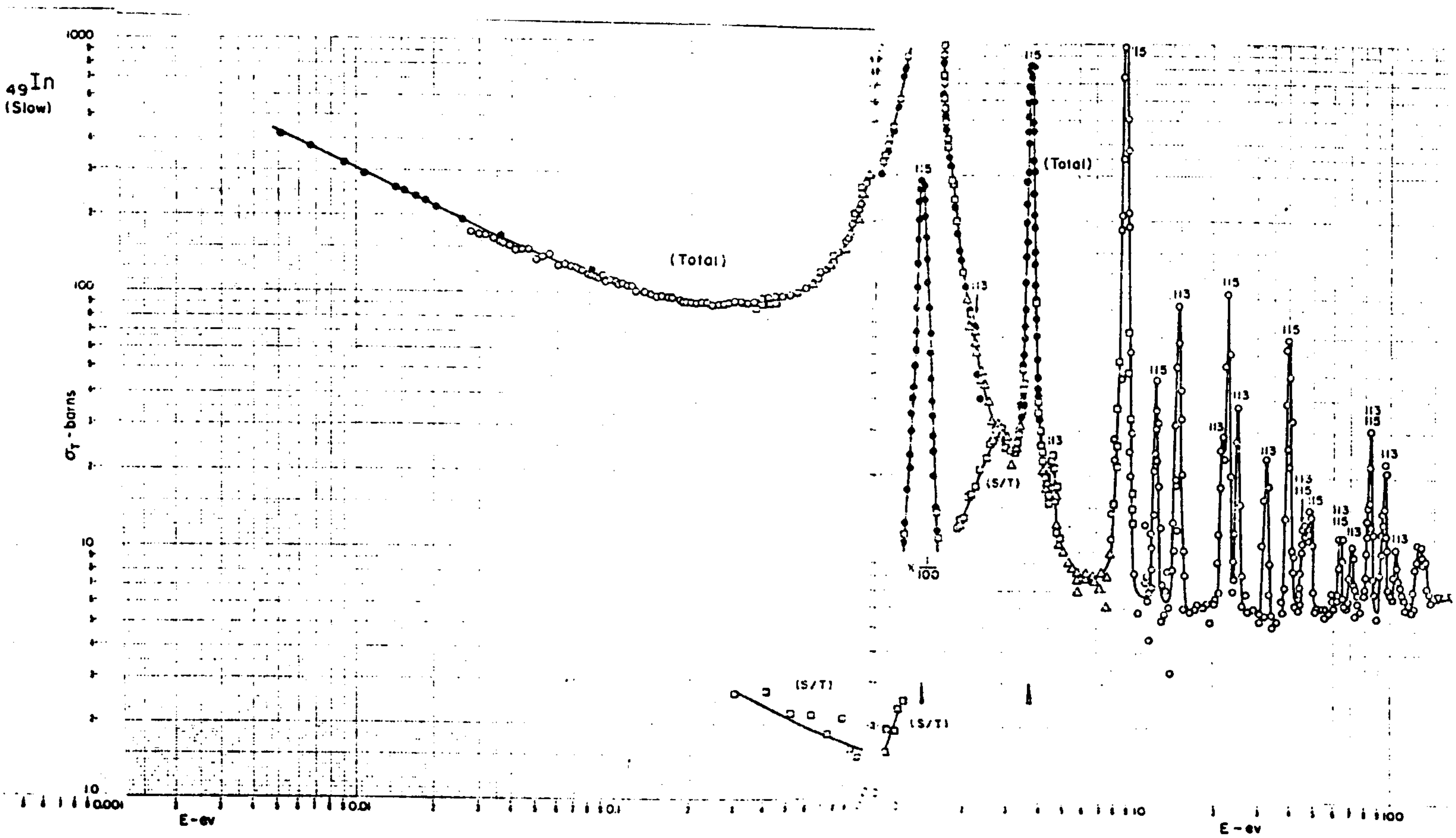

Figure VI.1. Neutron Absorption Excitation Function For Indium