Neutron Energy Calibration using the cross-section ratio method and determination of average cross-section

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Introduction

Precise knowledge of neutron flux and neutron energy distribution is required for determining neutron cross sections with an accuracy of ~3% from threshold to 20 MeV which are important to nuclear reactor technology and multi-elemental analysis of various samples by NAA.

A variety of methods are available for neutron energy measurements [1-4]. Some of these involve special equipments or modification of the target assembly and are incapable of measuring energies near the target within a range of 100 mm. Conventional activation analysis approach of measuring fast neutron energy has been, by taking ratio of cross-sections of (n, p) and (n, 2n) reactions on two different target materials irradiated at the same place and duration. This approach has its own advantages. In the present work, estimation of neutron energy is done by using the cross-section ratio method of single target material. For the present study we have used ^{58}Ni as reference isotope. The cross-sections for (n, 2n) and (n, p) reactions of ^{58}Ni as well as their ratios, are strongly neutron energy dependent.

Calculations

The (n, p) and (n, 2n) reactions cross sections are calculated in the present work using the computer code EMPIRE [5] which utilizes the Hauser Feshbach formalism for cross-section calculations. The transmission coefficient for neutrons and protons are calculated in the code using the global optical model potential of Koning [6].The level densities have been calculated using the generalized superfluid model which is specific for the code. The effect of pre-equilibrium emission on the reaction cross-section has been incorporated in the calculations using the PCROSS model for proton and DEGAS model for neutrons.

We utilized the ratio of (n, p) to (n, 2n) reaction cross-sections as calculated from the code for calibration of the neutron energy in the energy range 13-16 MeV i.e from the threshold of the (n, 2n) reaction cross-section. The values of the cross-sections calculated using the code are validated by comparing them with the experimental measurements as given in the EXFOR library. The results are shown in fig. 1.

From the fig., it is observed that the (n, p) reaction cross-section decreases whereas (n, 2n) reaction cross-section increases in the range 13 to 16 MeV.

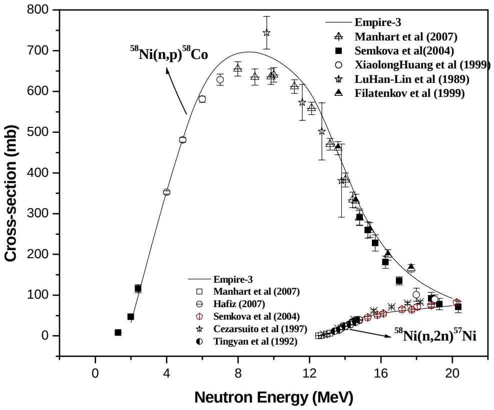

Fig. 1 Calculated and experimental ^{58}Ni (n, p) and ^{58}Ni(n, 2n) reaction cross-sections

It is also easily observed from fig 2 that the ratio is stongly neutron energy dependent and thus could be used to calibrate the neutron energy in the desired range of energy using the ratio of cross-sections.

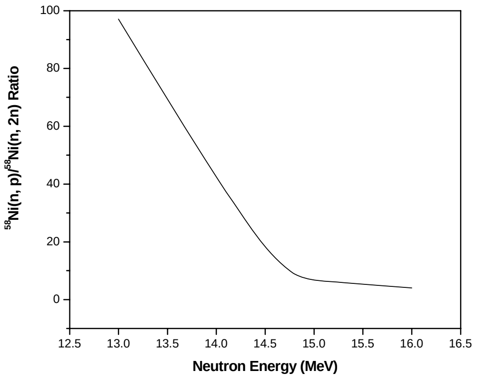

Fig. 2 Ratio of ^{58}Ni (n, p) $^{58g+m}$Co to ^{58}Ni (n, 2n)^{57}Ni reaction cross-section.

Measurement of cross-section at a given neutron energy is affected by the neutron spectrum. Neutrons produced from neutron generator have energy dependence, due to emission angle of neutrons as well as due to the scattering of neutrons from structure materials surrounding the Tritium Deuterium target. The contribution of low energy neutrons due to primary and secondary scattering is significant (~ 30%). Since neutron cross-section has strong energy dependence the cross-section measurement is inherently affected by the neutron flux distribution. Table 1 shows the calculation of cross-section based on calculated neutron flux distribution [7].

Table 1. Calculated values of ^{58}Ni (n, p) $^{58m+g}$Co and ^{58}Ni(n, 2n)^{57}Ni reaction cross-section

Neutron Energy (MeV)	Neutron flux N(E) x 10^{10}	σ (n, p) mb	σ (n, 2n) mb
14.0	0.18	407.5	26.1
14.2	0.87	379.1	30.6
14.4	5.37	355.6	34.6
14.6	7.9	341.2	41.5
14.8	6.56	325.5	44.2
15.0	2.5	298.9	45.4

The average value of the cross-section for a reaction is calculated as:

$$\bar{\sigma} = \frac{\int_0^{Emax} \sigma(E)N(E)dE}{\int_0^{Emax} N(E)dE}$$

From table 1 the average value of energy comes out to be 14.63MeV (E_{avg}) and the maximum flux is obtained for 14.6 MeV (E_{peak}) neutrons. for ^{58}Ni (n, p)$^{58m+g}$Co reaction the average cross-section comes out to be 338.38 mb which is not same as the cross-sections at E_{peak} (341.2 mb) neither the value at E_{avg} (339 mb). Similarly for the ^{58}Ni(n, 2n)^{57}Ni reaction the cross-section values at E_p(41.5mb) and E_{avg}(42 mb) differ from that of the average value 40.7 mb. This calculation shows the importance of neutron flux for cross-section determination and in determining the neutron energy. The ratio measurement will therefore predict neutron energy which may differ from average neutron energy or peak neutron energy. This difference will become significant if there is large contribution of scattered neutrons. Hence calibration of neutron energy using cross-section ratio method should be used cautiously. We are further studying the isotopes which could be used for neutron energy calibration in a wide range starting from threshold to 20 MeV which could be of great importance for advanced fission and fusion based reactors.

References

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