FLUX PROFILE ANALYSIS IN BORON CONCENTRATED PARAFFIN WAX USING β - γ COINCIDENCE TECHNIQUE

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INTRODUCTION

Many ideas and techniques of atomic and nuclear physics are based on the properties of the radioactive elements and their radiations. Neutron Activation Technique (NAT) is used for neutron flux mapping in homogenous boron concentrated paraffin wax. For this purpose, gold foils as activator detectors were prepared by irradiating process in an Americium-Beryllium (²⁴¹Am-⁹Be) neutron field. After this, the induced activity was measured by time coincidence method using a Sodium iodide (thallium) NaI (TI) crystal detector and organic scintillation “Anthracene” detector for gamma ray and beta particle detection respectively. The flux profile was mapped by measuring induced activity. Errors in measurements and calculations were estimated by Poisson distribution.

THEORY AND MEASURING METHODS

Gold foils can be used as the activator detector. The nuclear interaction on gold is ¹⁹⁷Au (n, γ) ¹⁹⁸Au. This reaction is induced to prepare ¹⁹⁸Au radioisotope. Relation for Incident flux and induced activity is shown in following equation.

$$\phi(E) = \frac{A(t) \times M}{N_A W \sigma_{act} (1 - e^{-\lambda_a t_a}) e^{-\lambda_c t_c} (1 - e^{-\lambda_m t_m})} \quad (1)$$

The model used for induced activity measurements due to irradiation is described as follow.

$$A(t) = \frac{N_\beta N_\gamma}{N_{tc}} \quad (2)$$

The induced activity was measured by 2π - β - γ coincidence method by irradiating the foils in paraffin with homogenous boron concentration tank. Foils were activated at different radii from the source.

CONCLUSSIONS

Flux profile mapped as the function of paraffin thickness decreases drastically and shows a good argument to the theoretical predicted flux. Theoretical predicted flux expands by considering the source as the point source. Errors are calculated by Poisson distribution. Calculated errors were found to increase exponentially. Nominal effects were found for relative induced activity measurements. 2π - β - γ Coincidence to NAA method is applicable for neutron flux profile mapping in paraffin wax with homogenous boron concentration.

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ABSTRACT

In this paper, Neutron Activation Technique (NAT) is used for neutron flux mapping in homogenous boron concentrated paraffin wax. For this purpose, activator detectors were prepared by irradiating process in an Americium-Beryllium (^{241}Am - ^9Be) neutron field for the required time period to induce approximate saturation activity. After this, the induced activity was measured by time coincidence method using a Sodium iodide (thallium) NaI (TI) crystal detector and organic scintillation “Anthracene” detector for gamma ray and beta particle detection respectively. The activator detectors were activated at different radii from the irradiator neutron source in boron mixed paraffin wax. The flux profile was mapped by measuring induced activity. Errors in measurements and calculations were estimated by Poisson distribution.

1. INTRODUCTION

Many ideas and techniques of atomic and nuclear physics are based on the properties of the radioactive elements and their radiations. The flux profile mapping in the boron mixed paraffin wax is one of the applications of such techniques, which explore the time coincidence technique for neutron activation analysis (NAA). Coincidence technique is used to identify or quantify the nuclear decays based on the multiple

ray's signatures. Coincidence counting refers to at least two radiations measured in each event. The application of coincidence technique to NAA is been reported in literature since 40 years now, number of publications describing the use of coincidence in NAA are available [1]. Time based beta-gamma coincidence method have an advantage since activity of radionuclide can be measured directly excluding corrections arising from decay parameters. Since time regulation of counting unit is comparatively large, it enables the coincidence unit to count accidental counts as well [2-3]. In this paper 2π - β - γ coincidence to NAA method is investigated for flux mapping. Second section of this paper explains theory & model for measurements, third section includes experimental methods & techniques. Fourth section contains results and discussions and last section concludes results.

2. THEORY

Gold foils can be used as the activator detector. The nuclear interaction on gold is $^{197}\text{Au} (n, \gamma) ^{198}\text{Au}$, which can be used as the prime nuclear reaction from the irradiating ^{241}Am - ^9Be neutron source. This reaction is induced to prepare ^{198}Au radioisotope. Relationship between formation of ^{198}Au nuclides and incident flux at energy E due to irradiation is described by the following equation.

$$N(E) = \frac{R}{\lambda} (1 - e^{-\lambda t_a}) e^{-\lambda t_c} (1 - e^{-\lambda t_m}) \quad (1)$$

where $R = \frac{N_A \phi W \sigma_{act}}{M}$ is the reaction rate for formation of radionuclide ^{198}Au , N_A is Avogadro's number, ϕ is incident flux in $\text{n/cm}^2\text{-sec}$, W is weight of activated specimen in grams, M is mass number of activated specimen in amu and σ_{act} is the activation cross section in barn at energy E . t_a , t_c and t_m are activation, cooling and measuring time respectively. For the flux measurement Eq. 1 changes to the following form

$$\phi(E) = \frac{A(t) \times M}{N_A W \sigma_{act} (1 - e^{-\lambda t_a}) e^{-\lambda t_c} (1 - e^{-\lambda t_m})} \quad (2)$$

where $A(t)$ is the induced activity of an irradiated specimen. However, measuring time can be neglected if it is much smaller compared to half life ($T_{1/2}$) of a specimen or activated detector.

2.1 Model for ^{198}Au

The β - γ coincidence method assumes a source of activity $A(t)$ which emits one beta particle cascade to one prompt gamma radiation per disintegration. Each of these radiations is detected by the dedicated detectors. If the background counts for both channels are negligible, beta detector is blind to gamma radiations and gamma detector is blind to beta particles. Then, measured activity can be written as [4].

$$A(t) = \frac{N_\beta N_\gamma}{N_{tc}} \quad (3)$$

Where N_β , N_γ and N_{tc} are counts rate in beta, gamma and coincidence channels respectively.

However, detectors are capable of counting background counts and the detector's efficiency depends upon the energy of incident radiations. These and other factors such as resolving time of the coincidence unit necessitate to be corrected in the above simple model. Decay scheme of ^{198}Au gives a good approximation of above model. Fig.1 shows the decay scheme of ^{198}Au with 98.99% probability of beta particle (0.963MeV) cascade to gamma (0.411MeV). The activated detector is sandwiched between an organic scintillation "anthracene" detector and a NaI (Tl) crystal detector, which provides 2π geometry for detection system. The probabilities of detection efficiency for gamma and beta detectors are described as ε_γ and ε_β . Thus the count rates in gamma and beta channels are approximately as.

$$N_\gamma = A\varepsilon_\gamma, \quad N_\beta = A\varepsilon_\beta$$

Fig.1. Decay scheme of ^{198}Au

Hence, the total count rates in gamma and beta channels are

$$N'_\gamma = A\varepsilon_\gamma + N_{\gamma bg} \quad (4)$$

$$N'_\beta = A\varepsilon_\beta + N_{\beta bg} \quad (5)$$

where $N_{\gamma bg}$ and $N_{\beta bg}$ are background counts for gamma and beta channels. The coincidence unit can also count chance or false coincidence due to background counts or accidental counts during coincidence counting. Thus, the total count recorded at the coincidence channel contains both true coincidence N_{tc} and chance or accidental coincidence N_{cc} counts. Consequently, the total counts in coincidence unit are.

$$N_c = N_{tc} + N_{cc} \quad (6)$$

Where $N_{tc} = A\varepsilon_\gamma\varepsilon_\beta$, $N_{cc} = 2\tau N_\gamma N_\beta$ and τ is the resolving time of coincidence unit. Dead time losses can also be disregarded due to extremely small decay time of anthracene and NaI (Tl) detectors being 10ns and 230 ns respectively [5-6].

3. EXPERIMENTAL SETUP & MEASURING SYSTEM

3.1 Experimental Setup

Neutron Activation Technique (NAT) was used for neutron flux profile mapping of ^{241}Am - ^9Be irradiator neutron source in paraffin wax with homogenous Boron concentration. The source strength of ^{241}Am - ^9Be was 100GBq.

A tank of 60cm×60cm×60cm was filled with a homogenous mixture of boron in paraffin wax. Neutron source in a plastic holder was placed at geometric center of the prepared tank. Series of ^{197}Au activator detectors were activated by placing them at various radial locations in paraffin (C: 73.8%wt, H: 12.9%wt, B: 13.3%wt) tank. The specifications of ^{197}Au foils are 99.99% pure, $150 \pm 1.0 \text{ mm}^2$ area, $0.53 \pm 0.015 \text{ g}$ weight, and $1.2 \pm 0.01 \text{ mm}$ thickness. ^{197}Au foils were activated at different radii but at same axial position from 0-20 cm for six days. Foils were placed by making 2.5 cm diameter holes in irradiating system. The entire system was shielded for gamma and neutrons with 10 cm thick lead bricks. Schematic diagram of entire system is shown in Fig. 2. Induced activity due to irradiation was measured by the measuring system discriminating 0.41MeV gamma peak and 0.963MeV energy of beta particle.

Fig.2. Cross sectional geometry of irradiation setup,

- position of irradiating source ($^{241}\text{Am-}^9\text{Be}$),
- positions of activation detectors (^{197}Au)

Irradiated detector's activity was measured by time coincidence method using timing single channel analyzer (TSCA) with a NaI (TI) crystal and organic scintillator "Anthracene" detector.

3.2 The activity measuring system

The activity measuring system is designed to implement the $2\pi\text{-}\beta\text{-}\gamma$ coincidence method. Primary purpose of the coincidence unit is to measure the induced activity of an irradiated specimen.

Fig.3: Detailed diagram of detection unit

The activity measuring system comprises of detection unit and data acquiring unit. Fig.3 shows the detailed diagram of detection unit. Block diagram of activity measuring system is shown in Fig.4. The detection unit consists of two photomultiplier tubes (PMTs), each connected with scintillators. One PMT is connected to the NaI (TI) detector and other is coupled with Anthracene detector. NaI (TI) is coated with thin aluminum film to make the detector numb to other radiations. Before measurement detection unit was enclosed in a dark box for light shielding. The detectors were provided with an operating voltage through HV-power supply. Output voltage was set approximately 3-5 volts for each detector with the help of pulsar and tested for detection. Output signals from PMTs are fed to data acquiring sub unit. Data acquiring sub unit comprises of the electronic module where the output of the PMT is shaped, amplified, timed, delayed, converted to a logical signal and then detected in both branched modules of the sub unit. The shaped logical signal is sent to the coincidence unit through timing single channel analyzer (TSCA) which is used to discriminate the threshold. Shapes of the bipolar and logical pulses were analyzed with the dual channel cathode ray oscilloscope (CRO). Counts in their respective channels were recorded and used for the above mentioned model for the activity measurement.

Fig.4. Block diagram of β - γ coincidence unit, Pre-AMP: pre amplifier, AMP: amplifier, ΔT : delay timer, TSCA: timing single channel analyzer, PM: photomultiplier tube, HV-supply: high voltage power supply

4. RESULTS AND DISCUSSION

Beta-gamma coincidence technique gives a good approximation for relative, induced activity measurement and coincidence to NAA. Average resolving time of the coincidence unit is 0.475 μ sec, which is much larger than the decay time of an activated specimen. It enables the system to measure the counts without implementation of complex corrections. Flux profile of the irradiator source with average neutron energy 4.24MeV was plotted as function of paraffin wax thickness by using 2π beta gamma coincidence method to NAA, shown in Fig.5. The neutron flux measurement was also performed at the central irradiation cell of irradiation unit (in contact with the irradiator source). Thermal flux and fast flux at the central irradiating cell were measured to be 4.43×10^4 n/cm²-sec and 6.64×10^6 n/cm²-sec with 1.006 cadmium ratio. In distribution, the flux was found to decrease drastically due to loss of energy. This shows rapid decrease in the neutron economy due to loss of energy and gaining thermal energy. Furthermore, experimentally measured curve is in good comparison with the theoretical predicted flux. Theoretically predicted flux assumes the source as the point source whose flux varies as a function of $e^{-r/L}$ where L is diffusion length

taken 48mm and D is the diffusion coefficient taken 2.6mm for paraffin [7]. Since the radioactive decay is a statistical process, errors in measurements were calculated by Poisson's distribution. Calculated errors are presented in Table1. Results show that percentage statistical error as a function of paraffin thickness increases exponentially with the increase in paraffin thickness.

Fig.5. Total neutron flux as function of paraffin wax thickness

Increase in statistical error is due to the fact of increasing randomness in neutron path. At distance 17.5 cm statistical error is 158.3%, which indicates that neutrons have lost entire linearity. Hence, this work indicates the viability of the use of coincidence technique to NAA for flux profile mapping in the paraffin wax moderator.

Table.1. Neutron flux and their statistical error with different paraffin wax thickness

Paraffin thickness (cm)	Foil weight (g)	Flux per gram (n/cm ² -sec)	% Statistical Error
0	0.4987	6.80E+06	3.80%
2.5	0.5315	5.9E+06	4.01%
5.5	0.5016	3.0E+06	4.40%
8.5	0.5430	0.6E+06	7.10%
11.5	0.5016	0.2E+06	19.40%
14.5	0.538	0.075E+06	33.10%
17.5	0.5111	0.0055E+06	158.35%

5. CONCLUSION

Time coincidence technique was explored to NAA and its application for flux profile mapping in Boron concentrated paraffin wax. A 2π -beta-gamma coincidence system with NaI (TI) and Organic scintillator “Anthracene” detectors were used. The described model was applied to study the robustness of 2π - β - γ coincidence apparatus against variations in measuring conditions such as nominal source activity, radiation background, induced activity etc. The Minor effects were noticed in calculated results, which permit the use of 2π - β - γ coincidence system in multiplicity of experimental setup and environments. Thus 2π - β - γ Coincidence to NAA method is applicable for neutron flux profile mapping in paraffin wax with homogenous boron concentration. In comparison to the theoretical estimation, a good agreement was found. This validates the model for induced activity calibrations and flux profile mapping. The obtained results validate the 2π -beta-gamma coincidence to NAA method for flux profile mapping.

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