Measurement Of Inelastic Scattering Cross–Sections For Reactor Fast Neutrons From Yb\textsuperscript{174} Using The Time Of Flight Technique

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ABSTRACT

One of the horizontal channel of the reactor of 5 MW has been used to measure the inelastic scattering cross section of fast neutrons (neutron energy between 0.4 to 3.5 MeV) scattered from the rare earth isotope Yb\textsuperscript{174} by using the time of flight (TOF) technique.

The excited levels of Yb\textsuperscript{174} studied were (KeV, J\textsuperscript{s}):
\[889.70(8^+), [1318.30(2^+)], [1606.30(3^+)] and [1884.60(5^+)]\] as the results of the integral cross – section of inelastically scattered neutron from these individual levels.

Using the asymmetry in the neutron detection at forward and backward neutron counter to deduce the direct interaction to the compound nucleus formation during the inelastic scattering reaction.

Eight large (NE-213) neutron counters (4 at 0\degree angle and 4 at 180\degree angle) were used with dimension of 100 cm in length and 8.5 cm in diameter viewed by two photomultiplier tubes to detect the scattered neutrons from the target and two Ge (Li) detectors on the perpendicular direction of neutron counters to measure the \(\gamma\) - rays from the decayed levels of the nucleus.

From the coincidence between any of the eight neutron counters and any of the two \(\gamma\) – rays detectors, the start signal in the TOF spectra was measured; trigger at the time of \(\gamma\) – rays and stop from the neutron counter. The time resolution of 8.8 ns has been obtained between the eight neutron counters and one of the \(\gamma\) – rays detectors.

Data acquisition and system control were recorded event by event by HP-computer via CAMAC system and IBM computer for off – line analysis.

The charge comparison method (CCM) was used for the discrimination between neutron and \(\gamma\) – rays, and the optimization of the parameters were done by using Cf\textsuperscript{252} neutron source.

The experimental results were corrected for the attenuation and multiple – scattering in the sample, when the final results compared with the (HFM) theory.

EXPERIMENTAL PROCEDURE

The inelastic scattering reaction is very important to use in study of energy distribution of fast neutrons passed through the shields of fusion and fission reactors to protect these types of reactors. The breading ratio in these reactors depending on the energy spectrum of scattering neutrons when measure the inelastic scattering cross-section in the fuel and reactor materials [1].

Detection of neutrons scattered from the target nucleus was done by using the time of flight technique (TOF) through the knowledge of velocity (\(v_n\)) and scattered energy (\(E_n\)) of fast
neutrons to limit the incident energy \( (E_n) [2,3]: \)

\[
\text{TOF(ns)} = \left[ \frac{72.3 \text{ D}}{E_n' \text{ (MeV)}} \right]^{1/2}; E_n' = \frac{1}{2} m_n v_n^2 \quad (1)
\]

where:

- \( D \): The distance from target nucleus to neutron’s counters in (m),
- \( v_n \): Neutron’s velocity in (m/ns),
- \( m_n \): Neutron’s mass.

To obtain the fast neutrons from RRA channel reactor, a fragment of depleted uranium \( U^{238} \) was used by putting it near the reactor core to attenuate the \( \gamma \)-rays and the other one of \( Cd \) to remove the thermal neutrons, we used also \( B_4C \) to remove the resonance neutrons.

Fast neutrons emerge out from channel through a gate 1cm diameter and at the target with 4cm. The \( \text{Yb}174 \) target \((0.45 \times 2.84 \times 2.82) \text{ cm}^3\) was fixed at 450 with respect to neutron beam direction [4]. The neutron flux measured was \( 1.25 \times 10^8 \text{ n/s} \).

Eight similar neutron's counters, each one 100 cm length and 8.5 cm diameter were used, reinforced with two ends of photo-multiplier 58 DVP attached to organic scintillation liquid (NE 213) to separate between neutrons and \( \gamma \)-rays. These eight counters were arranged in two groups \( \Sigma A \) (forward hodoscopes) and \( \Sigma B \) (backward hodoscopes) at 00 and 1800 with respect to incident neutron's beam, the distance between the neutron's counters and the target was 1m.

Fig. (1). Schematic Diagram of RRA - Channel.
Two Ge(Li) detectors were used to detect the transmission of γ-rays from excited nuclear levels of the target. These two detectors were put at 90° corresponding to incident neutron beam, the crystal faces of these detectors were covered with Pb shield to protect from background rays.

**ELECTRONIC DESIGN**

The start signal of time of flight represents the coincidence time signal between the scattering neutrons and γ-rays which are released at time of γ-ray pulse.

The final signal was get directly after delay of 150ns through an analog to digital converter (ADC) connected with (CAMAC Multi-Crate Int.) system to control automatically the data passed through a magnetic tape with terminal computer HP-2748.

The γ-rays spectra emissioned after inelastic scattering process were recorded on a magnetic tape through two analog to digital converters - 4096 to distinguish the coincidence with neutrons scattered from the nucleus levels.

The separation method between γ-rays and fast neutrons has been performed by means of pulse shape dependence on density of ionization with different particles excited in neutron counters [5,6]; also we used the charge comparison method for this separation using the neutron source Cf252 for slow and fast components.

The detection of scattering fast neutrons from the target nucleus was done by means of recoil protons scattered through H2 atom in the eight NE-213 neutron's counters.
EXPERIMENTAL RESULTS

The coincidence events between $\gamma$-rays and scattered neutrons ($\gamma,n$) at neutron scattering energy were calculated by:

$$T(En') = \varepsilon_\gamma \varepsilon_n n \sigma_{n,n}(E_n) N \varphi(E_n) n(E_n)$$  \hspace{0.5cm} (2)

$$N = \left[ N_0 M a \right] / A$$  \hspace{0.5cm} (3)

$$n (En) = 0.453 \exp(-En/0.965) \sinh(2.29E1/2)$$  \hspace{0.5cm} (4)

where:

- $\varepsilon_\gamma$: Ge(Li) detector efficiency for $\gamma$-rays,
- $\gamma$: Solid angle of Ge(Li) crystal,
- $\varepsilon_n$: Neutron's counter efficiency,
- $\omega$: Solid angle of neutron's counter,
- $N$: Number of atoms in target nucleus,
- $N_0$: Avogadro number = 6.023 x 1023 mole$^{-1}$,
- $M$: Target mass = 5.684 gm,
a: Natural depleted abundance of Yb target used = 98.6 

A: Atomic weight of target = 173.939, 

\( \Phi_0 \): Incident neutron flux on nucleus target, 

\( \Phi_n \): Fission spectra of reactor at neutron incident energy (0.18 — 12.00) MeV. 

The equation of inelastic scattering cross-sections of any excited level of Yb: 

\[
\sigma_{n,n'}(Yb) = \frac{T(Yb)\gamma_n a(Yb)}{\epsilon_n^{\gamma_n} d(E_n) M(Yb) N_0 a(Yb)} \Phi_0(E_n) \Phi_n(E_n) M(Yb) N_0 a(Yb) 
\]

\( \sigma_{n,n'}(after) = [\sigma_{n,n'}(before)][\xi S_i^{-1} S_f^{-1}] \) 

where: 

S_i^{-1}: Neutron beam attenuation before reaching the target, 

S_f^{-1}: Neutron beam attenuation after passing the target, 

\( \xi \): Multiple scattering coefficient in nucleus target. 

![Graph](image)

**Fig. (5): INELASTIC SCATTERING CROSS-SECTIONS OF 1218.8 (2-) LEVEL** 

The experimental results of inelastic scattering cross-sections were compared with theoretical program CINDY [7] depending on Hauser — Feshbach theory.
Fig. (4). Inelastic scattering cross sections of $2897(3^+)$ level where points are the experimental results and solid line represent theoretical fit.

Fig. (6). Inelastic scattering cross-sections of $1606.8(3^+)$ level of $\gamma = 174$ compared with theoretical fit of CINDY.
REFERENCES


Fig. (7). INELASTIC SCATTERING CROSS - SECTIONS OF 1884.6 (5-.) LEVEL [Yb - 174]