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Pulse shape measurement of KENS thermal neutron source in the eV region by N-RAS

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ABSTRACT

In the eV region, pulse data from a moderator are scarce and have not been measured systematically. The pulse width in the eV region can be obtained by analyzing the neutron resonance absorption TOF spectra since it is represented by convolution of the resonance peak and the pulse shape of neutrons from a moderator. we constructed a neutron resonance absorption spectrometer (N-RAS) at KNES. We measured resonance peaks of Ta and U at low temperature(~20K), which resonance parameters are well known and the widths are narrow, in order to obtain pulse data of neutrons from the H_2O thermal moderator at KENS. We also evaluate the pulse shapes by the computer simulation. The pulse widths obtained experimentally are almost the same as those of calculated ones, and there exist little difference in widths compared with those evaluated by using the slowing down theorem in a infinite medium.

1. Introduction

Neutron spectrometers at pulsed spallation neutron source have been used for studying material structures and dynamics. Recently, some spectrometers which use high energy neutrons (in the eV region) are developed. But, at the pulse neutron source, although the information about the pulse shape of the neutrons emitted from a moderator is needed for data analysis when the energy is analyzed by the time-of-flight (TOF) method, However, the pulse shapes have not been measured systematically, since measurement of the time distribution of the eV region neutron is very difficult by the conventional the crystal monochromator. However, if the resonance absorption spectrum is measured, since the spectrum is the convolution of the resonance peak and neutron pulse shape, we can get the information about the pulse shape by analyzing it[1]. So, we performed the measurements of the resonance spectrum.

2. Neutron Resonance Absorption

Fig.1 is the layout of neutron resonance absorption spectrometer. A white neutron emitted from moderator is incident on the sample. When the neutrons are captured by the sample, γ-ray is emitted promptly, which is detected by a scintillation counter. The energy of incoming neutrons is determined by their TOF.

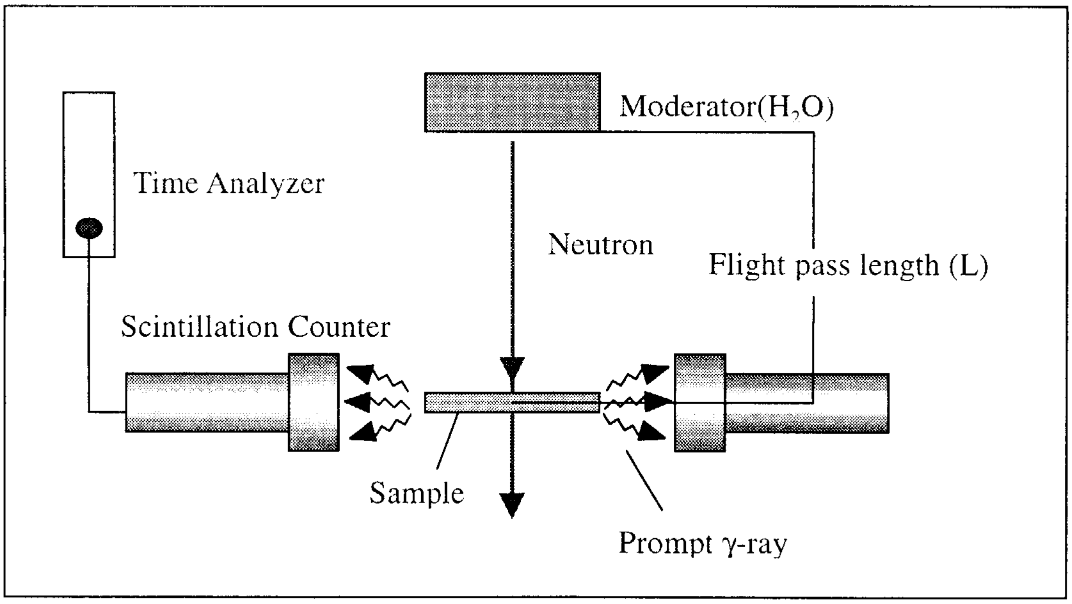

Fig.1 Layout of N-RAS

The TOF spectrum of neutron resonance absorption, *Ia(t)*, is given by

$$I_a(t) = \int\int dE dt_0 \left(1 - \exp\left[-n_d \sigma(E, T_{eff})\right]\right) I_0(E, t_0) \delta(t - t_0 - L/v), \qquad (2.1)$$

Where $\sigma(E, T_{eff})$ is the resonance absorption cross section and n_d is the number density of the resonance absorbing atoms per unit area perpendicular to the neutron beam, and L is the flight length, v is the neutron velocity at the resonance energy E_0. Here, the absorption cross section is modified by the Doppler broadening which corresponds to the thermal motion of the absorber atom. Diffusive motion of the absorbers in a solid is slower than the thermal vibrations, so we can neglect the effect of the diffusion in this method. The absorption cross section is written as follows,

$$\sigma(E)=\frac{\sigma_0\xi}{2\sqrt{\pi}}\int dy\exp\left[-(\xi/2)^2(x-y)^2\right]\Big/\left(1+y^2\right), \tag{2.2}$$

Where $x=2(E-E_0-R)/\Gamma_t$, $\xi=\Gamma_t/\Delta$, $R=(m/M)E_0$ and $\Delta=2\sqrt{Rk_BT_{eff}}$. Where Δ is effective Doppler width, σ_0 is the peak values of the resonance of absorption cross section, E_0 is the resonance energy, and m and M are the mass of the neutron and the absorber atom. The intrinsic line width Γ is defined as the full width at half-maximum (FWHM) of the resonance. T_{eff} is called effective temperature corresponding to the average energy of vibrational degree of freedom of the lattice[2][3]. $I_0(E,t_0)$ is a pulse shape function of the incident neutrons. We adopted the asymptotic solution of the neutron slowing down equation in the infinite system, written as

$$I_0(E,t)=(\Sigma_s vt)^2\exp(-\Sigma_s vt). \tag{2.3}$$

Here, Σ_s is a macroscopic neutron cross section, but we treat this as a parameter. In the analysis, when the neutron was absorbed, a prompt γ-ray is emitted from the compound nucleus in the order of 10^{-14} sec. We detect this γ-ray by N-RAS, analyze the resonance peaks, get a value of parameter Σ_s, and finally obtain the pulse shape by substituting the value of Σ_s to equation (2.3).

3. Experiment and Simulation Calculation.

The experiments have been carried out by using the resonance absorption spectrometer DOG at KENS, Neutron Scattering Facility at KEK. At this facility, 500MeV proton beam hit the tantalum target to produce the fast neutrons. The fast neutrons are slowed down by the light water moderator, and are supplied to each spectrometer. The reflector is Be, and decoupler is B_4C, the decoupling energy of which is 95eV. DOG spectrometer is placed at H7 beam line of KENS. The flight path length is L=9.53m. The samples we adopted were uranium and tantalum, because they have some resonance peaks in the eV region and their resonance parameters were well known (See Table.1). γ-rays emitted from the resonance atoms were detected by plastic scintillators at a distance of 3.5cm from the center of the sample.

Table.1 Resonance parameters of U and Ta

	E(eV)	σ_0 (b)	Γ(meV)	Γ_i (meV)
U	6.67	21790	27.5	26
	20.9	32199	34	25
	36.8	40121	57	25
	66.15	21535	48	26
Ta	4.27	19460	57	53
	10.35	9400	60	55
	24.085	5940	60	53
	39.52	16690	100	60
	64.01	1730	70	64

We also performed simulation calculation for the KENS target-moderator-reflector system. LCS was used for the calculations with ENDF/B-V cross-section data. The geometry of the KENS target-moderator-reflector system was simulated precisely. We calculate the time distribution of the neutrons from KENS thermal moderator.

4. Result and Discussion

Fig.2 shows the resonance spectrum of U. Sharp peaks appear at the resonance energies. We performed the least square fitting with equation(2.1) to these resonance peaks to obtain the parameter Σs. n_d's of U and Ta is 12.147×10^{19} (#/cm^2), 4.165×10^{19}(#/cm^2) and effective temperature(T_{eff}) is 73.95(K), 87.356(K), respectively. Fig.3 shows the experimental data and the fitting curve. The fitting curve is in very good agreement with the experimental data. By substituting Σs obtained by the fitting for equation(2.3), neutron pulse shape can be determined. We compared this results with the simulation. Fig.4 shows the pulse shapes of the incident neutrons determined from the fitting result and from calculation simulation in each resonance energy of U.

The results obtained by the experiment and calculation are in good agreement at each energy, so it can be said that the simulation calculation is usable in the eV region. Next, we deduced the FWHM's of neutron pulse shapes. Fig.5 shows the FWHM's of the neutron pulse shapes at the resonance energies of U and Ta, and the calculated value from simulation . It turns out that the experimental result and simulation well correspond again. And we fitted the FWHM of this simulation calculation result by equation,

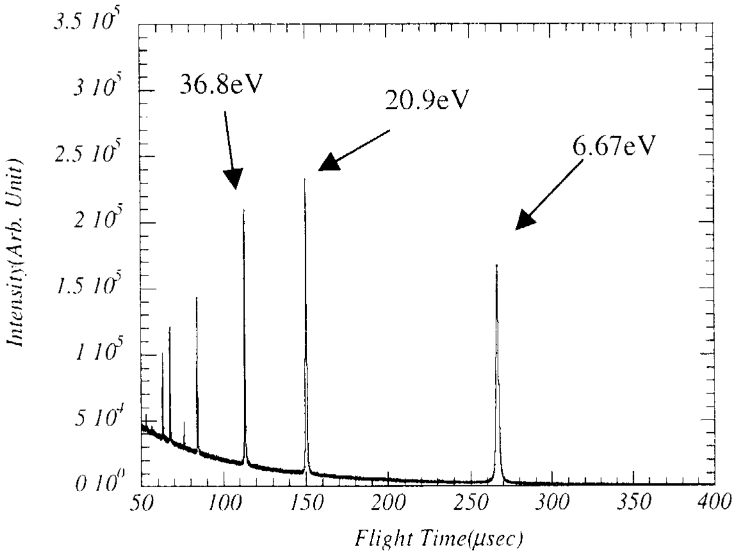

Fig.2 Resonance spectrum of U foil

$$\Delta t = aE^{-0.5}. \qquad (4.1)$$

This equation is obtained from the equation(2.3). But this equation did not give good fit to the result, so we change the value (–0.5) of the index of the energy, and redid the fitting. Finally, when the value of the index is –0.475, good fit was obtained. There is a little difference from the slowing down theorem in the infinite system. This will be due to the effect of the time width of the proton incident of the KENS target. The proton time width Δt_p is about 0.1 micro seconds. So, we considered that the FWHM Δt_r obtained experimentally was affected by Δt_p. We assumed that Δt_r was expressed as follows.

$$\Delta t_r = \sqrt{\Delta t^2 + \Delta t_p^2}. \qquad (4.2)$$

Here the Δt is the theoretical FWHM deduced from the equation(2.3). By using Δt and Δt_p, we can obtain theoretical value of Δt_r corresponding to experimental one. We also performed the fitting to Δt_r by the equation(4.1) to obtain the value of the index. The index giving lest fit was –0.477. This value is very close to the value (-0.475) of the simulation results.

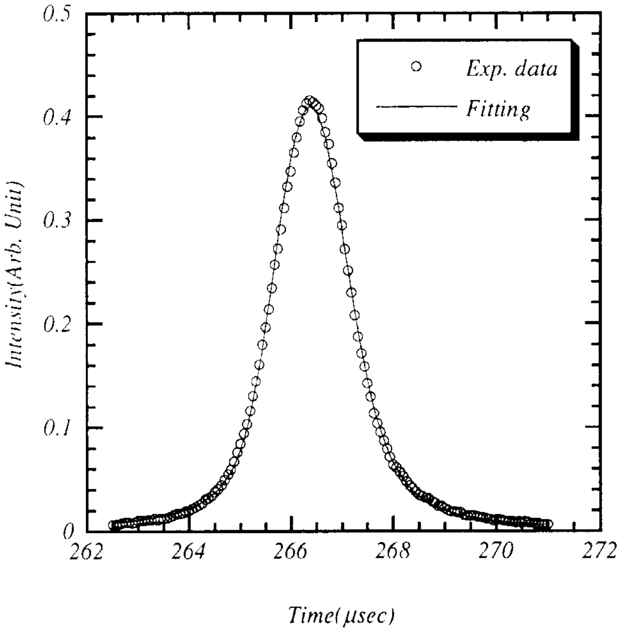

Fig.3 Experimental data and fitting curve of the resonance peak of U foil at 6.67eV

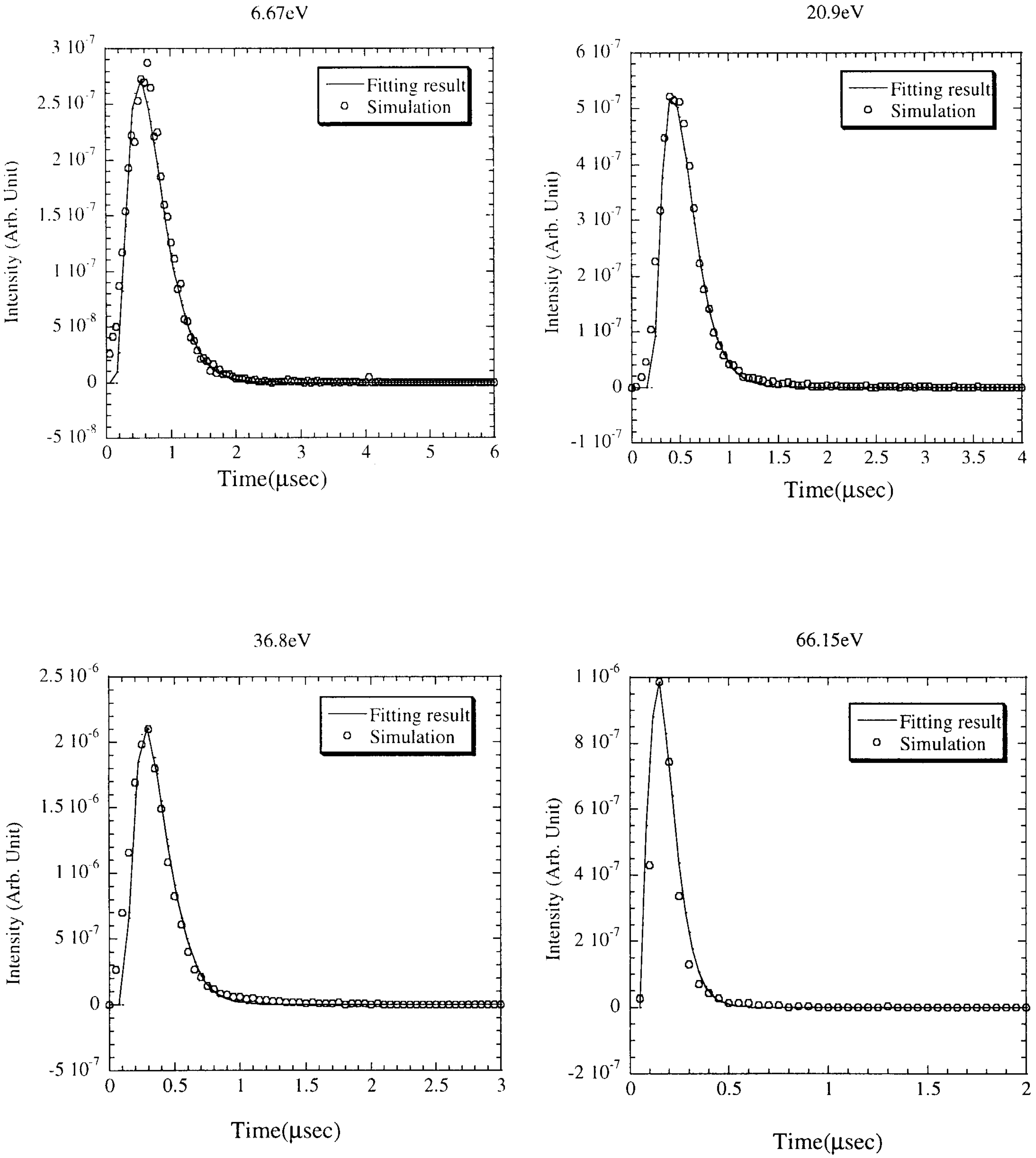

Fig.4 The neutron pulse shapes determined from fitting result and simulation calculation at energy 6.67, 20.9, 36.8, 66.15eV

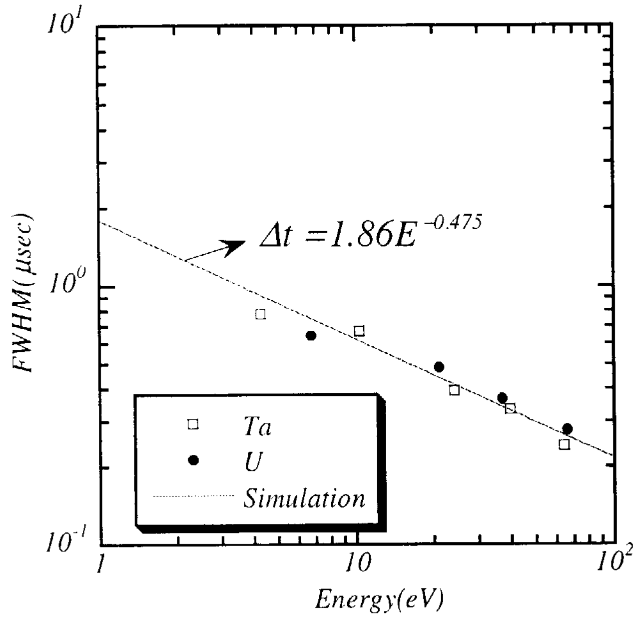

Fig.5 FWHM determined from fitting result of resonance peaks of U and Ta, and from simulation calculation.

5. Conclusion

It was turned out in this study that we could obtain the pulse data of the eV region of neutrons emitted from a light-water moderator by N-RAS. The experimental results are good agreement with the simulation calculation.

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