6. Utilizations of Filtered Neutron Beams at DALAT Nuclear Research Reactor

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ABSTRACT

Neutron beam utilizations in basic and applied researches have been important activities at the Dalat nuclear reactor. The neutron filters with single crystal of silicon are used to produce thermal neutrons at the tangential horizontal channel and quasi-monoenergetic 144 KeV and 54 KeV neutrons at the piercing beam tube. The paper presents some relevant characteristics of the filtered neutron beams at the two horizontal channels. Applications of neutron beams in prompt gamma-ray activation analysis and in nuclear data measurements are briefly described.

I. INTRODUCTION

The exploitation of the Dalat nuclear research reactor began in early 1984 with main activities in neutron activation analysis (NAA) and radioisotope production. The space around the horizontal beam ports had been empty until 1987, when a pneumatic transfer system was installed near the thermal column for rapid NAA and delayed neutron counting analysis. These instrumental analytical techniques, together with the development of radiochemical methods have substantially strengthened our capability in analytical services. However, there was a number of elements, for which the neutron activation method is not suitable, or cannot be applied at all. Thus, prompt gamma-ray activation analysis (PGAA) has been developed, and to some extent, the new non-destructive analytical technique enabled us to overcome the above mentioned difficulty. From 1989, thermal neutrons from the tangential horizontal channel No 3 have been used for PGAA. The insertion in this channel of a neutron filter assembly with single crystal of silicon has significantly enhanced the thermal-to-fast fluxes ratio and the collimation of the extracted neutron beam. The beam port facilities and arrangements were designed not only for PGAA, but also for neutron radiography and thermal neutron transmission experiments. Encouraged by the success of using neutron filters in channel No 3 for producing the thermal neutron beam, efforts have been made in the last years in extracting and using quasi-monoenergetic intermediate neutrons at the piercing horizontal channel No 4. Single crystal silicon filter in combination with additional neutron absorbers, such as B, S, Ti provides quasi-monoenergetic neutron beams of 144 KeV and 54 KeV. The neutron beam intensities are high enough for a number of applied and basic researches.

II. THERMAL NEUTRON BEAM AT TANGENTIAL CHANNEL (CHANNEL NO.3)

II.1. Experimental set-up and neutron beam characteristics.

In order to improve the thermal-to-fast fluxes ratio and to decrease gamma background as much as possible, different combinations of neutron filters consisting of graphite, lead, single crystal of silicon etc. were tested (Fig. 1). The main characteristics of the thermal neutron beam with some filter assemblies are shown in Table I.

Table I : Main characteristics of the filtered thermal neutron beam.

Composition of the filter assemblies	F(th) (n/cm2/s)	F(f>1MeV) (n/cm2/s)	R(Cd/Au)	I(gamma) (R/h)
No filter	5.8 E7	4.5 E5	5	4
80mmC + 50mmPb	1.7 E7	3.5 E4	12	1.8
80mmC +100mmPb	5.5 E6	1.2 E4	19.5	0.8
comp. No2 + 366 mm Si	3.5 E6	n E1	77.5	0.22

The variation of the neutron beam parameters with the thickness of the silicon filter was also investigated and shown in Fig 2.

The single crystal silicon filter improved significantly the collimation and the sharpness of the neutron beam as shown in Fig. 3, where the resolution ratio L/D determined by taking the radiographs of the cadmium foil with holes of different diameters is plotted versus the thickness of the filter [1,2]

From the above mentioned experimental results it is obvious that the use of single crystal silicon filter with optimum thickness would considerably improve the relevant characteristics of the thermal neutron beam. In fact, such improvement has been observed through the increase in the precision and sensitivity of PGAA due to the reduction of the background under peaks in the prompt gamma ray spectra. As an example, in Fig. 4 and Fig. 5 are shown two prompt gamma spectra of the same sample obtained without and with the neutron filter, where the peaks of interest at low energy range (for instance 182 KeV peak of Gd) appear only in the latter case.

II.2. Applications

The thermal neutron beam has been utilized in PGAA [3], neutron radiography [4] and measurements of the macro neutron cross-sections of geological samples [5]. Some applications

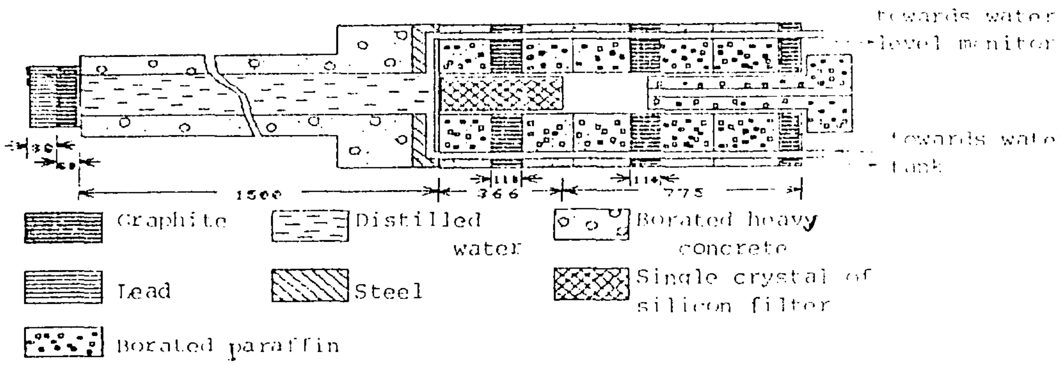

Fig. 1 : Sectional view of the neutron beam facility in the Tangential channel (No 3).

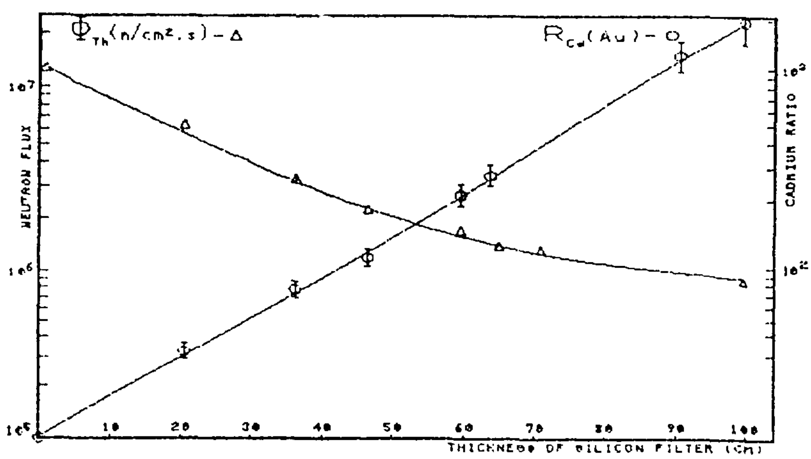

Fig. 2 : Variation of the thermal neutron flux and cadmium ratio (Au) with thickness of the silicon filter

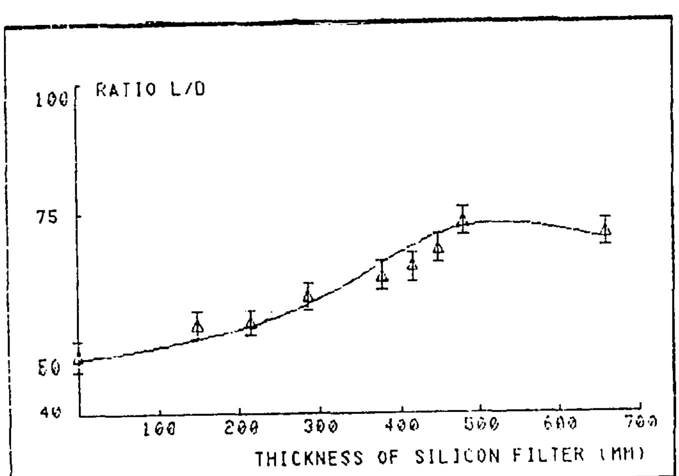

Fig. 3 : Variation of the L/D resolution ratio versus thickness of the silicon filter.

of PGAA in elemental analysis will be presented below.

In the experiments, prompt gamma spectra were measured by the coaxial HP-Ge detector with FWHM of 2 KeV at 1332 KeV. The data-handling system is an 8K channels ADC/MCD combination interfaced with a fast computer IBM/PC-AT of 26 MHz. The elemental concentrations were determined by the relative method with the use of certified reference materials such as NBS-1573, IAEA-SL-1, IAEA-A-11, NBS-1632A, NBS-1571, NBS-Bowen's Kale etc.. Besides, the internal standard method has also been used in cases where matrices of analysed samples and standards are not similar. Table II shows the estimation of the analytical sensitivity of elements based upon 1 gram sample for 1 hour irradiation.

Table II : Sensitivity for PGAA measurements at Dalat Reactor (estimate is based on 1g sample in 1h irradiation)

Elements	Sensitivity (%)
B,Gd,Sm	0.0001 - 0.0005
Cd(*),Hg,Dy	0.001 - 0.002
Cl,Mn,Nd	0.01 - 0.04
K,Na,V,Ti	0.02 - 0.5
Si,Al,Ca,Fe,Ni,H	0.4 - 2.0
N,C	5.0 - 10.0

Among the elements listed in Table II, B,N,H,C cannot be determined by conventional NAA while PGAA is an unique non-destructive method of analysis based on the reactor facility. From routine determinations of boron concentration in biological, geological and environmental samples, several interesting practical uses of the PGAA method can be mentioned as following :

- Comparison of the boron concentrations in natural gingsengs and in callus ginsengs obtained by the plant tissue culture technique would permit to choose the suitable culture medium , the quantity of boron needed to add into that medium as well as to apply some relevant procedures of tissue culture process.
- Investigation of the correlation between boron and tin concentrations in geological samples serves as the geo-chemical indication in exploration and assessment of natural mineral resources.
- Analysis of boron in sediment and sand samples has been carried out because boron could be chosen as a relevant candidate for labelling sand in harbours.
- Determination of the C/H ratios in crude oil.
- Determination of the nitrogen concentration in various categories of animal foods using a (5 x 5) inches NaI(Tl) detector helps farmers to regulate rational food portions to domestic animals during different growth periods.

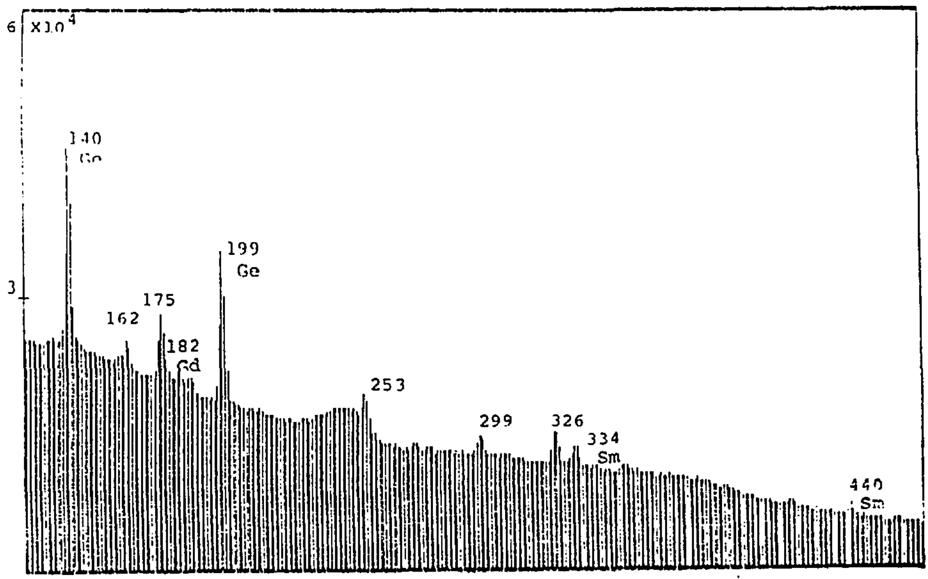

Fig. 4 : A portion of the prompt gamma spectrum of a rare earth sample irradiated by the neutron beam without the silicon filter.

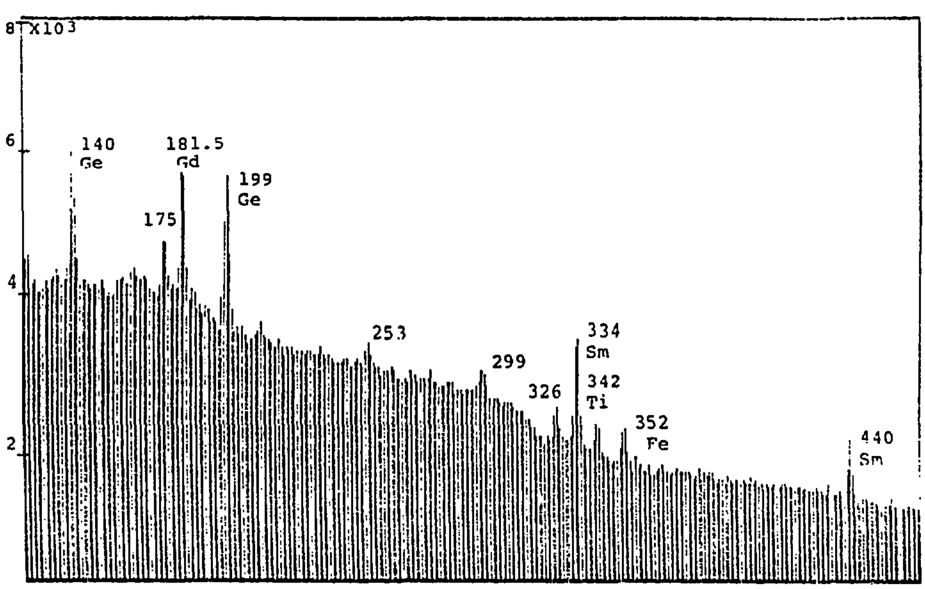

Fig. 5 : The corresponding spectrum portion of the same sample irradiated by the neutron beam with the single crystal silicon filter of 366 mm thickness.

- The PGAA technique is also used in analysis of Gd,Sm,Nd in products derived from separation and extraction process of rare earth ores. The prominent advantage of gadolinium analysis with trace concentrations in other rare earth matrices by PGAA comparing with INAA and even RNAA is proved.

- Advantage of PGAA in analysis of macro-constituents in various materials as cement, steel etc. is exploited in the estimation of the quality of some industrial products.

III. FILTERED NEUTRON BEAMS AT PIERCING HORIZONTAL CHANNEL No 4

III.1. Filtered neutron beams characteristics.

Due to the abundance of fast and epithermal neutrons, the piercing horizontal channel is most suitable for producing quasi-monoenergetic neutrons in the intermediate - energy region by using neutron filters. A 98 cm long single crystal of silicon filter has been installed in the channel (Fig. 6), enabling us to produce well collimated beam of thermal neutrons, as well as neutrons with energy 144 KeV and 54 KeV. Fig. 7 shows the pulse-height distribution of recoil protons measured with a cylindrical proton proportional counter type SNM-38. A 764 KeV peak corresponding to the total energy of (n,p) reaction with thermal neutrons on He-3 serves as reference energy. The energetic spectrum of the filtered neutron beam was obtained by differentiating the recoil proton energy distribution of Fig. 7 . The FWHM of the 144 KeV and 54 KeV lines are 22 KeV and 8 KeV respectively. To obtain single line spectra, additional selective neutron absorbers were used (Fig. 8, 9). The fluxes of quasi-monoenergetic neutrons measured at 25 cm from the beam port outlet by activation of Au-foils are as following :

F(th) = 1.8E7 n/cm2/s
F(54 KeV) = 4.0E6 n/cm2/s
F(144 KeV) = 1.2E7 n/cm2/s

III.2. Utilization of filtered neutron beams in nuclear data measurements. Present status and future prospects.

The intensities of the neutron fluxes and the quality of quasi-monoenergetic neutron beams as shown in Fig. 8,9 are generally adequate for a number of nuclear data measurements, enabling the Dalat nuclear research center, with very limited resources, to approach to some up-to-date fundamental and applied research directions in nuclear physics. The filtered neutron beams provide an efficient tool for measuring the average nuclear resonance parameters in unresolved region. We have started recently the measurements of total neutron cross-sections with 144 KeV neutrons. The experiments were intended basically for checking our neutron transmission technique using literature data as reference. U-238 and C-12

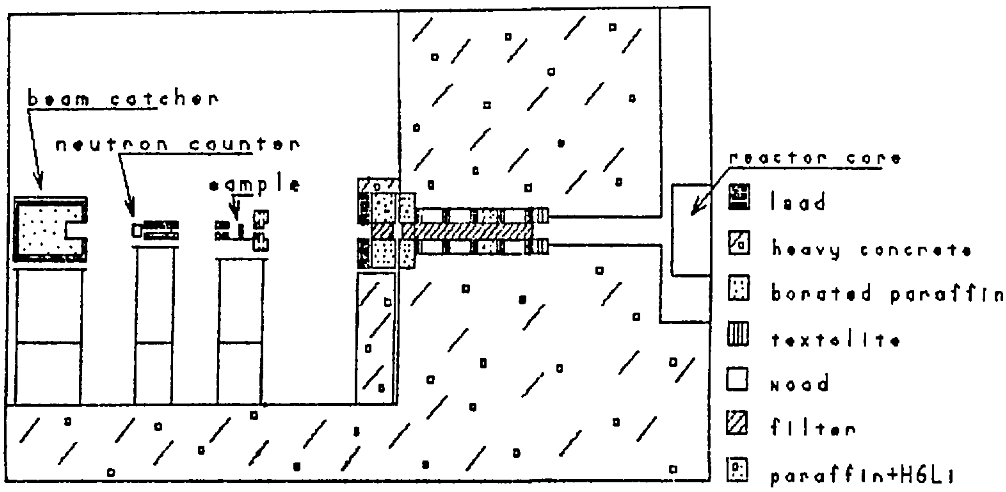

Fig.6: Experimental set-up at the piercing beam port of Dalat nuclear reactor

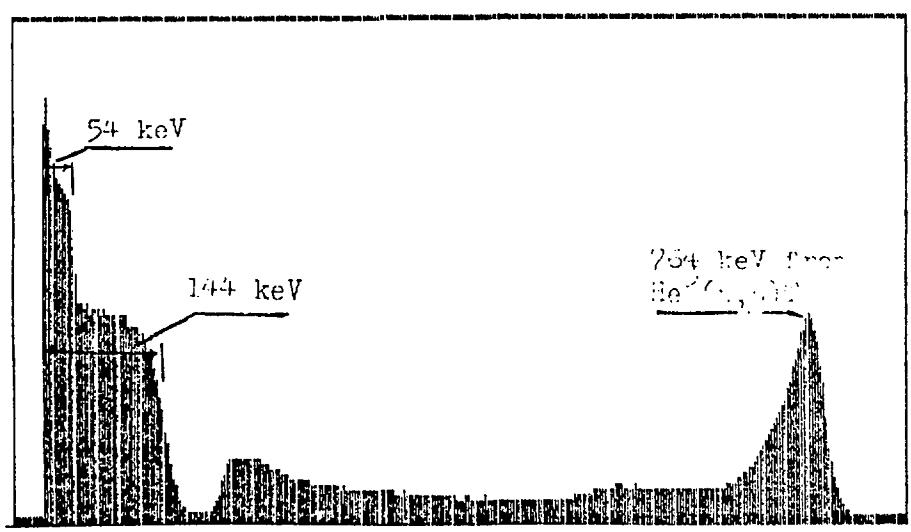

Fig.7: Recoil proton energy distribution obtained with hydrogen proportional counter (4 atm) SNM-38 (98 cm single crystal of silicon neutron filter)

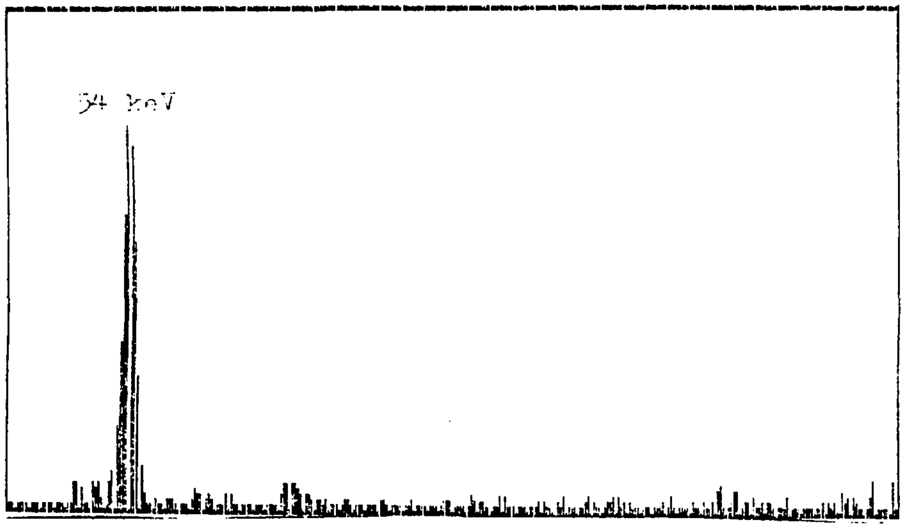

Fig.8: 54 keV differential energy spectrum
(98 cm Si +50 g/cm^2 S +0.4 cm B_4C)

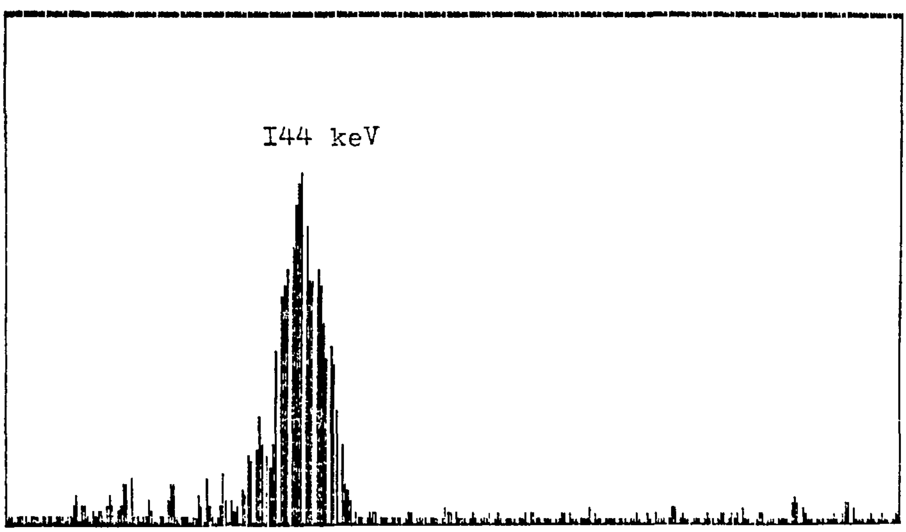

Fig.9: 144 keV differential energy spectrum
(98 cm Si +10 cm Ti +0.4 cm B_4C)

were chosen as targets in such experiments due to the high accurracy of the literature data. Metallic depleted uranium and nuclear-grade graphite have been used for target preparation. The isotopic abundance of U-235 in the uranium target was 0.2 % as determined by gamma spectrometry method. In Table III are shown the "observed" total neutron cross-sections (σ_t^{obs}) of U-238 defined as

$$\langle \sigma_t^{obs} \rangle = \mathrm{Ln}\ (T/n)$$

where T is the neutron transmission and n is the sample thickness given in nuclei/barn. The average total neutron cross-section $\langle \sigma_t \rangle$ can be obtained by extrapolating the "observed" values to zero sample thickness.

Table III: Observed 144 KeV neutron total cross-section of U-238 with different thicknesses of the sample.

No	Thickness (nuclei/barn)	Transmission	$\langle \sigma_t^{obs} \rangle$ (barn)
1	0.048	0.5706 +- 0.0100	11.68 +- 0.36
2	0.094	0.3437 +- 0.0084	11.31 +- 0.26
3	0.159	0.1659 +- 0.0077	11.33 +- 0.29
4	0.172	0.1454 +- 0.0077	11.29 +- 0.32
5	0.207	0.1003 +- 0.0074	11.13 +- 0.36

The fitting procedure yielded the results : $\langle \sigma_t \rangle$ = 11.66 +- 0.14 barns for U-238 which is in good agreement with the literature data (for example $\langle \sigma_t \rangle$ = 11.5 +- 0.2 in [6]). The corresponding values for C-12 are $\langle \sigma_t \rangle$ = 4.24 +- 0.12 and $\langle \sigma_t \rangle$ = 4.28 +- 0.06 [7]. The accuracy of the experimental results was due almost to the neutron counting errors, which could be reduced by increasing the number of measuring cycles. Thus the results obtained in the control experiments proved the ability of our experimental conditions for the measurements of neutron cross-sections in the unresolved region. At present, measurements of total neutron cross-sections and isomeric ratios at neutron energies of 144 KeV and 54 KeV are underway. The obtained data are compared to those with thermal neutrons in order to evaluate the s and p-neutron strength functions [8], and to reveal the neutron energy dependence of the contributions of p,d ... neutrons in the formation cross-sections of compound nuclei.

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IV. REFERENCES

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