# Investigation of the Sub-threshold Fission Cross Section for $^{232}$Th and $^{238}$U


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**Abstract** Time-of-flight spectra from 1st to 15th gamma-rays multiplicity coincidence of $^{232}$Th and $^{238}$U were measured on the 121.65 m flight path of the IBR-30 using the16-section liquid (n, γ)-detector "PARUS" [1]. Two plates of metallic thorium and a $U_3O_8$ powder with 99.9 % of $^{238}$U were used as the radiator-samples. The $U_3O_8$ powder was packed in the aluminium tank. The spectra from 1st to 7th multiplicities coincidence of γ-rays and their averaged multiplicities $\langle K \rangle = \Sigma P_k * K$ (K - multiplicity number, $P_k$ - part of multiplicity) were used to obtain the resonance and group capture cross-sections at the energy range from 1 eV to 4.65 keV. The spectra from 9st to 15th multiplicities coincidence of γ-rays were served to determine the sub-threshold fission cross-section of $^{232}$Th and $^{238}$U. The normalization of the sub-threshold fission cross-sections at the energy range from 1 eV to 4.65 keV was done using the fission cross-sections for $^{232}$Th and $^{238}$U at the energy range from 2. 5 MeV to 4 MeV.


We have carried out measurements of the TOF-spectra from 1st to 15th multiplicity coincidences of gamma-rays of $^{232}$Th and $^{238}$U to determine the radiation capture cross-sections at the energy range from 1 eV to 4.65 keV. These measurements have been performed on the 121 m neutron flight path of the IBR-30 (W = 10 kW, f = 100 Hz, τ = 4 μs) with the 16-section liquid detector "PARUS" [2] with a total volume of 80 l. The general view of this detector is given in Fig.1.

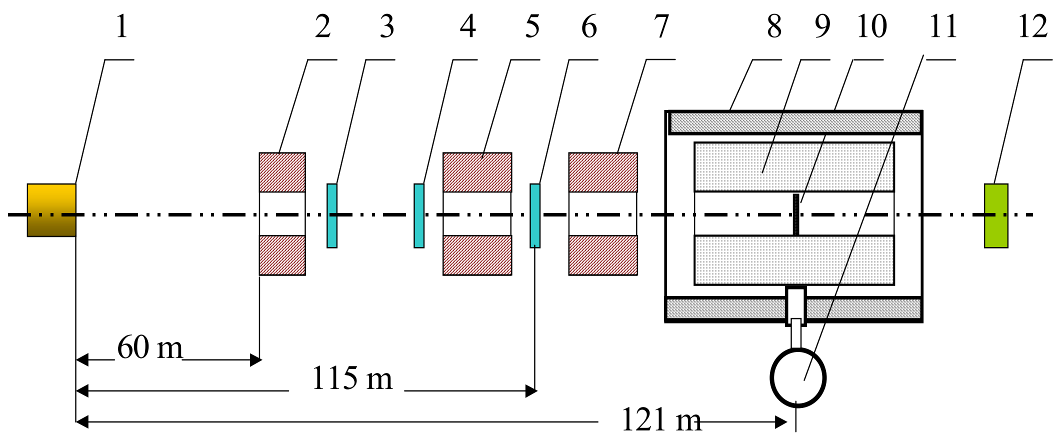


**Fig. 1** The general view of the experiment: 1 – the IBR-30 fuel core moderator; 2, 5, 7 – collimators; 3 – resonance filter; 4– monitor; 6 – sample-filter; 8 – lead shielding of the (n,γ)-detector; 9– liquid detector; 10 – radiator-sample; 11 - HPGe - detector; 12 - neutron detector

The intensity level of the neutron source was controlled by two boron counters SNM-12. The neutron flux on the sample was determined by the following expression:

$$\varphi(E) = \frac{400}{E^{0.9}} \quad [\text{n/cm}^2\,\text{s eV}] \quad (1)$$

Two plates of metallic $^{232}Th$ (99.4%, 4 g) with a total thickness of 0.2 mm and with an area of S = 4.5 x 4.5 $cm^2$ were used as the radiator-samples. The $U_3O_8$ powder with $^{238}U$ (99.999%) and 3.86 g of a weight, packed in the aluminium tank, was served as standard radiator-sample as well.

To determine background components in time-of-flight spectra were used the resonance filters from Al, Mn, Na, Cd and $B_4C$, which were fixed in the neutron beam. The background components were subtracted and measured spectra were brought to a general monitor coefficient.

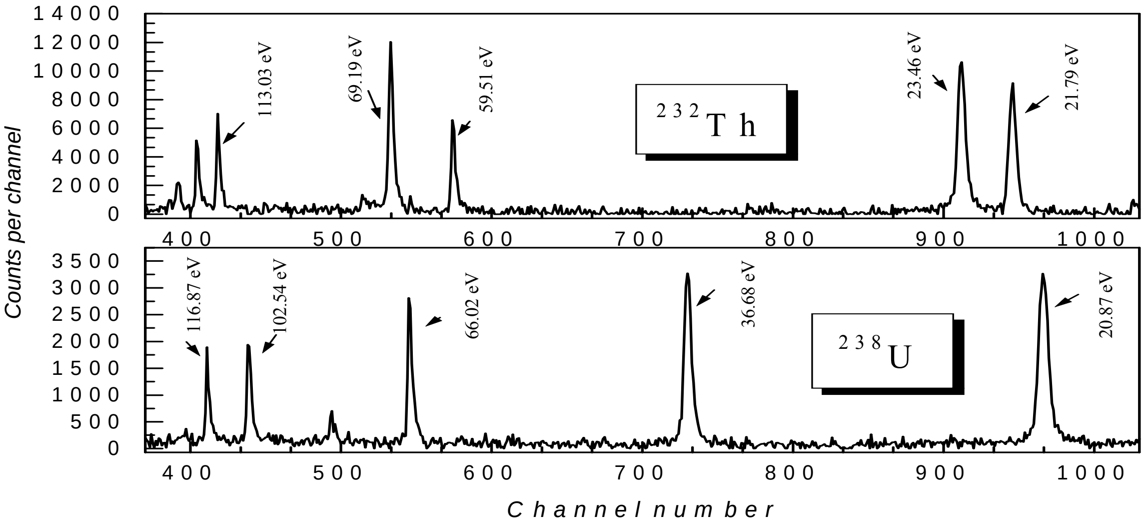


**Fig. 2**. The measured time-of-flight spectra of $^{232}Th$ and $^{238}U$ after background subtraction.

The integral counts within the energy groups are connected with $^{232}Th$ and $^{238}U$ capture cross-sections by the following expression:

$$\sigma_c(Th) = \sigma_c(U)\frac{M^U S^U n^U N_c^{Th}}{M^{Th} S^{Th} n^{Th} N_c^U} \quad (2)$$

where: $\langle\sigma_c\rangle^{Th}$ and $\langle\sigma_c\rangle^U$ - capture cross-sections, $M^U$ and $M^{Th}$- monitor coefficients for the U and Th samples, $n^U$ and $n^{Th}$ - thicknesses of radiator-samples, $S^U$ and $S^{Th}$ - areas of radiator-samples.

We assume that the registration efficiency of $\gamma$ – rays for the U and Th samples is the same. Then to determine capture cross-sections of $^{232}Th$ one can use the expression (2), knowing capture cross-sections of $^{238}U$.

Since an influence of scattered neutrons is observed in the first three multuplicities, the summation from the $4^{th}$ multiplicity to the $7^{th}$ one was performed to obtain capture cross-section. The experimental errors of capture cross sections are about 7%.

Also the radioactive capture cross-sections were calculated by the GRUKON code [3] on the base of the estimated data of various libraries.

To determine the $^{238}U$ and $^{232}Th$ radioactive capture cross-sections were carried out several campaigns of measurements to obtain a good statistical accuracy in counts per / channel in every multiplicity. It was also allowed to observe a weak resonance effect of the sub-threshold fission. To achieve the statistical accuracy in the fission cross-section the measured TOF spectra from $8^{th}$ to $15^{th}$ multiplicities were used in the broad energy region. These spectra are shown in Fig.3.

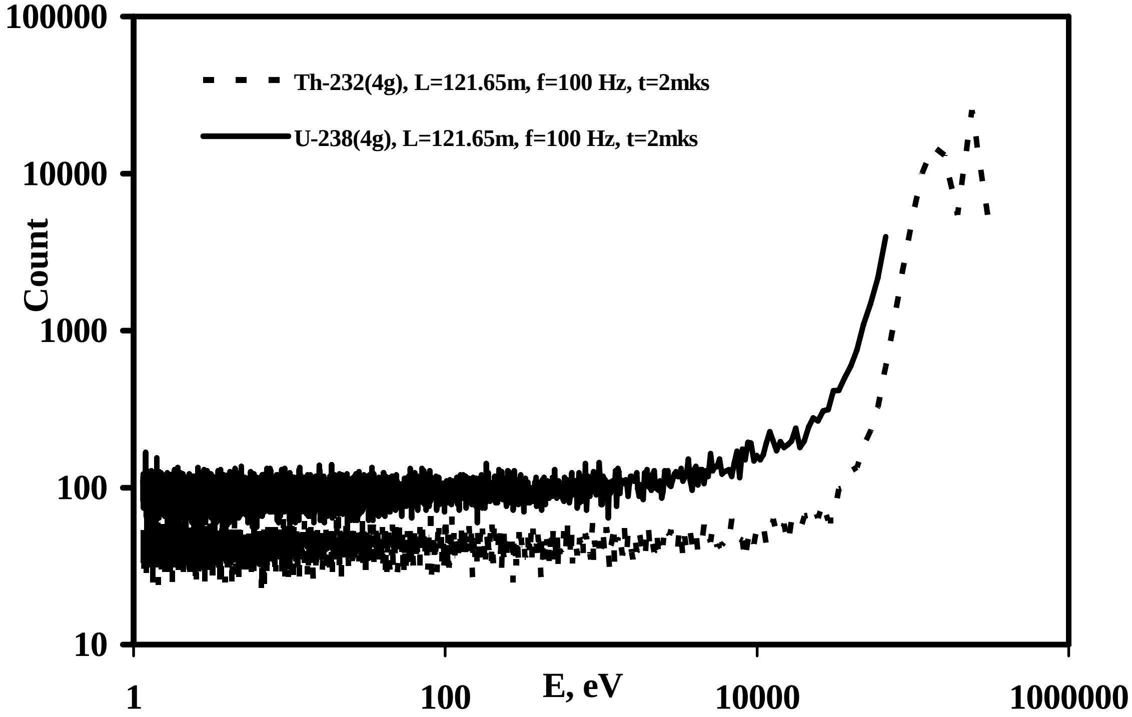


**Fig. 3.** Sum of the time of-flight spectra of $^{232}Th$ and $^{238}U$ from $8^{th}$ to $15^{th}$ multiplicities without background subtraction.

As one can see, that any resonance structure of the sub-threshold fission cross sections was not observed in the energy region from 1 eV to 10 keV. The accuracy of determination of sub-threshold fission cross sections for Th and $^{238}U$ was done by comparison the fission cross sections in the energy range 1 eV – 4.65 keV with one $<\sigma_f>^{HE}$ = 0.13 barn of $^{232}Th$ and $<\sigma_f>^{HE}$ = 0.58 barn of $^{238}U$ in energy range from 2.5 MeV to 4 MeV by the following expression:

$$N_f^{HE} = \phi^{HE} < \sigma_f >^{HE} MSn$$

$$N_f^{LE} = \phi^{LE} < \sigma_f >^{LE} MSn \quad (3)$$

$$\frac{< \sigma_f >^{LE}}{< \sigma_f >^{HE}} = \frac{N_f^{LE} \phi^{HE}}{N_f^{HE} \phi^{LE}}$$

where: $<\sigma_f>^{HE}$ and $<\sigma_f>^{LE}$ - fission cross-sections at the HE – high energy and at the LE - low one, M - a monitor coefficient, n -a thickness of the radiator-sample; S- an area of radiator-sample, $N_f^{LE}$ , $N_f^{HE}$ - counts within the energy groups, $\Phi^{LE}$., $\Phi^{HE}$ – neutron fluxes within the energy groups.

It should be stressed that the background components in the measured spectra was practically coincide with the own background of the “PARUS” setup, consisting of the electronic noise and cosmic radiation.

In future, we are planning to continue this investigation in order to determine the sub-threshold fission cross-sections by this method at better background conditions at the setup IREN-1 (FLNP JINR, Dubna). [4]

## References


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