# Measurements of Neutron Total and Capture Cross Sections at the TOF spectrometers of the Moscow Meson Factory

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**Abstract.** At the 50 meters flight path of the pulsed neutron source RADEX of the Moscow Meson Factory (MMF) INR RAS measurements of neutron total and capture cross sections were carried out. For these measurements a detector system "REPS" consisting of the 8-sectional liquid (n,γ)-detector with a volume of 40 liters (L=49.3 m) and the neutron detector with $^{3}$He counters (L=51.5 m) of a high efficiency $\varepsilon(E_{th.})$=95 % was used. Time-of-flight spectra were measured for the thin metal radiator-samples of $^{55}$Mn, $^{93}$Nb, Mo, In, $^{148}$Sm, $^{165}$Ho, $^{181}$Ta, W and $^{238}$U with a diameter of 80 mm. The analogous values of the group total and capture cross-sections for above mentioned materials were obtained from the measured time-of-flight spectra at the 18 m (25 m) flight path of a pulsed neutron source with Rb target of the radiochemistry setup MMF by means of $^{3}$He, $^{10}$B and NaI (Tl) counters. These values were also obtained by GRUCON code on the basis of the estimated data libraries.

To investigate the resonance structure of the neutron cross-sections measurements of time-of-flight spectra have been carried out at the 50 m flight path of the REPS setup (see Fig.1) [1] and at the 18 m flight path of the radiochemical setup (RCS) of the MMF (see Fig. 2).

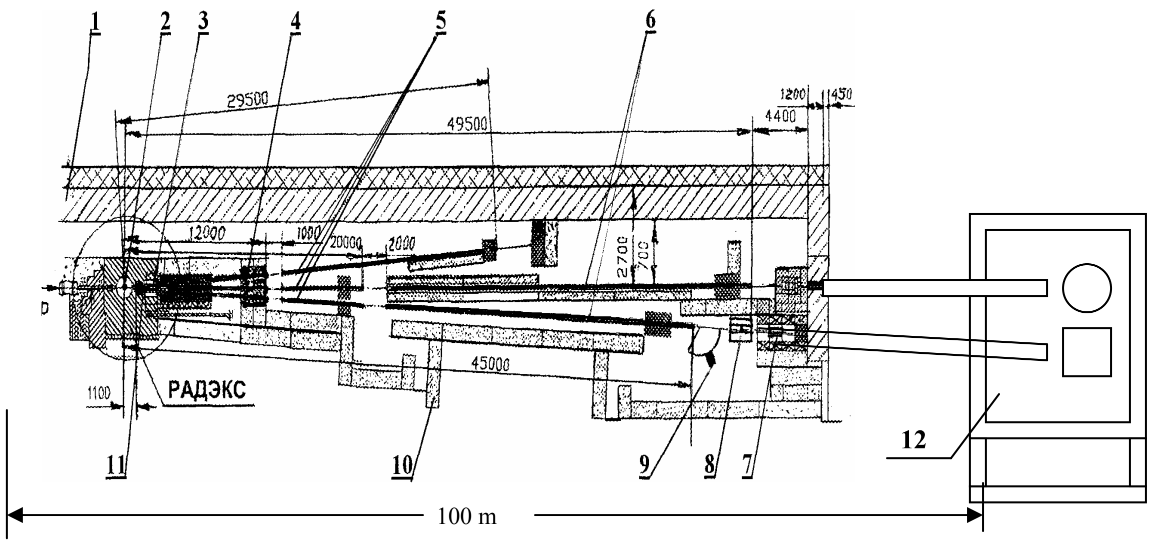


**Fig.1** A schematic view of the TOF neutron spectrometer: 1- brick wall, 2-tungsten target with a water moderator, 3- biological shielding of the neutron source RADEX , 4 – cast-iron shielding from neutrons and gamma-rays, 5 – neutron guide in the from of steel vacuum tube, 7- $^{3}$He neutron detector, 8 – multisectional liquid (n,γ) – detector, 9 – multiangular setup to investigate the neutron scattering, 10 – concrete shielding of the neutron spectrometer, 11- gate of a neutron beam, 12 - experimental building.

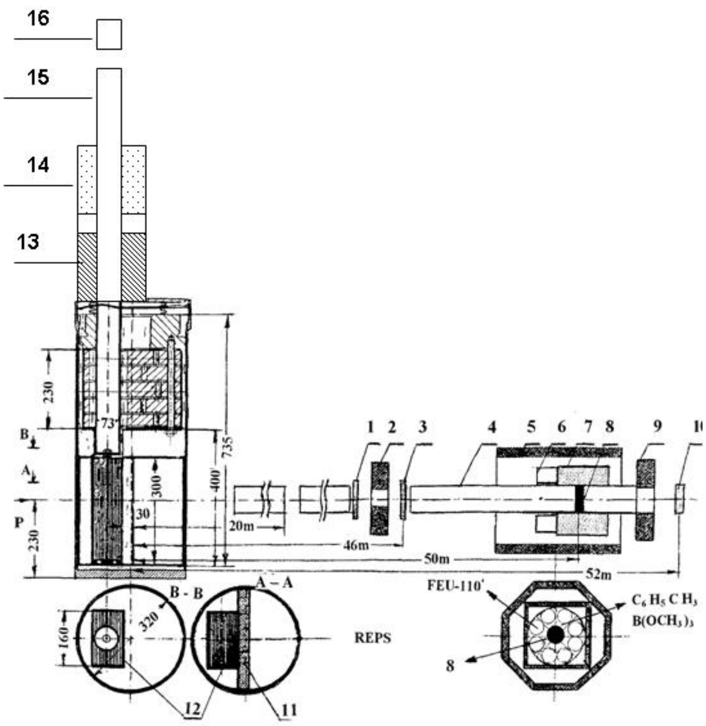


**Fig. 2** The setup REPS at the 50 meter flight path of the pulsed neutron source RADEX with W target and water moderator: 1 - monitor counter, 2, 9 - collimators, 3 – sample-filter, 4 - neutron guide,5 – boron and lead shielding, 6 – FEU-110 photomultiplier, 7 - 8-sectional liquid scintillation (n,γ)-detector, 8 –radiator- sample, 10 - neutron $^{3}$He detector, 11 - water moderator, 12 - W target, 13 – Pb shielding, 14 - neutron multiscattering detector, 15 -neutron guide, 16 - neutron $^{10}$B detector. Indexes 13, 14, 15, 16 correspond to a vertical flying base of the RADEX, where they plan to perform some new experiments, including measurements of the n-n scattering cross section.

The measurements were performed by means of the 8-section liquid (n, γ)-detector and neutron detectors with $^{3}$He counters. The metal targets made from a natural tungsten with a thickness of 7 cm were used as the pulse neutron sources (at the RADEX setup) [2]. At the RCS the metal targets made from a natural Rb with a thickness of 6 cm were also served as a source [3]. Targets were illuminated by a proton beam with an energy of 209 MeV at the RADEX setup and with an energy of 160 MeV at the RCS. The operated parameters of the pulsed neutron source of MMF were the pulsed proton current of linear accelerator $I_p$ = 11 mA, the proton energy $E_p$.=209 MeV, the proton pulse repetition rate f = 50 Hz, the proton pulse duration τ = 2 –200 mks.

As the radiator-samples and filter-samples were served metal and oxide disks made from $^{55}$Mn, $^{93}$Nb, Mo, In, $^{148}$Sm, $^{165}$Ho, $^{181}$Ta, W and $^{238}$U with a diameter from 50 mm to 80 mm of a different thickness. An intensity level of the neutron beam at the REPS setup was controlled by a $^{3}$He counter (SNM-18) installed at 114 meter flight path before a tungsten target of the

RADEX source. At the RCS a $^{10}B$ counter (SNM-13) was in use before a Rb target.

The data acquisition was realized by means of measurement modules on the basis of PC with two types of equipment and software: at 1 μs time channel width (author T.G. Petukhova FLNP JINR) and 0.01 μs (developed at INR Troitsk and JINR, [4]). The minimal duration of the time channel is limited to the minimal duration of a proton beam of the accelerator. These two systems in existing measurement conditions were approximately equivalent. The main feature of these measurements is usage of the ion guide as a neutron guide. This allowed perform new experiments requiring much more time measurement and higher energy resolution.

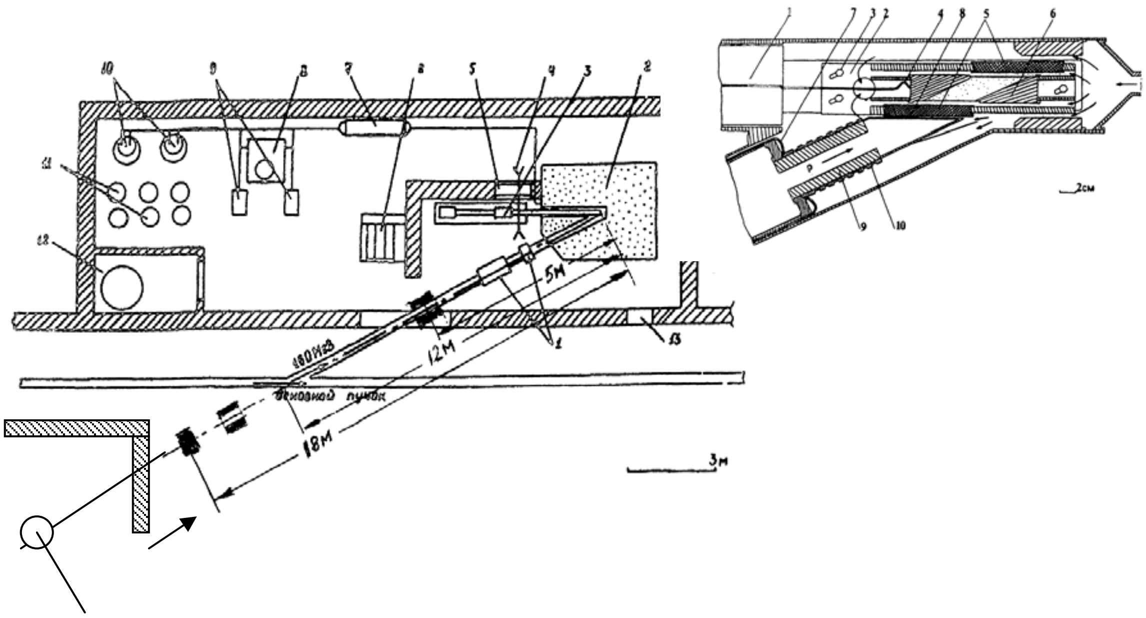


**Fig. 3** A schematic view of the neutron setup with a Rb target: 1 – proton ion guide with equipment for a beam control, 2 – cast-iron cube shielding for a target placement, 3- equipment for a target movement, 4..12 – functional elements of the RCC, 13 – entrance into a target hall. A detailed view of the target construction is shown on the right.

In the last 2007-2010s measurements of the time-of-flight spectra of the gamma-rays have been carried out at the radioactive neutron capture by nuclei of $^{55}Mn$, $^{93}Nb$, Mo, In, $^{148}Sm$, $^{165}Ho$, $^{181}Ta$, W and $^{238}U$. For these measurements the 8-section liquid (n, γ)-detector with a total volume of 40 litres and $^{3}He$ neutron detector have been installed at the 50 meter flight path of the REPS setup of the Moscow Meson Factory (MMF). A duration of analog pulses was 35 ns and 1 μs from the (n, γ)-detector and from the $^{3}He$ neutron counter respectively. The registration efficiency of the (n, γ)-detector was determined using the γ-lines of $^{60}Co$ source and was equal to 30 % at the energy resolution of 30 %. The registration efficiency of thermal neutrons of $^{3}He$ neutron counter was approximately 95 %. The experimental time-of-flight spectra are shown in Fig. 4 (x-axis corresponds to the energy).

The background components in time-of-flight spectra come out from the gamma-rays and neutrons scattered in the experimental hall. These components were measured by resonance filters having so-called deep “black resonances” like, for example, Al (35 keV), Mn (2.4 keV and 336 eV) and W(20 eV). It should be stressed that protons falling onto the target cause neutrons with a broad energy spectrum in which a 15 % fraction of fast neutrons in the energy range from 14 MeV to 209 MeV after moderation. These neutrons fly out from the target mainly forward where detectors of the REPS setup are located and result in background increase and in overload of spectrometric electronic equipment. At 18 meter and 114 meter flight paths, where proton ion guides were used as neutron guides, the fraction of background neutrons is less because these neutrons fly towards the proton beam.

In the near future 18 meter flight base of an isotope setup will be prolonged by means of the lengthening of the neutron guide channel into the next room through a hole in a concrete wall, that also allows improve background conditions.

In the previous measurements at the REPS setup new resonances of a natural W have been observed at the energy of 7 eV and 18 eV. These results are very interesting in respect to the nucleus theory and its practical applications.

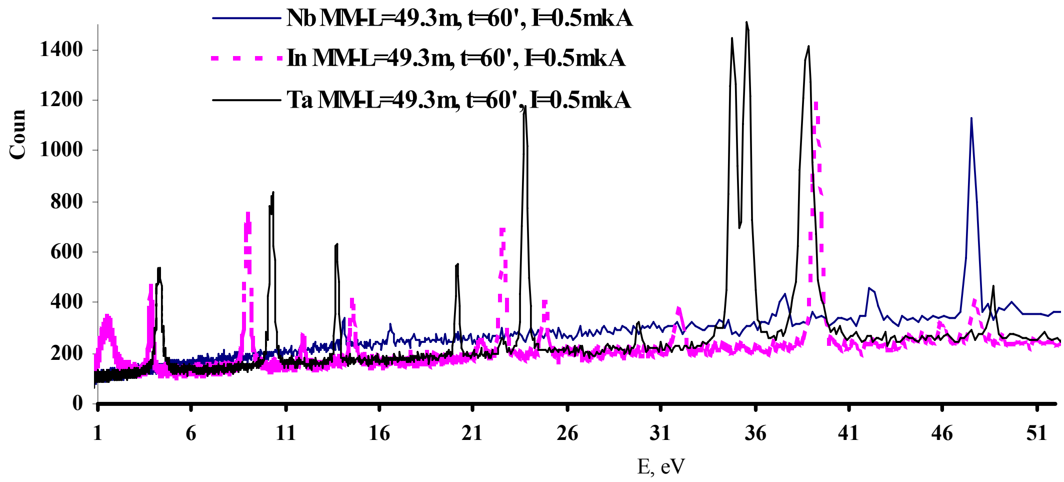


**Fig. 4**. Time-of-flight spectra of $^{93}$Nb (d=2 mm), In(d=0.5mm),$^{181}$Ta(d=0.2 mm) transmissions, measured by the liquid (n,γ)-detector at 49.3 m flight path. Parameters of proton beam are: $E_p$=209 MeV, $I_p$=5 mA, f=50 Hz, Δt=1.5 μs, $dt_{ch}$=1 μs.

To determine fluxes from thermal neutrons time-of-flight spectra measurements were carried out at the 50 meter flight paths of the neutron source RADEX by means of $^3$He counter and at 18 meter flight path of the isotope setup by means of $^{10}$B counter at a neutron burst duration of Δt = 65 μs and 200 μs at a frequency repetition rate of 1 Hz and 50 Hz.

In Fig. 5, 6 time-of-flight spectra, measured at 50 m of the neutron source RADEX and at 18 m flight path of the isotope complex, are presented.

As one can see from the Figure 6 a maximum peak of thermal neutrons is situated at the energy of 0.062 eV and a spectrum of thermal neutrons is located in the energy range from 0.0032 to 0.25 eV. It is important that a thin W sample installed in the neutron beam practically did not decrease the neutron beam intensity. It allowed estimate the background components in this energy region using W resonances with a precision of 3 %.

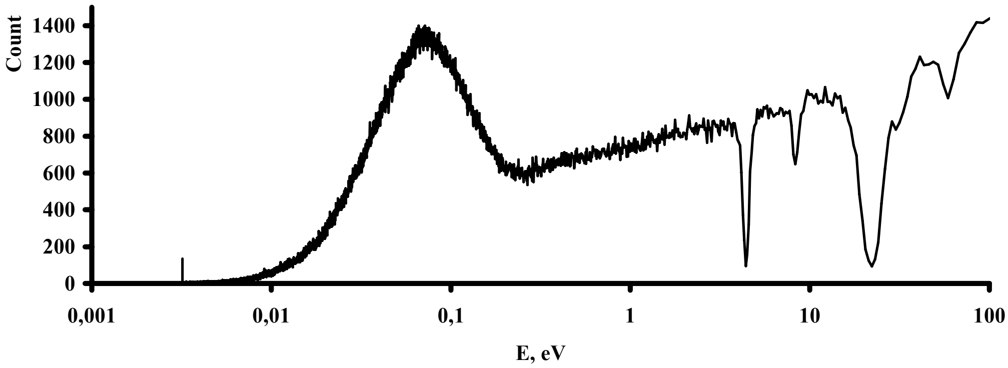


**Fig. 5.** Time-of-flight spectra of W (d=0.4 mm) transmissions, measured by the $^3$He counter at 51 m flight path of the REPS setup. Parameters of proton beam are $E_p$=209 MeV, $I_p$=5 mA, f=1 Hz, $\Delta t$=65 μs, $dt_{ch}$=16 μs, $t_{mes}$ = 60 minutes.

Since the registration efficiency of thermal neutrons by $^3$He counter was approximately 95 % and an illuminated detector surface came to 30 cm$^2$ then averaged flux of thermal neutrons will be $\Phi_{max}$ = 3000000 n/(cm$^2$*sec) at 51 m flight path of the REPS setup at the proton beam parameters $E_p$=209 MeV, $I_p$= 10 mA, f = 50 Hz, $\Delta t$ = 200 μs.

The test measurements were performed using the $^3$He counter at the18 m flight path of the isotope complex with the Rb target (see Fig.3). The neutron counter was placed by a flank to the neutron flux to achieve the registration efficiency of thermal neutrons of 94 % at a flank surface of 7 cm$^2$. Because of copper plates with a thickness of 3 cm located behind the ion guide in the neutron beam the neutron flux decreased by order of magnitude 10. In this case the thermal neutrons flux was 600 n/cm$^2$ s. That is why the neutron detector should be well shielded from neutrons and gamma-rays at 27-degree turn of the ion guide and precisely adjusted along the neutron beam rigidly collimated by the ion guide.

If we suppose that thermal neutrons are emitted in $^{10}$He counter direction installed at a distance of 18 m from the target surface of 3 cm$^2$, than the thermal neutrons flux at the source surface should be approximately $10^{13}$ n/cm$^2$s. Evidently the thermal neutrons flux will be $3*10^6$ n/sm$^2$s at a distance of 18 m from the neutron source where the ring monitor detector was placed.

It would be possible to carry out investigations of the (n,n) and (n,p) scattering by the method of incoming beams and overtaking neutrons [6] using of W and U targets to increase the neutron beam intensity.

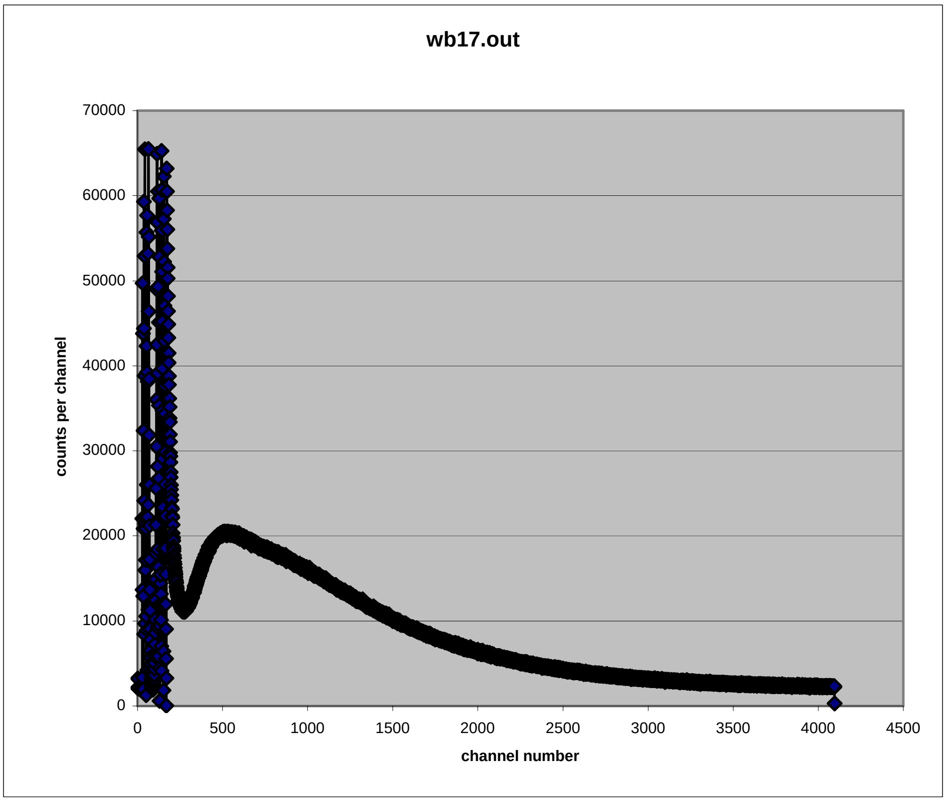


**Fig. 6** Time-of-flight spectra, measured by the $^{10}B$ counter at the18 m flight path of the isotope complex. Parameters of proton beam: $E_p$=160 MeV, $I_p$=5 mA, f=50 Hz, Δt=165 μs, $t_{ch}$=4 μs, $t_{mes}$ = 10 min.

## Conclusion

During last years 2007-2010 several experiments on the resonance structure investigation of neutron cross-sections at time-of-flight spectrometers of the MMF were carried out. Time-of-flight spectra of Mn, Cr, Nb, Mo, In, Ta, W and U metal samples were measured at the REPS setup using the 8-section liquid (n.γ)-detector and $^{3}He$ counter. The averaged group total transmissions and cross-sections were extracted from the experimental spectra in the energy range from 1 eV to 10 keV.

Two new resonances in the radioactive capture for natural W were revealed at the energies of 4 eV and 17 eV. The new time-of-flight neutron spectrometer was constructed on the basis of 18 m ion guide of the radioisotope setup of the MMF. Test measurements were carried out to determine its characteristics. Similar test measurements were also carried out at the 114 meter ion guide before the neutron source RADEX. These original spectrometers allow increase measurement time of nuclear-physical values in the thermal and resonance neutron energy region.

Also there is in process of creation the vertical neutron guide with high vacuum on installation "RADEX" for original experiments on measurement of n-n scattering and definition of charge radius of a neutron.

**References**


1. Berlev A.I., Grigoriev Ju.V., The REPS setup for the investigation of the neutron cross- sections structure and fundamental characteristics of neutron: Preprint INR RAS №1183/2007. – Moscow: INR RAS, 2007.
2. Benetsky B.A., Vahetov F.Z., Grachev M.I. e.a., Program of experimental researches on device RADEX: Preprint INR RAS № 1058/2001. – Moskow: INR RAS, 2001.
3. B.L. Juikov, V.M. Kohanuk, Ju.G. Gabrielants e.a., Device for production of radio nuclei on 160 Mev beam removal of Moskow Meson Factory // Radiochemistry. – 1994. – V.36, Release 6. – P. 499-504.
4. 4. Berlev A.I., System for registration, gathering and accumulation of experimental data from nuclear – physical installations by time – of - flight method: Preprint INR RAS № 1189/2007, Moscow: INR RAS, 2007.
5. 5. Grigoriev Yu.V., Method for determination cross-sections of neutron – neutron interaction: Pat. USSR № 549023. – Moscow, 1976.
6. 6. E.A. Koptelov, V.A. Fedchenko, O.N. Goncharenko, M.I. Grachev, L.V. Kravchuk, V.A. Matveev, A.D. Perekrestenko, Yu.V. Ryabov and S.F. Sidorkin. Spallation neutrons at INR RAS – a facility status report // ICANS-17, 2005.