The Investigation of the Resonance Structure of the Neutron Cross-Sections with the Time-of-Flight Spectrometers at the Moscow Meson Factory.

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Abstract In 2007-2008 measurements of the time-of-flight spectra of different multiplicities coincidences of the gamma-rays have been carried out for ^{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 and ^{3}He neutron detector have been installed at 50 m flight path of the REPS setup of the Moscow Meson Factory (MMF). They have revealed 5 new resonances in the neutron radioactive capture cross-section of W at the energies of 4 eV and 18 eV and of ^{55}Mn at the energies of 228 eV, 359.4 eV and 375.2 eV.

On the basis of the 12 m proton ion guide and of the Rb target of the isotope complex of the MMF an original time-of-flight neutron spectrometer has been designed placed at the 18 m flight path. It allows to investigate the neutron cross-sections resonance structure and some fundamental neutron characteristics in the broad energy range.

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

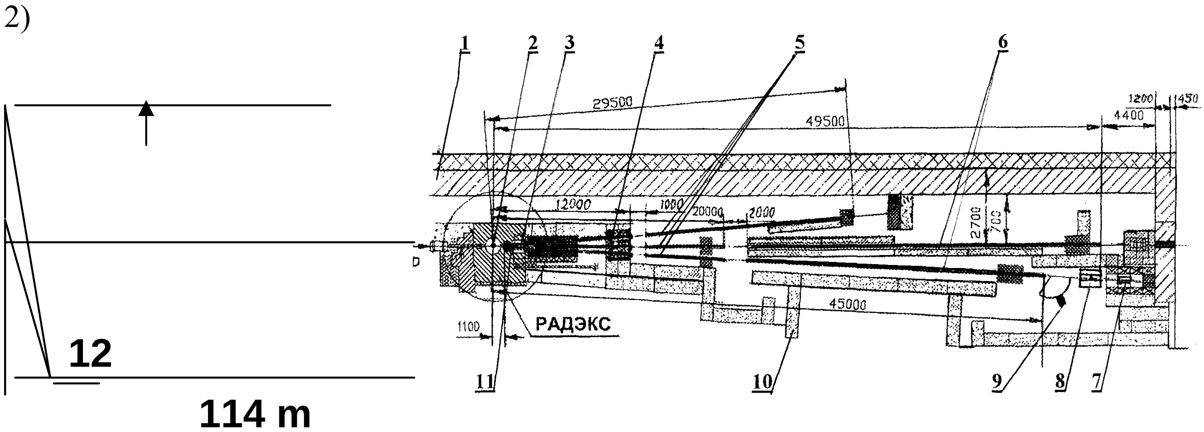

Fig.1. A schematic view of the time-of-flight neutron spectrometer: 1- brick wall, 2- tungsten target with a water moderator, 3- concrete biological shielding of the neutron source RADEKS , 4 – cast-iron shielding form neutrons and gamma-rays, 5 – neutron guide in the form of steel vacuum tube, 7- ^{3}He neutron detector, 8 – multisectional liquid (n,γ) – detector, 9 – multiangular setup to investigate an neutron scattering, 10 – concrete shielding of the neutron spectrometer, 11- gate of a neutron beam, 12 – ^{3}He counter (SNM-18)

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 RADEKS setup) [2]. At the RCC the metal targets made from a natural Rb with a thickness of 6 cm were in use with the same purpose [3]. Targets were illuminated by a proton beam with an energy of 209 MeV at the RADEKS setup and with an energy of 160 MeV at the RCC. The operated parameters were the following: the average pulse current I = 5 – 10 mA and an proton bursts repetition frequency f = 1-50 Hz with a duration of Δt = 1 – 200 μs.

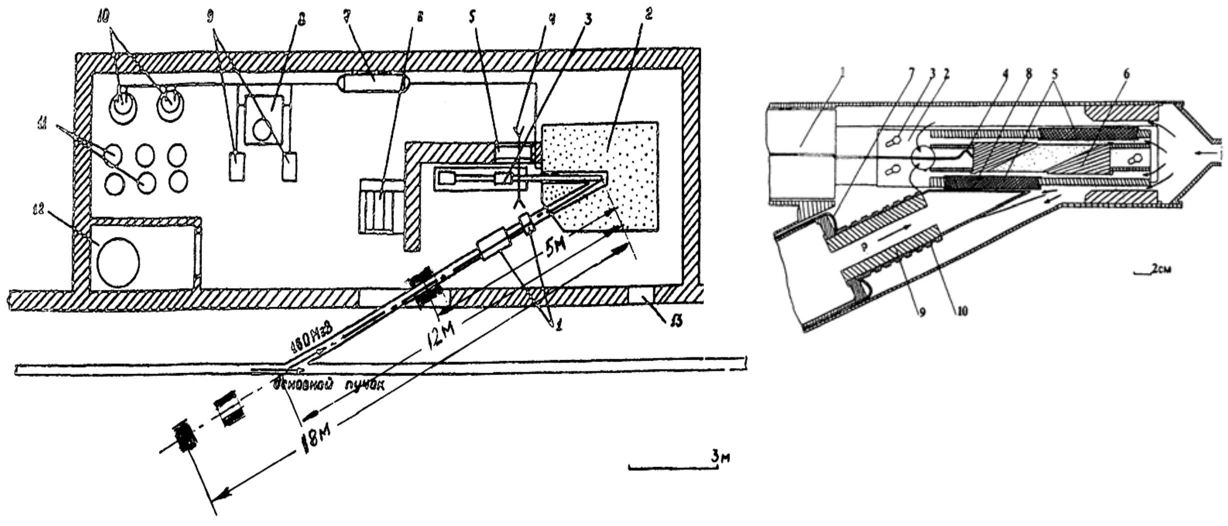

Fig. 2. A schematic view of the neutron setup with a Rb target: 1 – proton ion guide with equipments for a beam control, 2 – cast-iron cube shielding for a target placement, 3- equipment for a target movement, 4..12 – functional elements of the RCC, 13 – entrance into a target hall. A detailed view of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

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 different thickness. An intensity level of a neutron beam at the REPS setup was controlled by a ^{3}He counter (SNM-18) installed at 114 m flight path before a tungsten target of the RADEKS source. At the RCC 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 analog software at 1 μs time channel width (author T.G. Petukhova FLNP JINR) and 0.01 μs (development of INR Troitsk and JINR, [4]). The main feature of these measurements is the usage of ion guide as neutron guide. This allowed to perform new experiments requiring more time measurement and higher energy resolution.

In 2007-2008 measurements of the time-of-flight spectra of different multiplicities coincidences of the gamma-rays have been carried out at a 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 o total volume of 40 l and ^{3}He neutron detector have been installed at 50 m 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 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. 3, 4, 5, 6, and 7 (x-axis corresponds to the energy). The background components in time-of-flight spectra are the result of the gamma-rays and neutrons scattered in the experimental hall. These components were measured by resonance filters which have so-called deep “black resonances” like Al (35 keV), Mn (2.4 keV and 336 eV) and W(20 eV). It should be stressed that protons falling to the target cause neutrons which have a broad energy spectrum with a 15 % fraction of fast neutrons in the energy range from 15 MeV to 209 MeV after moderation. These neutrons fly 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 m and 114 m flight paths, where proton ion guides were used as neutron guides, the fraction of background neutrons less because these neutrons fly towards the proton beam.

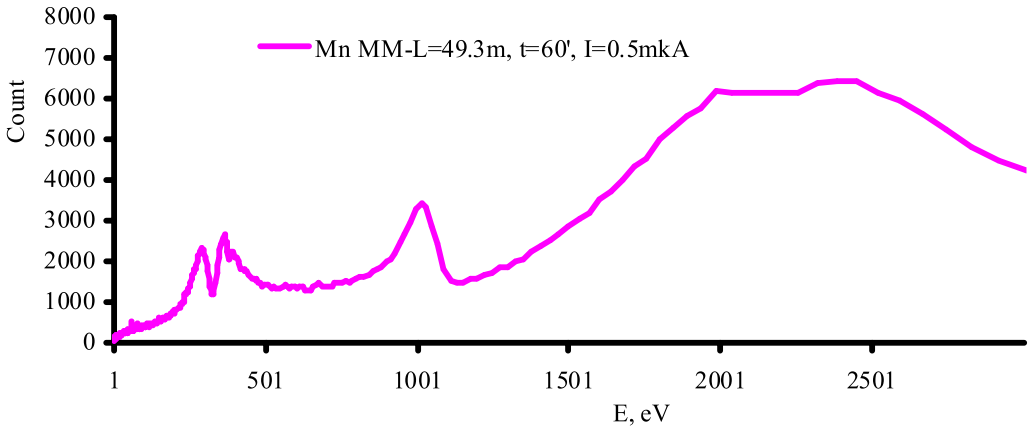

Fig. 3 Time-of-flight spectrum of the neutron radioactive capture by ^{55}Mn sample (d=2 mm), measured by the liquid (n,γ)-detector at 49.3 m flight path. Parameters of proton beam are E_p=209 MeV, I_p=5 mA, f=50 Hz, Δt=1 μs, dt_{ch}=1 μs

As one can see from the Fig.3, a more complicated resonance structure is observed in the radioactive capture cross-section of a natural Mn for the first time. So instead of one resonance 3 resonances are observed at the energy of 336 eV with E_0=228 eV, 359.4 eV and 375.2 eV. Also two resonances instead one are observed around 2375 eV. Moreover, the resonance structure with several weak resonances exists in the energy region from 20 eV to 80 eV. 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.

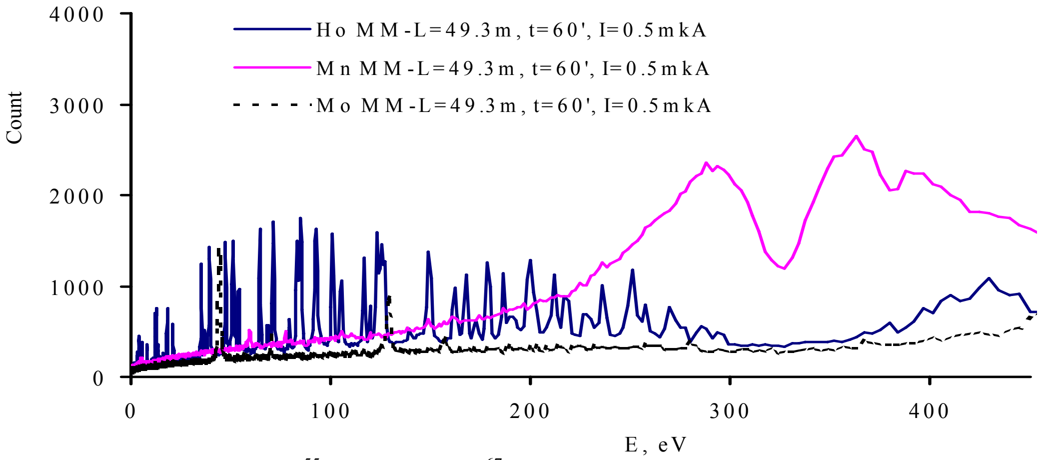

Fig. 4 Time-of-flight spectra of ^{55}Mn (d=2 mm), ^{67}Ho (d=5 mm) and Mo (d=0.4 mm) transmissions, measured by the liquid (n,γ)-detector at 49.3 m flight path. Parameters of proton beam are E_p=209 MeV, I_p=5 mA, f=50 Hz, Δt=1.5 μs, dt_{ch}=1 μs.

To obtain resonance parameters of new mentioned resonances of Mn one needs to repeat such measurements with better statistical precision and with higher energy resolution.

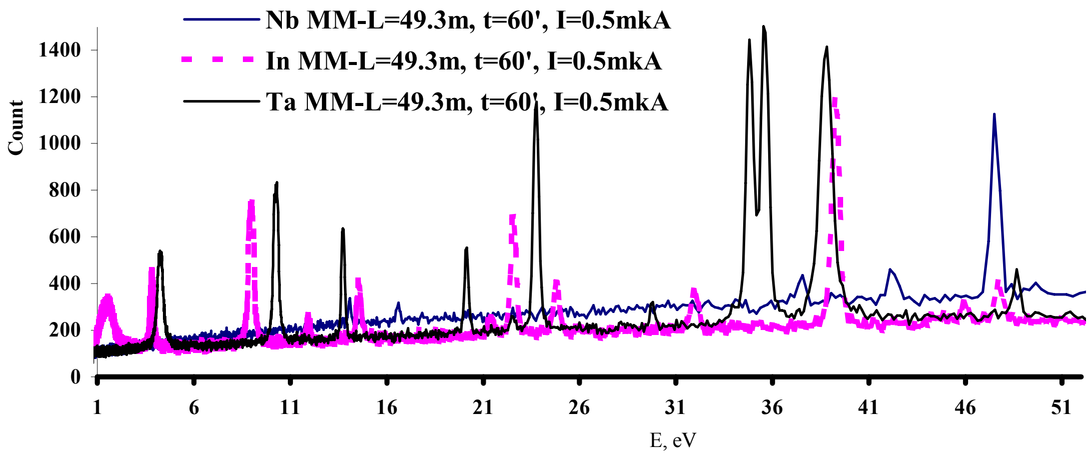

Fig. 5. Time-of-flight spectra of ^{93}Nb (d=2 mm),In(d=0.5mm),^{181}Ta(d=0.2 mm) transmissions, measured by the liquid (n,γ)-detector at 49.3 m flight path. Parameters of proton beam are E_p=209 MeV, I_p=5 mA, f=50 Hz, Δt=1.5 μs, dt_{ch}=1 μs.

It should be mentioned that new resonances for other materials except Mn and W were not observed in the energy range from 1 eV to 3 keV.

To determine fluxes from thermal neutrons time-of-flight spectra measurements were carried out at 20 m, 50 m and 114 m flight paths of the neutron source RADEKS and at 18 m flight path of the isotope complex by means of ^{3}He counter at a neutron burst duration of Δt = 65 μs and 200 μs and at a frequency repetition of f = 1 Hz and 50 Hz.

In Fig. 6-8 time-of-flight spectra, measured at 50 m and 114 m flight paths of the neutron source RADEKS and at 18 m flight path of the isotope complex, are presented.

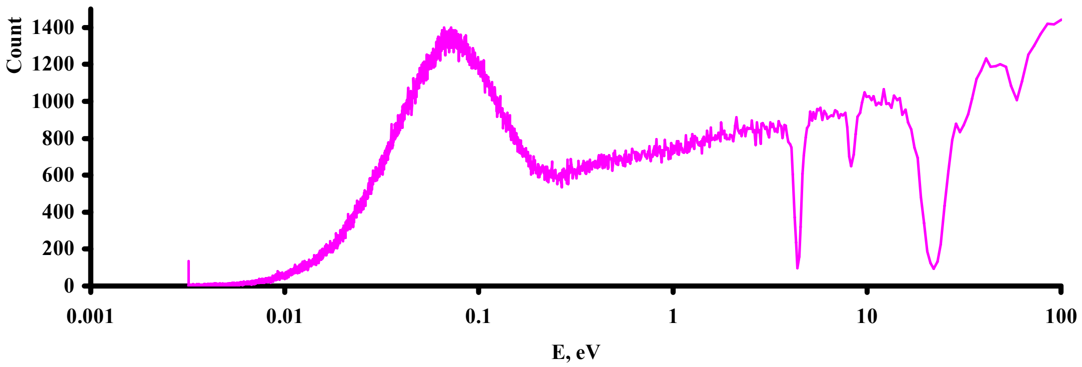

Fig. 6 Time-of-flight spectra of W (d=0.4 mm) transmissions, measured by the ^{3}He counter at 51 m flight path of the REPS setup. Parameters of proton beam are E_p=209 MeV, I_p=5 mA, f=1 Hz, Δt=65 μs, dt_{ch}=16 μs, t_{mes} = 60 min

As one can see from the Fig. 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 to estimate the background components in this energy region using W resonances with a precision of 3 %.

Since the registration efficiency of thermal neutrons by ^{3}He counter was approximately 95 % and an illuminated detector surface came to 30 cm^2 that an averaged flux of thermal neutrons will be Φ_{max} = 3000 n/cm^2 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, Δt = 200 μs. This flux corresponds approximately to the thermal neutrons flux at the IBR-30 reactor and about 100 times less than at the IBR-2 reactor at JINR, Dubna [5].

The test measurements were performed using the ^{3}He counter at 18 m flight path of the isotope complex with the Rb target (see Fig.2). 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 an 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.

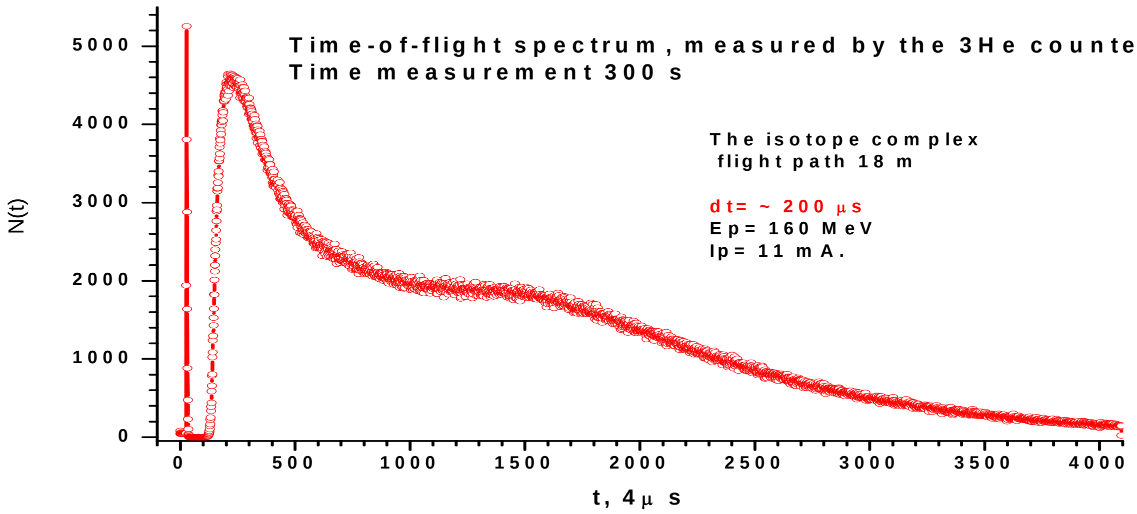

Fig. 7 Time-of-flight spectrum of an opened beam, measured by the ^{3}He counter at 18 m flight path of the isotope complex at E_p=160 MeV, I_p=11 mA, f=50 Hz, Δt=200 μs, dt_{ch}=16 μs, t_{mes} = 5 min.

If we suppose that thermal neutrons are emitted in ^{3}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^{11} n/cm^{2}s. Evidently the thermal neutrons flux will be $3*10^4$ n/sm^{2}s at a distance of 3 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.

Conclusion

During the last two years 2007-2008 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 and three new resonances for ^{55}Mn at the energies of 228 eV, 359.4 eV and 375.2 eV.

The new time-of-flight neutron spectrometer was constructed on the basis of 12 m ion guide of the radioisotope complex of the MMF. Test measurements were carried out to determine its characteristics. Similar test measurements were also carried out at the 114 m ion guide before the neutron source RADEKS. These original spectrometers allow to increase time measurement of nuclear-physical values in the thermal and resonance neutron energy region.

Authors thank the director of INR RAS academician V.A. Matveev, vice-director L.V. Kravchuk for their support and also leader of linear proton accelerator of the MMF A.V. Feshchenko, V.L. Serov, M.I. Grachev for their help. Authors also express thanks to A.A. Bergman, B.I. Fursov, V.M. Kochanyuk and other colleagues for help and assistance.

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