A versatile multi-detector gamma-ray spectrometry system for investigation of neutron induced reactions

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Abstract

At the Joint Institute for Nuclear Research Frank Laboratory of Neutron Physics a new multi-detector gamma-ray spectrometry system was constructed. It consists of 24 hexagonal NaI(Tl) detectors, which can be arranged in different configurations depending on the requirements of the experiment. Basically, the detectors are arranged in 2 cylindrical arrays of variable diameter and distance between them.

The main characteristics of a single NaI(Tl) detector chain (time and energy resolutions, gamma-neutron separation) were investigated.

A test measurement has been performed at one of the neutron beam-lines of the pulsed white-spectrum neutron source IREN. Registering the prompt gamma-ray emission yield from the resonance neutron capture by the nuclei of a certified Tantalum sample, via the well separated resonances in $^{181}Ta(n,\gamma)$-reaction, the neutron energy dependent resonance neutron flux density was determined.

In combination with a multi-section parallel-plate gas-ionization chamber as a fission fragment detector, positioned in the center of the system, it is possible to investigate the neutron-induced capture and fission reactions on a number of heavy isotopes, important for fundamental and applied neutron and nuclear physics.

Keywords: Nuclear Reactions; Resonance Neutron Capture and Fission Reactions; Prompt Gamma-Ray Emission

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1. Introduction

At the Joint Institute for Nuclear Research (JINR) Frank Laboratory of Neutron Physics (FLNP), where already half a century the thermal and resonance neutron induced nuclear reactions are studied, a new electron accelerator driven white spectrum pulsed neutron source IREN has been built and successfully tested [1, 10]. The improved characteristics of this facility, in comparison with those of the former pulsed neutron fast reactor IBR-30, will allow measuring some of the neutron-nuclear reaction data with better precision and accuracy.

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Accurate measurements of the neutron capture and fission cross-sections and their ratio (α-value),as well as the fluctuation of the prompt gamma-emission in resonance neutron induced fission, are of great importance for stockpile stewardship, nuclear forensics and medicine, safeguards, s-process nucleo-synthesis, the generation IV reactor design and nuclear waste transmutation[2, 3]. Also, there is a need from more precise data on the neutron inelastic scattering on many isotopes from the NEA High Priority List (HPL) [3].

More precise nuclear data on the fission fragment yields [4] and neutron/gamma fluctuations, in resonance neutron energy region [5], can help in testing different models of fission and, thus, improve our knowledge about the fission process itself.

Measurements with radioactive samples are more difficult to be realized because of the need to use small amounts of the element being investigated, more powerful neutron sources and multi detector systems.

2. New experimental setups

Two new experimental setups for the investigation of neutron-induced nuclear reactions are in a stage of construction and testing. One will utilize the IREN pulsed white spectrum neutron source and time-of-flight (TOF) method for separation the interaction of neutrons with different energies. The characteristics of the IREN as a pulse neutron source, after the last modification of its neutron producing target (NPT), as well as details on the data collection and analysis, can be found in ref. [5,6, 10].

The other setup is using d(t, α)n reaction for obtaining a continuous flux of 14.1MeV neutrons and the associated α-particle method (APM) for tagging the neutrons [7].

The both setups will utilize the recently constructed 24 NaI(Tl) detector spectrometer of gamma-rays (also sensitive to neutrons) (Fig.1),equipped with a computerized system for multichannel, multi parametric data acquisition and analysis (Fig.2).

The multi-detector gamma-ray spectrometry system (Fig. 1) consists of 2 rings (arrays) of 12 NaI(Tl) detectors(Amcrys-H) each with variable ring diameter and distance between both rings. Such setup will give the possibility not only to measure the multiplicity, energy and angular anisotropy of the prompt fission gamma rays, but also to separate the contribution of the prompt fission neutrons by their longer time-of-flight (TOF) from the fissile target to the detectors. The construction allows arranging up to 44 detectors in two concentric rings of ~100 cm diameter. The signals from all detectors are recorded simultaneously in digitized form and are stored on the hard disk of a personal computer for further off-line analysis by an AFI Systems Data acquisition system ADCM. A more detailed description is given in [5,6].

This setup was used to investigate the NaI(Tl) spectrometer time resolution, in view of the ability to separate the contribution of the scattered neutrons from those of the capture (n,γ)-reaction, as well, as to measure the energy dependence of the resonance neutron flux density by means of the neutron capture reaction on ^{181}Ta.

Fig. 1. Multi-detector gamma-ray spectrometry system: Two arrays of 12 NaI(Tl) detectors, Hamamatsu PMT+HV generator, HV generator power supply.

Fig.2. The multichannel ADCM-16 board (left) and 2 boards in a computer, to form a32 channel ADC system (right).

3. Time-resolution of a single NaI(Tl) detector

The time resolution of a single NaI(Tl) was determined using a calibration ^{60}Co point gamma-source. It was positioned between the NaI(Tl) detector and a NE-213 detector, which pulses were used to open a time-gate for measuring (sorting out) the correlated events. The results, obtained at two gamma-ray energy thresholds E_γ <3MeV and E_γ <1.23 MeV[8], are also shown in Fig. 3.

The possibility of using the TOF technique for separation of the contribution of neutrons from that of gammas using a single NaI(Tl) detector was checked by ^{252}Cf(sf), which was placed on the surface of one of the two NaI(Tl) detectors used. The distance between the

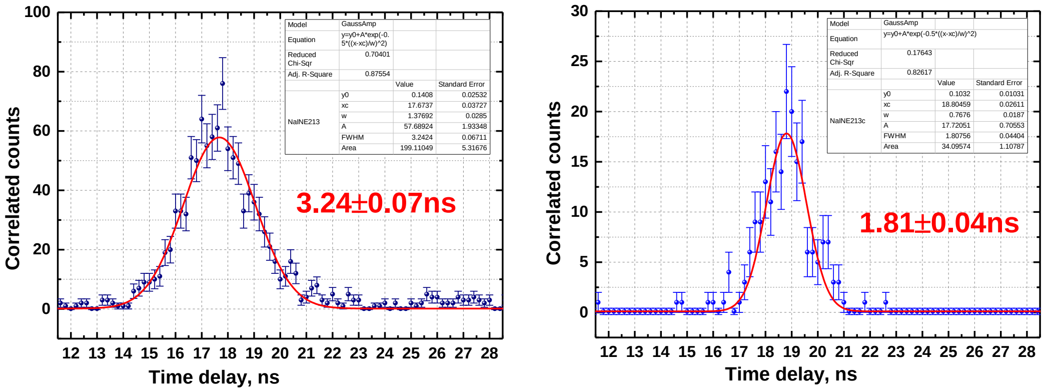

Fig. 3. Left: ^{60}Co γ-rays ($E_\gamma < 3$ MeV) NE213-NaI(Tl) coincidences.
Right: ^{60}Co γ-rays ($E_\gamma > 1$ MeV) NE213-NaI(Tl) coincidences.

^{252}Cf(sf) and the opposite NaI(Tl) detector was ~ 40 cm. The results are shown in Fig. 4.

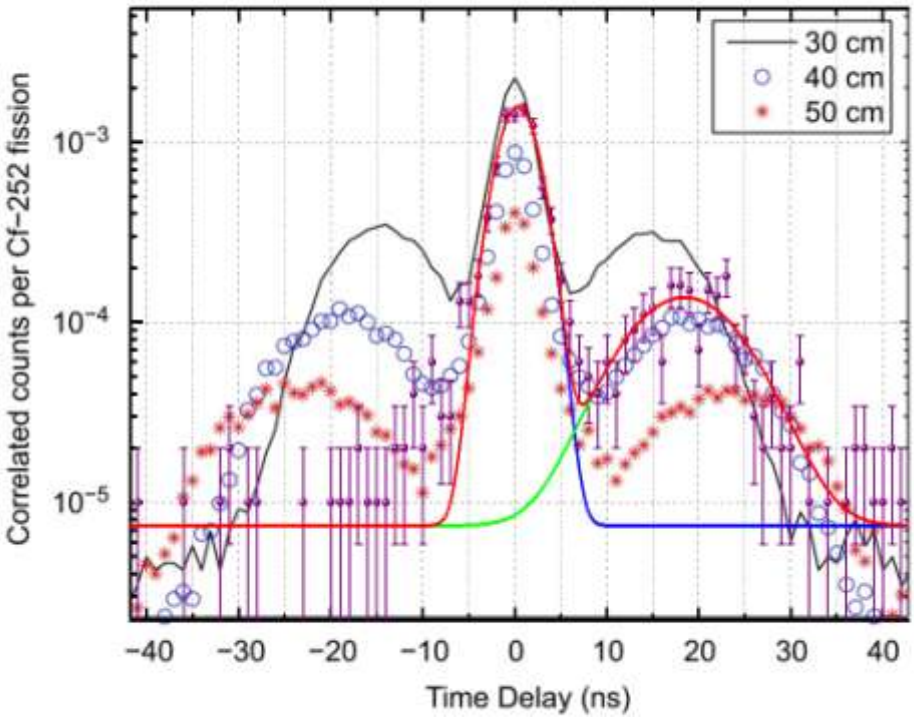

Fig. 4. ^{252}Cf(sf)gamma-ray(with energies $E_\gamma > 1$ MeV) coincidences measured by 2 NaI(Tl) detectors, compared with the literature data, taken from ref. [9].

From Fig.4 it can be concluded that, using the "extended" version of the gamma spectrometer (Fig.1 in ref. [5]), it is possible to separate signals from neutrons and gammas because of their different TOF from the target to the NaI(Tl) detectors. A better separation of the neutron and gamma contributions from ^{252}Cf(sf) was achieved when sorting only the events with E_{γ} >1MeV.It can be seen that our results are in good agreement with the 40cm data of ref. [9], obtained by using much faster than NaI(Tl) BC-501A liquid scintillation detectors.

4. Energy dependence of the resonance neutron flux density

The resonance neutron induced ^{181}Ta(n,γ) reaction and the TOF-method were used for the determination of the energy dependence of the neutron flux density at the60m measuring station of the IREN facility. The accelerator was working at a repetition rate *f*=25 Hz (e-beam pulse duration τ_e~100ns, ~1A peak current, ~400W power), the fast neutron pulse-width was$\Delta_t \cong$ 250ns. The neutron TOF-spectrometer time-resolution at this distance is Δ_t/L~ 4 ns/m, which is ~20times as better as than that of the former IBR-30 pulsed reactor. The neutron beam diameter was ~20cm.The sample (≈30.06g) was made from a natural tantalum foil with a thickness of ~0.11mm. The abundance of the ^{181}Ta in natural tantalum is 99.988 %. The areal density of the sample (effective thickness) was ~ 6x10^{20} atoms/cm^2.

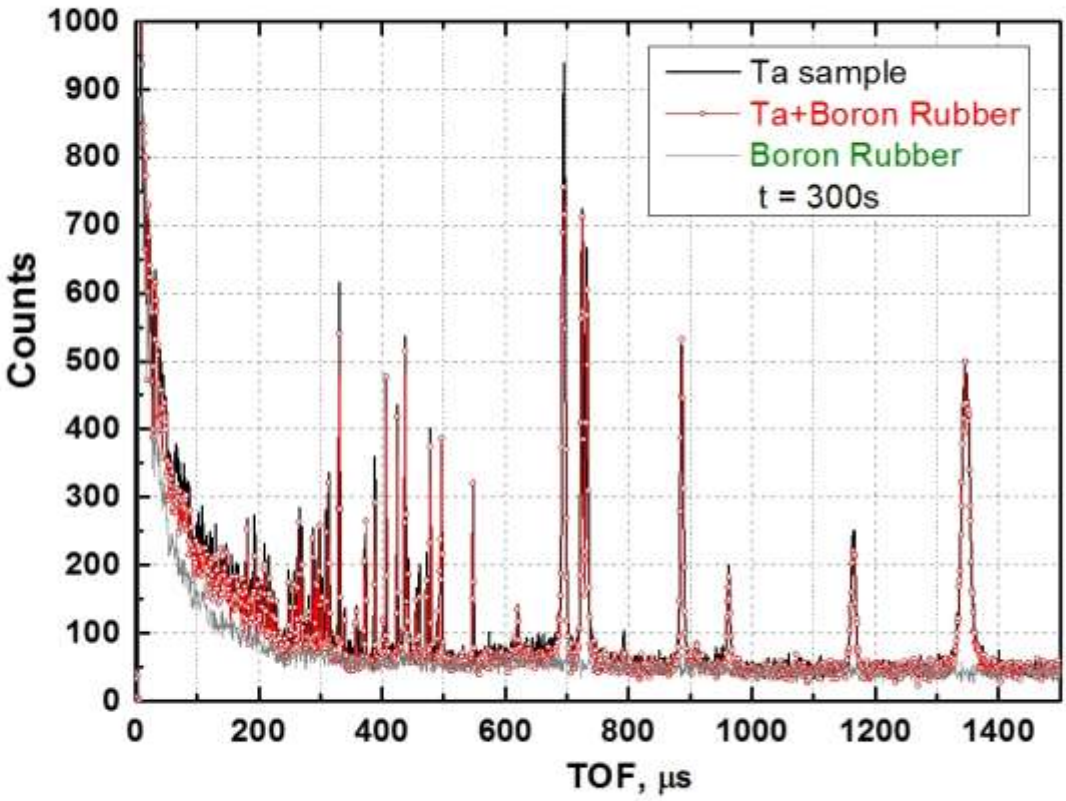

Fig. 5. A typical TOF spectrum of ^{181}Ta(n,γ) yield up to E_n ~ 64eV(with detector B-rubber screen and without it) and the gamma-background at IREN FP3/60m.

5. Conclusion

In order to measure nuclear data, needed for modelling of generation IV nuclear facilities with a better precision, a new experimental gamma-ray spectrometry system was tested at FP3/60m of the pulsed neutron source IREN. By this multi-detector γ-ray spectrometer it is possible to investigate the neutron capture and fission reactions on a number of radioactive targets. The neutron capture and fission gammas can be separated by their different multiplicities: the mean fission γ-ray emission multiplicity is about 7-8 gammas/fission, while that from the capture process is about 2-3 gammas/capture. A standard ^{252}Cf source can be used for system calibration.

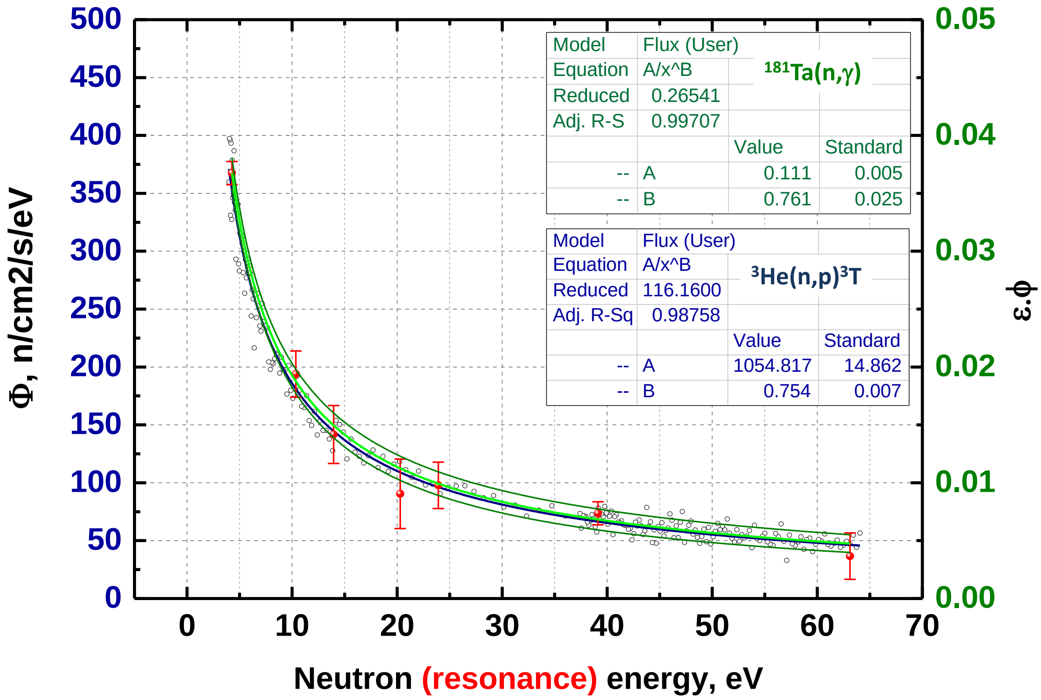

Fig. 6. The experimentally obtained relative neutron flux density values at IREN FP3/60m (dots with error bars), the power function $y=ax^b$ fitted to the experimental data, ^{181}Ta(n,γ) resonances at corresponding neutron energies up to E_n ~ 64eV, measured for 4 h. Open points are data taken from Ref. [10].

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