EXPERIMENTAL SETUP FOR INVESTIGATION OF THE RESONANCE NEUTRON INDUCED FISSION OF ^{239}Pu

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Introduction

The neutron induced fission of ^{239}Pu is still of big interest because of its importance for the nuclear power industry. New, more precise, measurements of the characteristics of the reaction products are needed for modelling the new generation nuclear power reactors core as well as for utilizing of the spent fuel **[1]**. The fission process is quite complicated phenomenon because it can go different ways. According to the nowadays knowledge, the capture of a s-wave neutron (spin s=1/2) of thermal (E_{th}~0.0253eV) or resonance kinetic energy (E_n<500eV) by ^{239}Pu ("ground" state spin and parity $I^{\pi} = 1/2^{+}$), forms a compound nucleus (CN) of ^{240}Pu mainly in 2 states **[2]** with $J^{\pi} = 1^{+}$ and $J^{\pi} = 0^{+}$, which belong to two, well separated (~1.25MeV), transition state bands with $K^{\pi} = 1^{+}$ and $K^{\pi} = 0^{+}$.

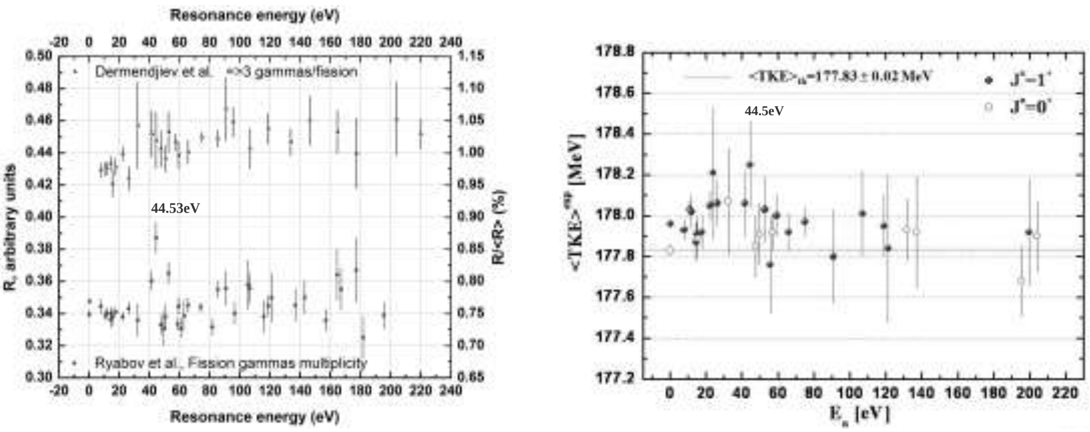
The de-excitation of the CN to its ground state can be by irradiating of one or more gamma-quanta (capture-reaction), or CN can split into two or more fragments (fission-reaction). The process of fission is accompanied by releasing (in average) of ~2-3 prompt fast neutrons and ~7-8 gammas. There are some other possible channels of CN-disintegration, which occur with less probabilities, but still of big importance when calculating the reaction energetics. One of them is so called ternary fission in which light energetic particles are irradiated. The other is the (n,γf)-reaction **[3]**, which was experimentally proven also to take place in the resonance neutron induced fission of ^{239}Pu **[4-9]**.

The multiplicity, total energy and spectrum shape of prompt γ-emission from fission of ^{239}Pu (and ^{235}U) could be the major source of uncertainty in the prediction of γ-rays heating in thermal or fast reactors cores, loaded with either uranium oxide (UOx) or mixed oxide (MOx) fuel. To reduce the present uncertainties, these characteristics need to be measured with an accuracy of ~7,5% in thermal and fast neutron induced fission of ^{239}Pu (and ^{235}U). In this resonance neutron energy region quite large fluctuations of the fission mean prompt neutron multiplicities $<\nu_p>$ were measured **[3]**. Such fluctuations have a significant impact on the reactivity coefficient of advanced water reactors **[10]**, but their origin is still not quite clear.

It was found that they correlate with mass yields A and mean total kinetic energy fluctuations $<TKE>^{exp}$ (**Fig. 1**) **[11]**, but in less extend than in the ^{235}U(n,f)-reaction **[12]**, probably because of the viscosity effects and the only channel with $J^{\pi}K=(0^{+}0)$ open to fission **[11]**.

Similar fluctuations were obtained in the independent fission-fragment yields **[13]**, also.

From energy conservation point of view, the fluctuations of the $<\nu_\gamma>$ have to anti-correlate with those of the $<\nu_p>$. Data of Ref. **[5]** (shown in **Fig. 1a**, bottom) are explained as



manifestation of the (n, γf)-reaction **[4-9]**, which act as a concurrent to the direct fission.

Fig. 1 a) Fluctuation of the fission relative γ-ray yields R/<R> **[14]** and $<\nu_\gamma>$; **b)** Fluctuations of the fission fragment <TKE> from resonance-to-resonance **[11]**

And particularly, it concerns the fission resonance at E_n=44.53eV, with a smaller fission width, where the contribution of the (n,γf)-reaction is expected to be more 'visible' that at the other 1^+ resonances.

The **Fig. 1a)**-data (up array) were obtained in a short term measurement conducted at the IBR-30 neutron time-of-flight spectrometer (TOFS). The fluctuations of the 3 or more gammas, measured in coincidence with the IC fission-fragment pulses, were found to be in the range of the experimental data uncertainties and not so well pronounced as in the experiments reported in Ref. **[3-5]**, in the whole neutron energy interval up to ~200eV. The relatively large error-bars of the experimental data and the moderate neutron energy resolution of the IBR-30 TOFS, together with the need for data of better precision, trigger us to start preparation of similar experiment at the newly commissioned IREN white spectrum pulse source, using NaI(Tl) multi-detector arrays and the multiplicity method for separation of the contribution of capture gamma-rays from that of the fission gamma-rays (and neutrons).

The experimental setup

The experimental setup is in the stage of development and construction. It will consist of: IREN as a "white" spectrum pulsed neutron source; vacuum tube collimated beam-line; a multi-sample parallel-plate gas ionization (fission) chamber (IC) loaded with ^{239}Pu samples, as a charge particle detector; NaI(Tl) arrays as detector-spectrometer of gamma-rays and a computerized system for multichannel data acquisition and analysis.

1. *The Intense Resonance Neutron Source (IREN)*

A linear electron accelerator LUE-200 is used as a driver of IREN. It consists of a pulsed electron gun, accelerating system, RF power supply system, based on klystrons with modulators, beam focusing and transport system, including a wide aperture magnetic spectrometer and a vacuum system. The accelerator is allocated vertically inside a 3-floors building. The IREN parameters are listed in the IREN web-site @ http://flnp.jinr.ru/554/.

2. The charge particle detector

As a detector of charge particles, alphas or fission fragments (FF), a multi-plate gas IC will be used. The IC and the disposition of its electrodes are shown in **Fig. 2**. It is loaded with three thin (~0.14 mg/cm^2) reactor grade plutonium (88% ^{239}Pu) layers of total mass ~2.1 mg, deposited on ~20 μm thick Al backings. Spots' diameter is ~2.5 cm. As a working gas a mixture of 95%Ar + 5% CO_2 will be used at a constant pressure less than 1 atm. The same chamber, filled with P-10 gas-mixture, was used in the experiment, described in Ref. **[14]** at the IBR-30 pulsed reactor, using a large 6-sections 210*l* liquid scintillation detector for gamma-ray detection **[15]**.

3. The multi-detector array for gamma-ray spectrometry

A multi-detector gamma-ray spectrometry system was designed and constructed (**Fig. 2**).

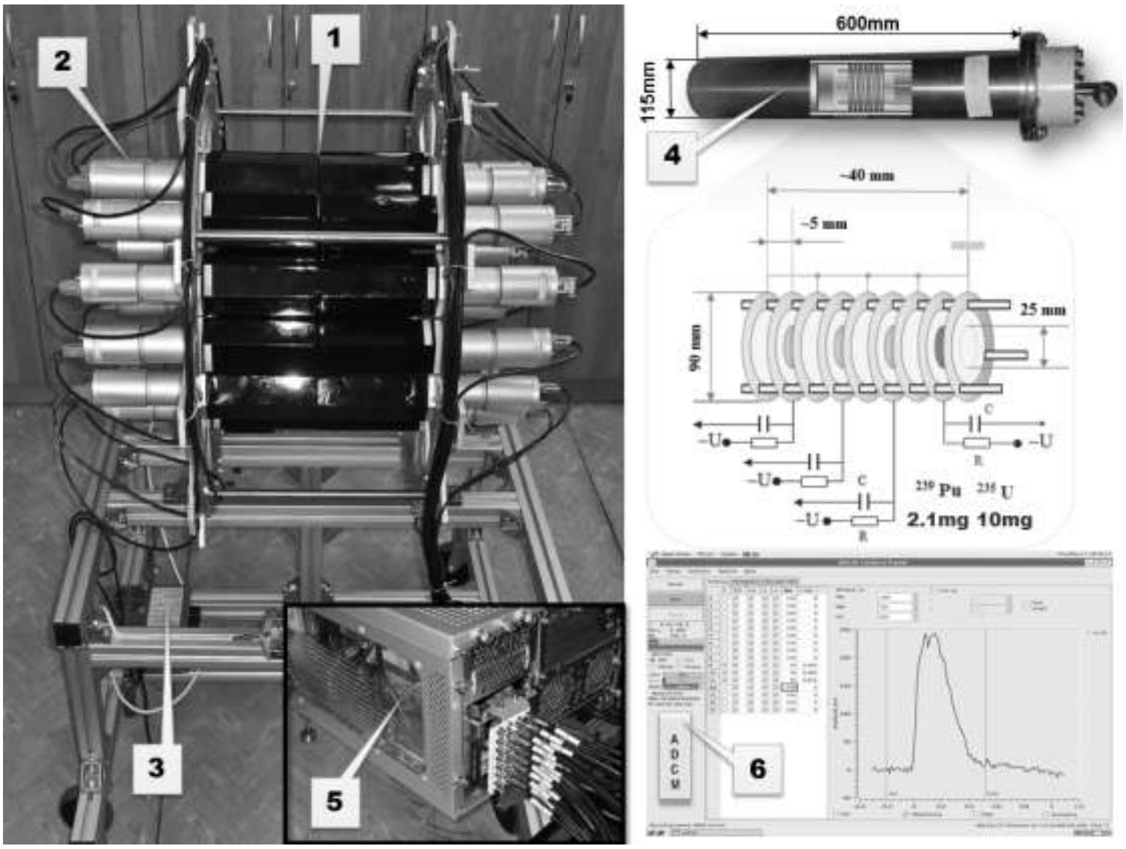


Fig. 2 Prompt fission gamma-ray spectroscopy system: 1- Two arrays by 12 NaI(Tl) detectors, 2- PMT+HV generator, 3 -5V DC for powering the HV generator, 4 -parallel plate gas ionization chamber , 5- computerized 32 channel ADC, 6 –Data acquisition software ADCM.

More detailed description of the spectrometer with associated electronics and data acquisition system (DAQ) will be published elsewhere. Here only a brief description is given. It consists of 2 rings (arrays) of 12 Amcrys-H **[17, 18]** NaI(Tl) detectors 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 gammas, 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 as many as 24 detectors to be arranged in a concentric ring of diameter more than ~1 m. The signals from all the 24 detectors are recorded simultaneously in digitized form and are stored on the hard disk of the personal computer for further off-line analysis by the AFI Data acquisition system ADCM **[19]**. A computer screenshot with a typical signal from a single NaI detector is shown in **Fig. 2**.

4. The data acquisition system

The data acquisition system (DAQ) of AFI-Dubna **[18]** consists of 2x16-channels data acquisition board ADCM16-LTC and a software package, which includes a kernel module (driver), a control program, and a reconstruction program. The ADCM16-LTC, 16-channel 14-bit 100 MHz Analog-to-Digital Converter (ADC) board with a signal processing core, is used together with a CCB-PCIe carrier board and utilizes one PCI slot of the PC. To drive the new 24 detector gamma-ray spectrometry system and 4 signals from fission fragments detector, the two ADCM16-LTC boards are connected together to form a system with 32 channels 14-bit. The theory of the ADCM operation is described in detail in Ref. **[19]**.

The DAQ is designed for a direct digitizing of signal pulses coming from gamma detectors and fission chamber. It has a built-in trigger circuitry with three modes of operation: time-driven, single-channel, and double (gamma-gamma) coincidences. So, software wise is possible accurately to reconstruct the amplitude and time-mark of any signal and to form the amplitude and/or time-spectra. The information from all the 24 NaI(Tl) detectors and the fission chamber is collected and stored on a separate computer hard-disks (acting as a file-server) simultaneously.

Two typical amplitude spectra from standard ^{137}Cs+^{60}Co sources, used for energy calibration, as well as the coincidence spectrum between the pulses of a single NaI and NE213 detectors are shown in **Fig. 3**. The energy resolution of a single NaI detector is ~7% for ~662 keV gammas from ^{137}Cs, the time resolution of a single NaI was found to be ~3 ns.

The neutron capture and fission gammas will be separated by their different multiplicities: the mean fission gamma-ray emission multiplicity is ~7-8 gammas/fission, when that from the capture process is ~2-3gammas/capture. Using a standard ^{252}Cf source the system can be properly calibrated. This way the neutron capture and fission processes can be simultaneously investigated and the capture-to-fission ratio coefficient fluctuations can be determined. The mean prompt capture and fission gamma ray multiplicities can be determined following the approaches developed by Theobald et al. **[20]** and by Muradyan et al. **[21]**.

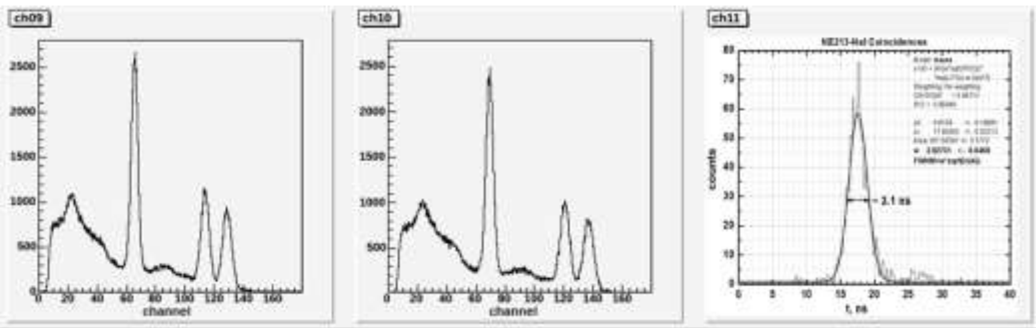


Fig. 3 Gamma-rays amplitude spectra from 2 NaI detectors and the coincidence spectrum between the both gammas from ^{60}Co source, measured by NaI and NE213 detectors.

The fission fragments counts from IC can be used as an additional (to the multiplicity) constrains to separate neutron capture and fission gamma induced events and to determine the corresponding reaction cross-sections. Other possible uses of the new build multi-detector system are outlined in Ref. **[22]**.

Conclusions

In order to fulfill the Nuclear Community requests for improvement of the existing knowledge and quality of nuclear data, needed for modeling of the generation IV nuclear facilities and, in particularly, on the prompt fission gamma ray emission in neutron induced fission of ^{239}Pu, new experiments are under preparation at the IREN facility.

Acknowledgements

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