A MULTI-SECTION FRISCH-GRIDDED IONIZATION CHAMBER FOR STUDIES OF NEUTRON-INDUCED FISSION AT THE GNEIS FACILITY

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Abstract

A multi-section Frisch-gridded ionization chamber adopted for operation at the neutron time-of-flight spectrometer GNEIS is described. The data acquisition system based on a waveform digitizer is discussed as well as the digital signal processing. Results of test measurements carried out in the neutron energy range 1-200 MeV with ^{235}U and ^{232}Th targets are reported.

Introduction

The study of neutron-induced fission has been and still remains one of the most important subjects of nuclear physics and has a great fundamental and practical importance. Nowadays, there is an increasing interest in studying neutron-induced fission of actinides at intermediate energies, i.e., between 20 and 200 MeV. It is motivated by nuclear data needs for feasibility studies of emerging nuclear systems dedicated to the generation of intense radioactive ion beams, incineration of nuclear waste, isotope production, etc.

Successful implementation of such tasks is impossible without a thorough understanding of the physics of the nuclear fission process at intermediate-energy, and can only be based on reliable experimental data. On the other hand, after many years of research the neutron-induced fission of actinides remains an intriguing subject of studies in nuclear physics.

Fragment mass distribution is one of the most important characteristics of the nuclear fission process. At present, a consistent description of mass splitting in fission is far from being achieved. It is believed that the formation of the fission fragment mass distribution is closely connected with the potential energy surface in deformation space (at the stage of saddle-to-scission descent) while dynamical effects (nuclear friction and inertia) have less influence on the shape of the mass spectra. A number of theoretical models have been proposed at different times to quantitatively predict fragment mass yields [1-5]. It should be pointed out that modeling of intermediate-energy neutron-induced fission is severely complicated by the fact that fission, being a relatively slow process, follows pre-equilibrium particle emission and competes with neutron evaporation. As a result, a number of nuclides, each with its own fission characteristics, will contribute to the experimental fission observables. This suggests that a model of fragment formation should be embedded in a proper nuclear reaction code which takes care of pre-fission particle emission (see, e.g., [6, 7]).

Further development of the fission reaction models requires new experimental data at intermediate energies. To date the neutron-induced fission cross sections of many actinides relevant to advanced nuclear applications have been measured at incident energies up to 200 MeV [8-11], but there is a lack of experimental data on fragment mass yields. So far we know only two experiments in which kinetic energy distributions and mass yields of the fission fragments in the reaction ^{238}U (n, f) and ^{232}Th have been measured as a function of incident neutron energy. The first experiment was performed by Zoller et al. [12] using the neutron source LANSCE at the LANL, but the distribution of the fragments obtained in [12] has a relatively poor statistical support. It is accumulated several thousands of events (per neutron energy interval of 1 MeV) for incident neutron energies from 10 to 100 MeV, which drops to a few hundred events in the region 100-200 MeV. Such a low statistical support complicates the comparison of obtained data with the theoretical predictions. The second experiment was carried out at the neutron beam of the cyclotron facility CYCLONE in Louvain-la-Neuve (LLN). The facility has been described in details in Refs. [13, 14]. It was measured the mass distribution of fragments from ^{238}U(n,f) and ^{232}Th(n,f) reactions at the neutron energies 32.8, 45.3, and 59.9 MeV [15].

In this work we report on the results of test measurements carried out in the neutron energy range 1-200 MeV with ^{235}U and ^{232}Th targets.

Experimental set-up

The experiment was carried out at the neutron time-of-flight spectrometer GNEIS [16] which is based on the 1 GeV proton synchrocyclotron of Petersburg Nuclear Physics Institute (Fig.1). The GNEIS facility is intended for investigations of neutron interaction with atomic nuclei in the energy range from 10^{-2}eV up to several hundred MeV.

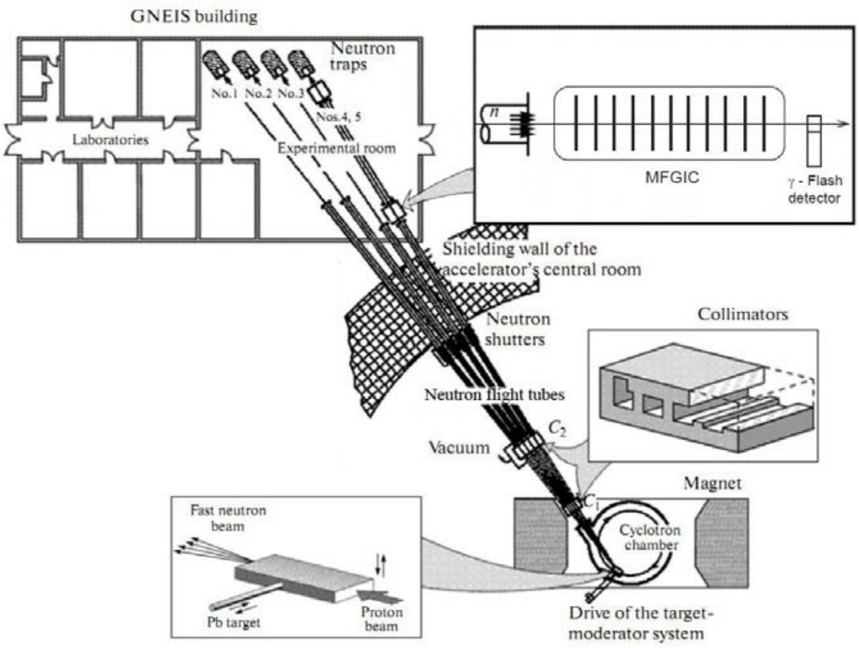


Fig.1. General layout of the measurements at the GNEIS facility.

To detect fission fragments, we used a multisection Frisch-gridded ionization chamber described in details elsewhere [15]. In contrast with our previous measurements, the chamber was slightly modified. In particular, we were forced (due to the background problems) to abandon the scheme with common anodes, so the present detector consists of 5 fully independent twin Frisch-gridded ionization chambers. The ionization chamber was located at a distance of 36.5m from the neutron source in a gap of flight tube of the neutron beam N5 of the GNEIS facility (Fig.2). Close to the chamber (downstream) was located a so-called γ-flash detector – FEU-30 PMT without scintillator which was used to produce a trigger (START) pulse for time-of-flight measurements.

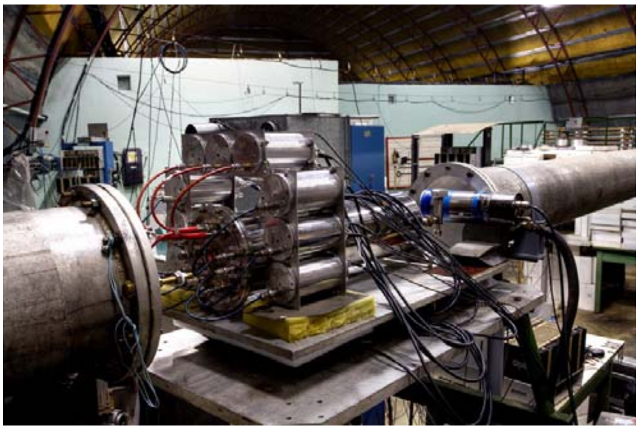


Fig.2. Multisection Frisch-gridded ionization chamber at the GNEIS.

The electrode assembly is placed into a thin-walled (1 mm) stainless steel detector housing. All the electrodes are of circular form with a diameter of 110 mm. The anodes are 50 µm thick aluminium foils, sandwiched between two 1 mm thick duralumin rings with inner diameter of 90 mm. The cathodes are stainless steel annular disks of 2 mm thick and 68 mm inner diameter. The target holders are mounted in the central part of each cathode using spring catches. The grids are mounted in parallel on the stainless steel rings of 2 mm thick and 90 mm inner diameter. The grids are made of gilded molybdenum wires of 80 µm in diameter spaced by 1.25 mm. The distance between anode and grid is 8 mm. The cathode to grid distance is 24 mm. The working gas mixture is composed of 90% argon and 10% methane (P-10). The chamber operates at pressure of 1.16 bar (without a continuous gas flow).

The fissile targets were prepared by vacuum evaporation of $^{235}UF_4$ and $^{232}ThF_4$ onto 30 µg/cm^2 thick Formvar backings. The backings were covered by 15-20 µg/cm^2 layer of gold to make them electrically conducting. The chamber sections N1,2 were loaded with the thorium targets, while the uranium ones were placed into the sections N4,5. In the central section, a calibration ^{252}Cf source was mounted. The targets parameters are summarized in Table.1.

Table 1. Parameters of the fissile targets.

Fissile material	$^{235}UF_4$ ~120 µg/cm^2	$^{232}ThF_4$ ~171 µg/cm^2	^{252}Cf ~1 f/sec
Conductor	Au ~15 µg/cm^2	Au ~15 µg/cm^2	Au ~20 µg/cm^2
Backing	Formvar ~30 µg/cm^2	Formvar ~30 µg/cm^2	Al_2O_3 ~45 µg/cm^2

Data Acquisition

The data acquisition system (Fig.3) of the experimental set-up is based on two flash ADC waveform digitizers CAEN V1721 which are used for signal processing. The Model V1721 is a VME module with 8 input channels, 8 bit and maximum sampling frequency 500 MS/s. The on-line processing computer software is based on a ROOT package [17].

For the present experiment, the chamber was loaded with 3 fissile targets: ^{235}U, ^{232}Th and ^{252}Cf. Three signal waveforms (cathode + 2 anode) were recorded for each section, so 10 signal waveforms were recorded for each neutron burst (9 from the chamber and 1 from the γ-flash detector). In total it was accumulated 23 thousands of fission events of ^{235}U and 15 thousands of fission events of ^{232}Th.

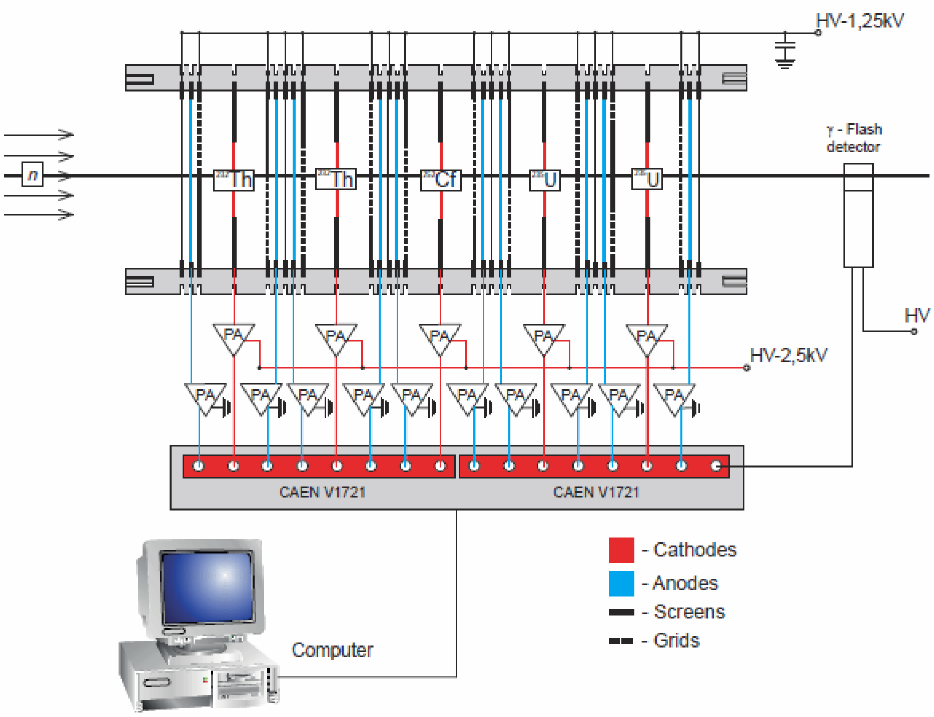


Fig.3. Data acquisition system.

Signal Processing

A specific feature of the TOF spectrometer GNEIS is its relatively high intensity of the neutron and gamma flash. This leads to the fact that each flash results in a noticeable ionization of the working gas in all sections of the chamber. As a result, the shape of background pedestal of a signal is different in different sections. An example of anode signals from each chamber section is shown in Fig.4. To determine the amplitude and time characteristics of the digitized signals, it is necessary to find some characteristic points on a time scale (Fig.5):

(1) peak of the signal from the γ-flash detector – the point in time T_1 when proton bunch impinges the Pb target;

(2) the beginning of the growth of the cathode signal – the point in time T_2 when ionization of the working gas by fission fragment takes place;

(3) the end of the growth of the cathode signal – point in time when all electrons pass through the grid;

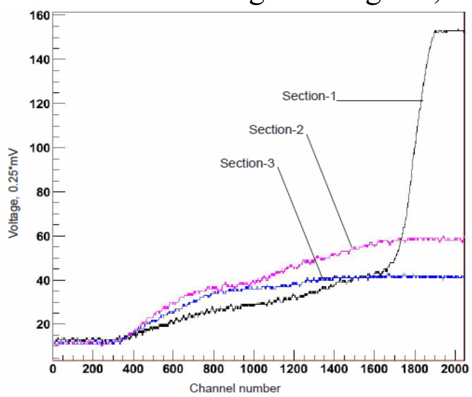
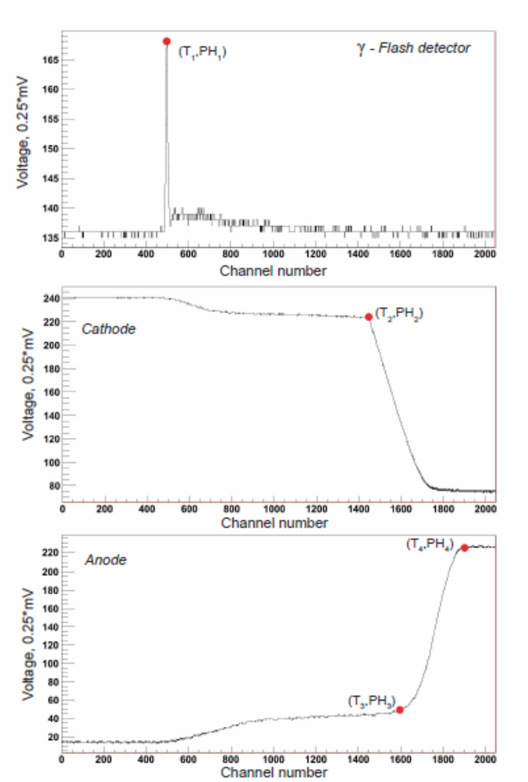


Fig. 4. Anode signals (channel width=2 ns).



(4) the beginning of the growth of the anode signals - the point in time T_3 when first electrons pass through the grid;

(5) the end of the growth of the cathode signal – point in time T_4 when all electrons reach the anode.

Calculation of signal characteristics:

* to determine the incident neutron energy by TOF method it's necessary to calculate the difference between T_2 and T_1;
* to determine the mass and energy of the fission fragments it's necessary to calculate the difference between pulse- heights PH_4 and PH_3;
* to determine the emission angle by drift-time technique it's necessary to calculate the difference between T_3 and T_2.

Fig. 5. Characteristic points of the signals.

Experimental data analysis

After the calculation of pulse height and time position for each signal from the chamber, the TOF (neutron energy) and pulse height (fragment mass and energy) spectra were obtained. The next step of the data processing procedure consisted in neutron energy and fission fragment energy calibrations for each individual target. The calibration implying transformation of the TOF scale into the neutron energy scale was performed using the relativistic formula and locations of the neutron resonances in the total cross section of lead (material of neutron producing target) observed as resonance dips in TOF spectra (Fig.6). The vertical arrows indicate position of the resonances while the numbers are resonance energies in MeV.

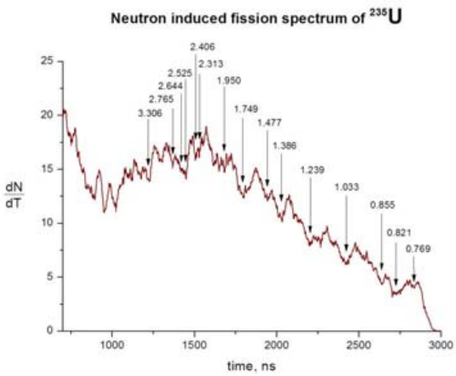
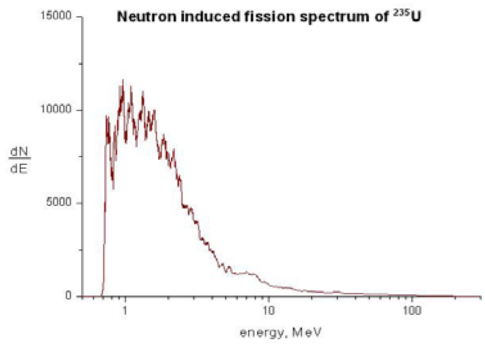
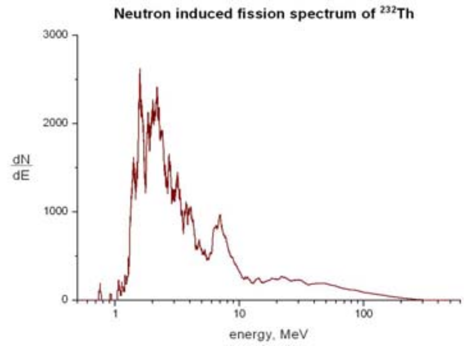


Fig.6. Neutron time-of-flight spectrum measured with the ^{235}U target

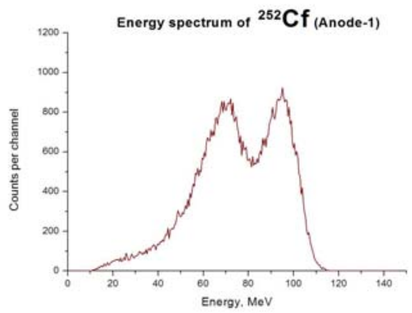
Calibration of the fission fragment energy scale was carried using the well-known alpha–particle lines of ^{235}U, ^{232}Th and ^{252}Cf. Transformation to the energy scale was carried out using the precision pulse generator. At the present stage of data processing the pulse height defect was not taken into account. Fission fragment kinetic energy distributions obtained in present measurements are given in figures below for all incident neutron energies.



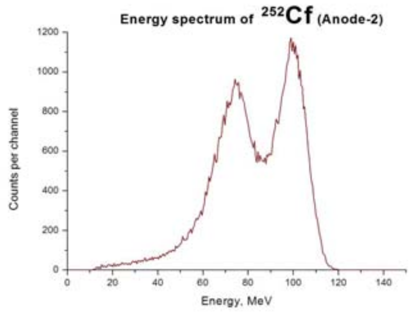
Fission events distribution for ^{235}U target versus incident neutron energy



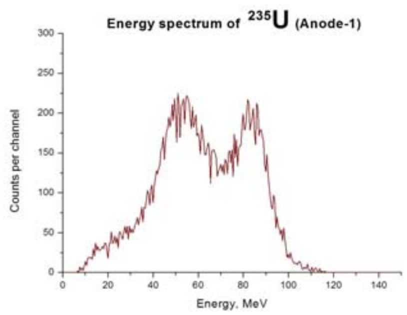
Fission events distribution for ^{232}Th target versus incident neutron energy



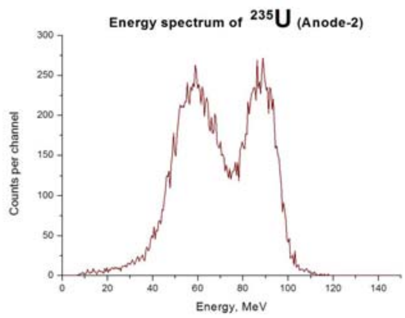
Raw fission fragments spectrum of ^{252}Cf (Anode-1)



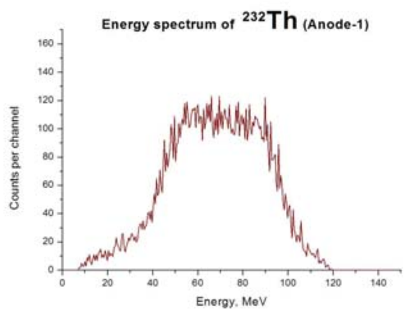
Raw fission fragments spectrum of ^{252}Cf (Anode-2)



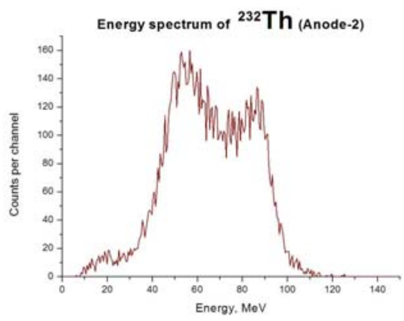
Raw fission fragments spectrum of ^{235}U (Anode-1)



Raw fission fragments spectrum of ^{235}U (Anode-2)



Raw fission fragments spectrum of ^{232}Th (Anode-1)



Raw fission fragments spectrum of ^{232}Th (Anode-2)

Anode-1 - through the backing, downstream; Anode-2 - from the fissile target, upstream.

Conclusion

A multi-section Frisch-gridded ionization chamber formerly used in fission experiments at quasi-monochromatic neutron sources was adopted for measurements on a "white" neutron spectrum in intermediate energy range. Beside a minor modification of the chamber itself, a new data acquisition system based on the flash ADC waveform digitizer was developed. A new experimental set-up was tested in the measurements of fission fragment mass and kinetic energy distributions at the neutron TOF-spectrometer GNEIS. The results of test measurements carried out in the neutron energy range 1-200 MeV with ^{235}U and ^{232}Th targets are reported.

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