Compact neutron calibration source based on ^{252}Cf radionuclide and a silicon semiconductor detector

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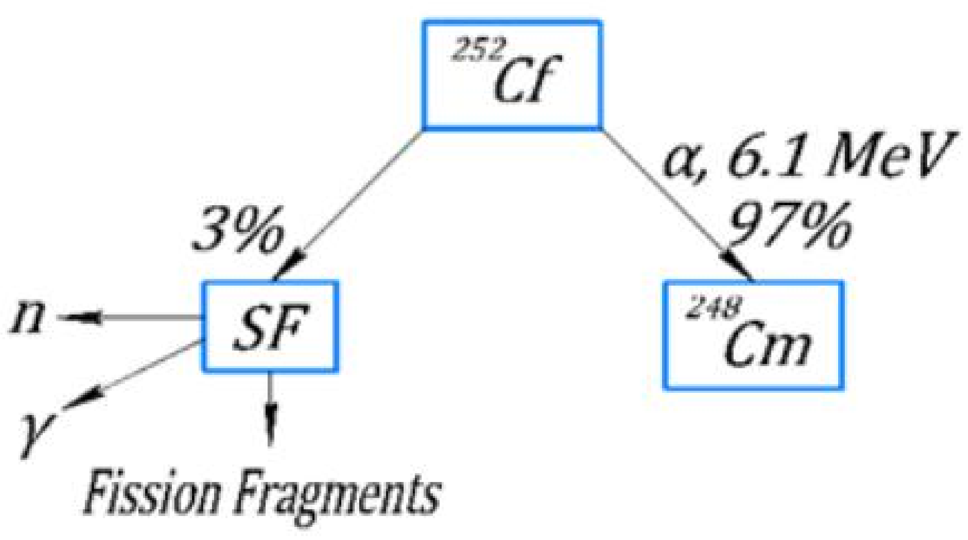
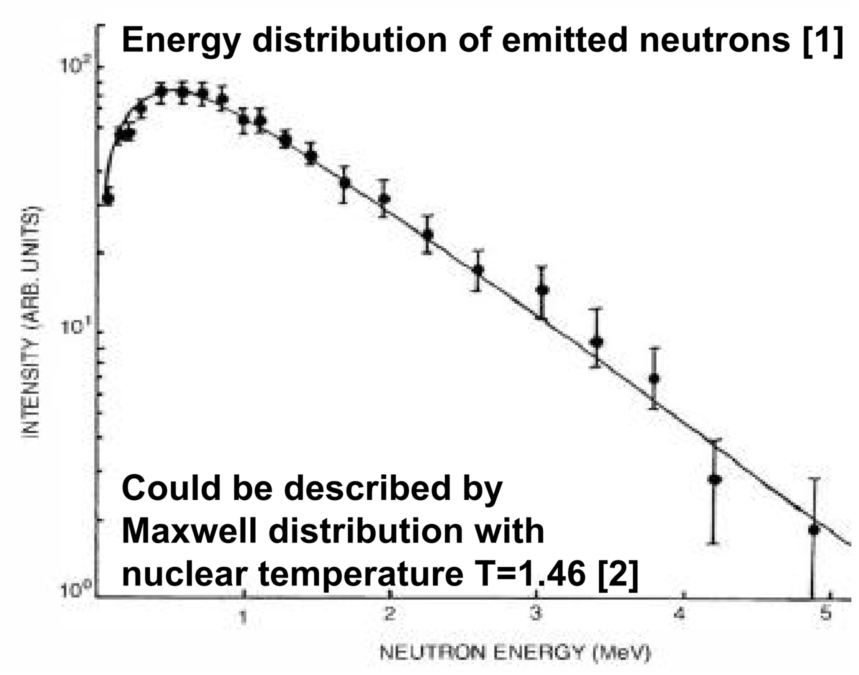
Motivation

The response function of the recoil nuclei in the neutrino or dark matter detectors can be determined only with the help of a neutron source with known energy spectrum. In this regard, research and development of a compact neutron calibration source with either known neutron energy spectrum, or time-of-flight neutron energy reconstruction is an important task for successful realization of a number of current and future nuclear and astrophysical experiments.

In this work we demonstrate the operation of a model of compact neutron calibration source based on Californium-252 radionuclide which undergoes spontaneous fission producing neutrons with a continuous spectrum and a semiconductor detector. The latter upon registration of fission fragments (FF) signal provides a time reference of the moment of neutron creation. *The reported study was funded by RFBR, project number 20-02-00571.*

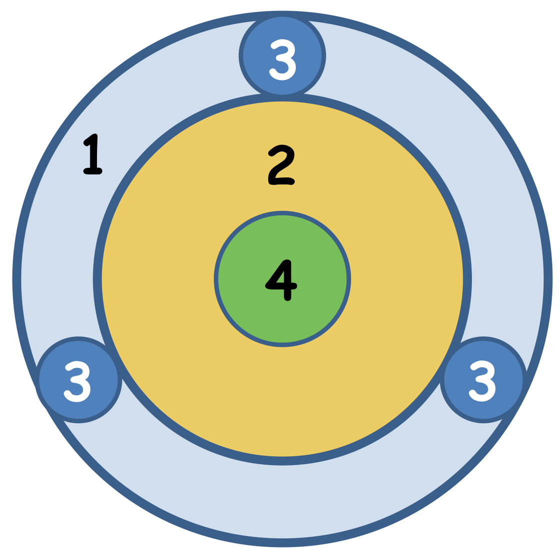
^{252}Cf decay scheme





- α-decay and spontaneous fission into two fragments (mean energies of 104 MeV and 79 MeV) with branching ratio 97:3
- each spontaneous fission event liberates 3,8 neutrons on average
- γ-rays in energy diapason of 100-1500 keV, prompt and due to impurities (^{249}Cf) or fission products (like ^{137}Cs)

Experimental setup

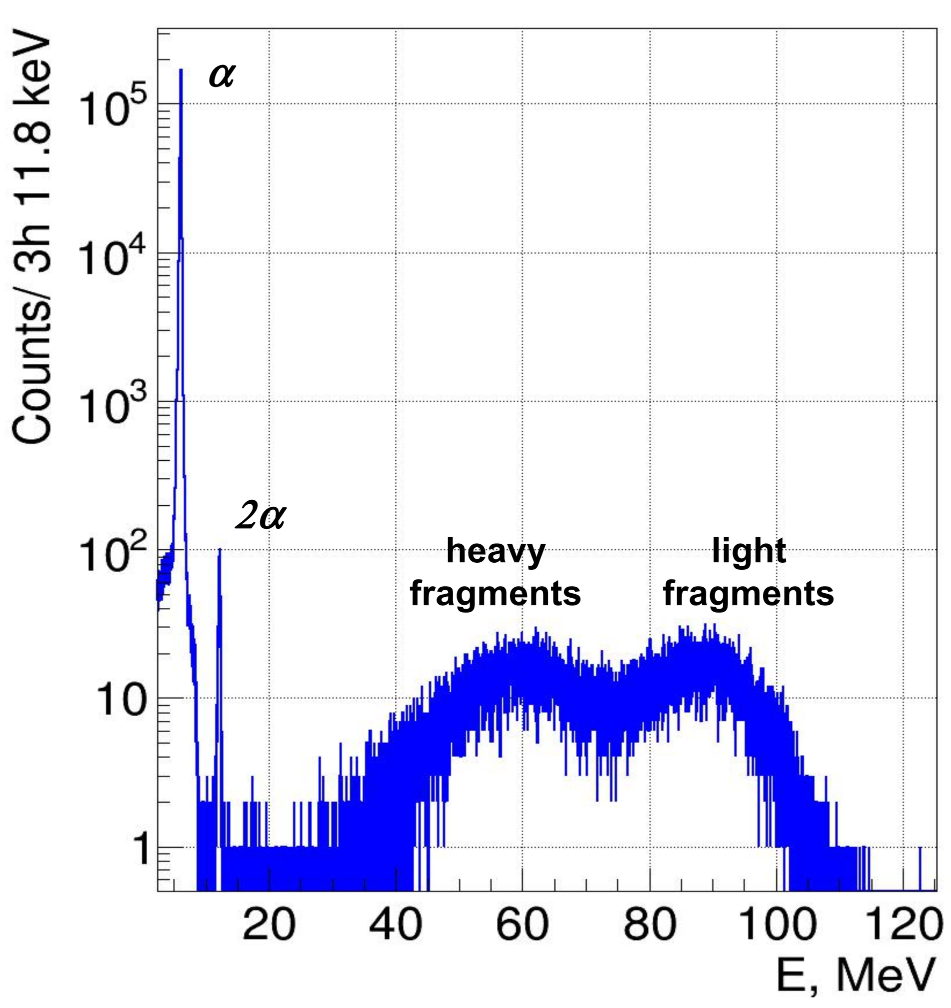


Sketch of the measurement setup:
1 - PMMA scintillator cylinder, inner ø 13cm, thickness 7 cm, height 15 cm
2 – lead shield
3 - three PMTs of type 97
4 - vacuum chamber with ^{252}Cf source and a semiconductor surface-barrier detector

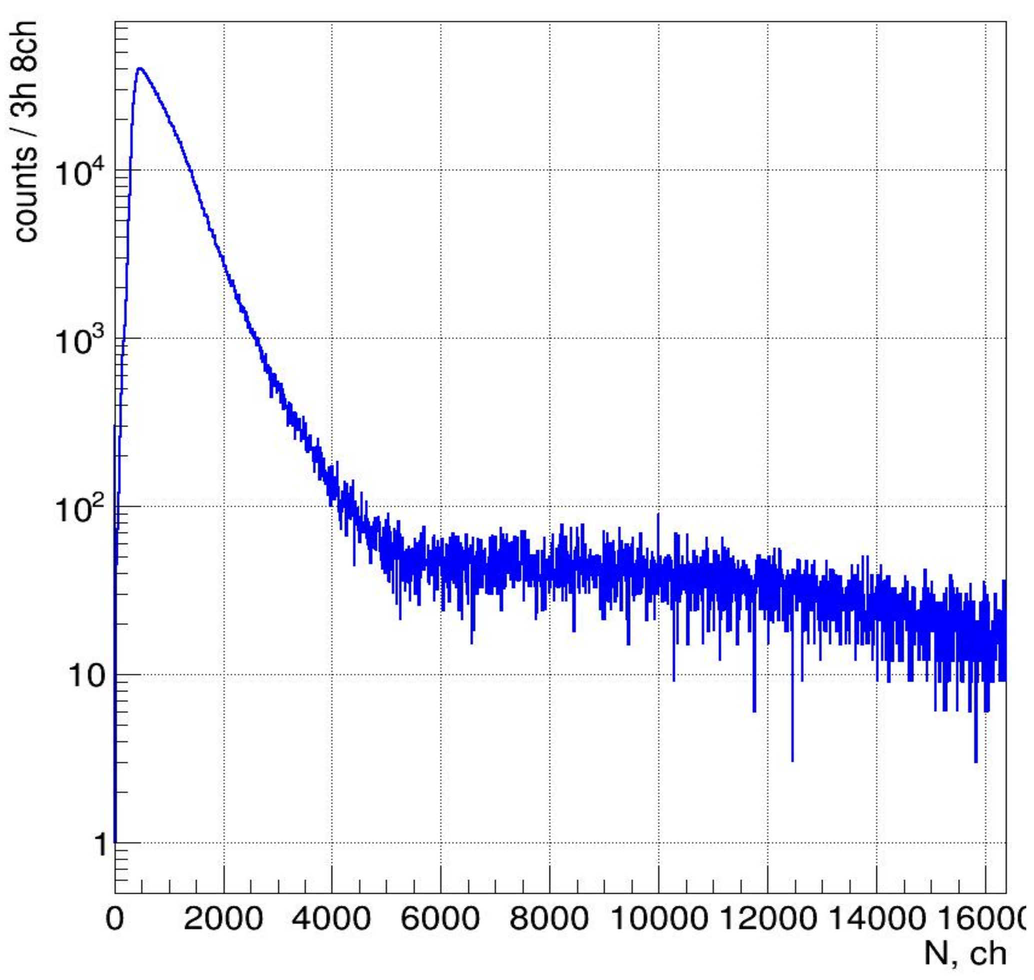
Spectrometric channel: CAEN multichannel preamplifier + CAEN 25 MHz ADC allowing digital pulse shaping. Employed software allows the analysis of the signals recorded by PMTs and semiconductor detector in coincidence mode.

Obtained results

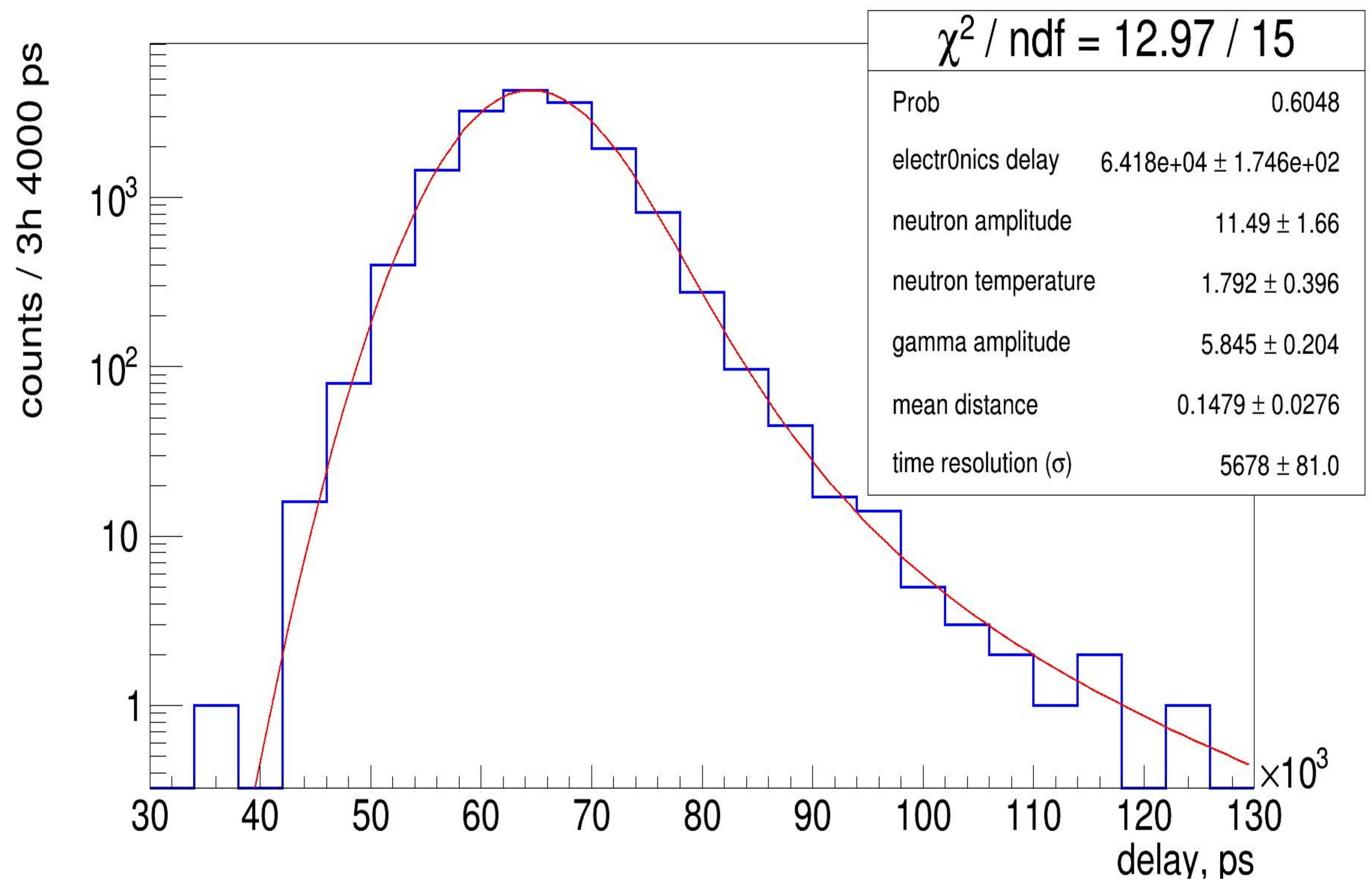
FF spectrum recorded by semiconductor detector



PMT summary spectrum due to neutrons and γ-rays transmitted through the lead shield



Time distribution of PMT signals relative to the moment of FF signal registration by semiconductor detector



Lack of the signal at t<60 nsec is caused by the slow raise of the leading edge of PMT pulse.

Fit was performed following the Maxwell distribution of neutron energy spectrum. Fit parameters:
- electronic delay
- temperature of neutron spectrum
- contribution of γ-rays signal
- neutron traveling distance

The nuclear temperature determined by fit (T=1.8±0.4) is consistent with the determined earlier (T=1.46) within the margin of error

Conclusions

- experimental setup for combined measurements of neutron and fission fragments spectra of ^{252}Cf radionuclide was implemented
- procedure of signal processing allowing the confident identification of neutron-related signal by accounting the time delay of neutron signal registration by PMTs with respect to the moment of FF signal registration by semiconductor detector was developed
- as a result, the possibility of application of ^{252}Cf radionuclide in combination with semiconductor detector as a compact neutron calibration source has been proven and confirmed
- additional investigations have revealed [3], that properly chosen semiconductor detector may withstand exposure of up to 10^9 of fission fragments before critical degradation, assuring therefore a sufficient lifetime of a considered calibration source

References:
[1] Knoll G F *Radiation Detection and Measurement*, (New York: John Wiley and Sons)
[2] Котельникова Г.В. и др., Энергетический спектр нейтронов спонтанного деления 252 Cf в области энергий от 0,5 до 7 МэВ, ФЭИ-575, Обнинск, 1975
[3] Bakhlanov S.V. et al., Journal of Physics: Conference Series 2103, 012138, 2021