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THE SETUP TO INVESTIGATE RARE PROCESSES WITH NEUTRON PRODUCING

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We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche

Studying rare processes with the formation of neutrons or determining characteristics for low-intensity neutron sources is a ticklish problem. Its solution depends to a large extent on the concept of designing a system to register neutrons and also on characteristics of the system. The registering system comprises both neutron detectors and registering electronics.

In this case the neutron registering system should meet a number of requirements:

1) It should allow highly reliable separation of true and background events registered by the neutron detectors.

2) it should be sufficiently effective to register neutrons in the energy region of interest.

3) the background should be low.

4) it should be well-protected from electromagnetic pick-ups.

5) it should permit time and amplitude information on each registered event.

To register fast neutrons, as a rule, both scintillation counters based on organic scintillators (plastic, NE-213, stilben and others) and thermal neutron counters (filled with BF_3 or ^3He) placed in a moderator (paraffin, polyethylene) are used. To register slow neutrons the above-mentioned BF_3 and ^3He-detectors are used. Measurement of time and amplitude distributions of registered events makes it possible to obtain information on characteristics of the processes under study (such as the rate of a process, the cross-section of a process) as well as on characteristics of low-intensity neutron sources (the intensity of a source, the duration and form of a neutron pulse in the case of a pulse neutron source).

By measuring the distribution of intervals between two consecutively registered events in duration and approximating the distribution data by the function of the form $e^{-n(t)\epsilon_n t}$ (where $n(t)$ is the neutron source intensity, which in the general case may be the time function; ϵ_n is the neutron registration efficiency of the setup, t is the time between two consequently registered events) one may determine the neutron source intensity. Let us note that to do this requires knowing the neutron registration efficiency of the detecting system, ϵ_n, which in its turn, may be found experimentally either using calibrated neutron sources (if it is possible) or by numerical Monte Carlo simulation. This reasoning deals with the registering system on the basis of scintillation detectors. In the case of thermal neutron detectors the characteristics under study of either processes or low-intensity neutron sources are also determined from the analysis of distributions of time intervals between consequently registered events, but taking into account neutron distributions in the time of delay and in their diffusion in the moderator (in this case the problem of extracting information on the sought-for parameters of the processes under investigation is best solved by the method of least squares by comparing experimental distributions of time intervals with the distributions resulting from the numerical simulation of the processes of neutron interactions with the matterial of the moderator and neutron counter (BF_3, ^3He)). Since the registering system must ensure reliable measurement of the neutron yield (even in the case where its value is comparable with the background level), it is necessary that the system is sectionalized, i.e. it should comprise at least two independent neutron registering channels. This requirement stems from the fact that in the case of registering neutrons (generated as the result of either the proceeding processes under study or emission of neutrons by the source under investigation) the distributions of time intervals between consequently registered events obtained for each section of the registering system should have the same form. If background processes of a sporadic nature are registered (a break-down of an interdinode gap in a photomultiplier or in a high-voltage divider of a photomultiplier; electromagnetic pick-ups in a spectrometric system comprising a charge-sensitive preamplifier; a high-voltage puncture in an entrance insulator of the BF_3 and ^3He-counters) time distributions of events registered by the detectors of each section are different, which, in its turn, enables us to exclude such events from further consideration in the process of the "off-line" analysis of experimental data.

Such principles of selecting events using the "off-line" analysis of experimental data do allow reliable measurement of the neutron yield exceeding the background level fluctuations. This approach to event selection is especially important for experiments where there is a need to ascertain not only the fact of neutron emission but also its time microstructure, taking into account that the neutron emission may be of sporadic nature. Below is a description of the setup constructed for experiments of such kind.

1 The detecting system

A general view of the detecting system of the setup is given in Fig.1. The detecting system consists of a scintillation detector 1 and thermal neutron detectors 2, 3. The scintillation detector 1 is made of plastic scintillator in the form of a cup with an outer diameter of 176 mm and 200 mm in height; the inner diameter is 120 mm and the depth is 160 mm. The thermal neutron detectors 2 and 3 (each of them is an assembly of 15 BF_3-counters of the SNMO-5 type) are put in a paraffin moderator 8 and placed around the detector 1 parallel to its axis at radii of 134 mm and 184 mm. The body of the BF_3-counter is made of stainless steel in the form of a cylinder 300 mm in length, 35 mm in diameter and with the wall 0.65 mm

thick. The anode of the counter is made of molybdenum fiber 100 μm in diameter. The counter is filled with BF_3 gas at a pressure of 240 mm Hg; the ^{10}B isotope content of boron is 87% . The counters of each group are connected in parallel and in principle form a separate thermal neutron detector. The body of a detector block (2 and 3) is made in the form of a vessel consisting of two cylindrical shells (5 and 6) 400 mm in height and 1 mm thick (diameter of the inner shell is 204 mm and of the outer shell is 480 mm) and a steel bottom 7 which is 4 mm thick. The detectors 2, 3 are submerged in paraffin to a depth of 300 mm. A copper screen 10 (in the form of a cylinder 318 mm in diameter) is interposed between counters of the first and second groups. Each group of counters has a separate high-voltage power source. To enhance noise-immunity the signals from each group of BF_3-counters (pulse amplitude is $\simeq$ 3 mV) come to the input of the corresponding preamplifier (the channel 2 for the counters of the inner ring and 3 for the outer ring) over a short cable ($\simeq$ 0.5 m) with a double screen. The outer screen is connected to the body of the thermal neutron detector block and the outer one to the body of BF_3 counters. High voltage ($\simeq$ 1.6 kV) is fed to the an anode wire of BF_3-counters through the preamplifier over the central wire of the cable. The vessel 11 with the neutron source 12 is placed inside the detector chamber 1. The neutron source, neutron detectors 1, 2, 3 are inside a box of borated polyethylene. Box walls are $\simeq$ 20 cm thick. It has allowed us to reduce the neutron background connected with cosmic radiation approximately by a factor of 10^2.

The use of the scintillation detector 1 makes it possible to discriminate by energy fast neutrons (emitted by the source) which arrive at the moderator and are registered by the detectors 2, 3 after they are slowed down in it. In this case the neutron source should be within the space enclosed by the scintillation detector which, in its turn, should be surrounded by the system of thermal neutron detectors. When either setting a device-amplitude threshold in the detector channel 1, or performing "off-line" analysis of events registered by the 2, 3 detectors with the introduction of a specified amplitude criterion for the channel 1, one can select events registered by the BF_3-counters corresponding to a certain energy range of fast neutrons.

2 Registering electronics

The registering electronics collects and accumulates data coming from the neutron detectors 1, 2, 3 (time of signal entering, amplitude and so on) before they are sent to a computer.

A block-diagram of the data acquisition and processing system is presented in Fig.2. The given system makes it possible to make independent measurements (e.g. of "energy-time" type) in real time for each of the three detectors. The system includes three measuring channels of the same kind. Each of them consists of a

P223 preamplifier [1], a KA234 forming amplifier [2], a KA007 analog-to-digital converter, a KL286 record synchronizer and a KL006 buffer memory [3].

A KL285 timer provides a means for registering time of event occurrence registered by the detectors 1, 2, 3 and for synchronizing the system operation. A time code from the timer is sent through an external bus to the KL286 record synchronizer into each measuring channel.

The system also includes a KS025 4-channel counter, a KK012 crate controller [4] and a KP201 high-voltage power source for thermal neutron counters and a KP205 power source for a photomultiplier [5].

After the system start-up the measuring cycle begins during which the timer with a frequency of 0.5 MHz sends a 24-bit time code to the synchronizers of amplitude channels through the external bus. When the ADC of any of the amplitude channels comes into action after the time for signal transformation elapsed the KL286 record synchronizer with the help of synchrosignals from the timer (at a frequency of 1 MHz) makes a record into the corresponding buffer memory of the amplitude code *(8 bits) and into its relevant time code (24 bits).*

The measuring cycle is completed when either a buffer memory or the inner counter of the timer ($\simeq 17\ s$) is overflowed. In so doing the timer sends the L signal to the CAMAC bus, disables the buffer memory and enables inputs of the KS025 counters, three of which begin to register signals coming from the detectors and the forth one measures "the dead time" of the system. This time is determined by the time of data output from the buffer memory to a computer.

After these data and the contents of counters are read out, the program-simulated signal to start the next measuring cycle is generated. The program of processing the incoming data provides for:

– storing the data in a computer RAM to construct amplitude and time spectra of events registered by the neutron detectors 1, 2, 3;

– recording experimental data to disk;

– constructing and displaying amplitude and time spectra on the monitor;

– calculating the main statistical parameters for amplitude and time distributions;

– indicating numerical and statistical information about channel loads, amount of data, and "dead", "live" and current time;

– forming a text file with the information about collected spectra;

– printing out the data.

The main characteristics for the system of storing and processing data are defined by the following parameters:

– the accuracy of time measurement – 2 μs;

– the number of channels of an amplitude spectrum – 256;

– the maximum duration of a continuous measuring cycle – 17 s.

It should be noted that to enhance reliability of the detecting system and registering electronics (when designing and constructing them) particular attention has been given to the number of important points.

First, BF_3-counters for each assembly 2, 3 have been chosen in such a way that their characteristics are closely similar (a signal amplitude value at the outlet of BF_3-counters is much the same at an equal voltage across them). Secondly, the detecting system consisting of BF_3-counters and a communication system is thoroughly screened (this is achieved by the use of iron and copper screens surrounding the entire detecting system). Thirdly, high-stable modules are used in the electronic system made in the CAMAC standard. In addition, special attention was given to reliability of adapting capacitors in preamplifiers, since even rare micro-breakdowns could lead to an imitation of the effect under study. The standard sources, ^{252}Cf, ^{137}Cs, ^{60}Co, were used to check all registering electronics and detectors for steady operation and also to calibrate spectrometric neutron channels. Figure 3 presents the amplitude distribution of events registered by the BF_3-counter at calibration of spectrometric channel by the ^{252}Cf source. The position of the main peak centre in the amplitude distribution of events corresponds to an energy release ($\simeq$2.3 MeV) in the counter (according to the channel of the thermal neutron capture reaction $n + {}^{10}B \rightarrow \alpha + {}^{7}Li^{*} + 2.3\ MeV$), and the position of the centre of the second peak, which forms $\simeq$ 7% of the area of the first peak, corresponds to the reaction channel registration $n + {}^{10}B \rightarrow \alpha + {}^{7}Li + 2.8\ MeV$. The efficiency of neutron registration by the detectors 2 and 3 amounts to 5.2% and 3.5% respectively. The efficiency was measured using the reference ^{252}Cf neutron source. The efficiency of registration of neutrons with a definite energy (emitted by the neutron source) by the scintillation detector is determined by the Monte Carlo method. For example, in the case of registering neutrons with an energy of 14.1 MeV and if an amplitude threshold in the channel 1 is set (corresponding in luminosity to the energy of recoil protons of 3 MeV) the efficiency amounts to 9.4%. Introduction of the above-mentioned threshold would make it possible to exclude from further analysis events caused by a possible reaction of the dd-fusion ($d + d \rightarrow {}^{3}He + n + 3.3\ MeV$, $E_n = 2.5\ MeV$) if the dt-fusion reaction ($d + t \rightarrow {}^{4}He + n + 17.6\ MeV$, $E_n = 14.1\ MeV$) is studied. Since the time of neutron "die out" in the detectors 2 and 3 is $\simeq$ 150 μs (thermal neutron lifetime in paraffin is $\simeq$ 178 μs) [6], the selection of events in the "off-line" mode is performed on condition that the time interval between signals coming from the detector 1 and the detectors 2, 3 is of the order of 400 μs. Figure 4 gives the distribution of time intervals between events successively registered by the detectors 2, 3. It was obtained using the ^{252}Cf source placed inside the detector 1 (the source intensity is $\simeq$ 300 s^{-1}). The requirement that signals from the detector 1 and the detectors 2, 3 should coincide within 400 μs naturally decreases the number of registered events, but under this condition the effect-to-background ratio increases and this, in its turn, makes it possible to decrease a lower limiting value for the neutron yield under measurement. The rates of counting background events for the detectors 1, 2, 3 (averaged over the interval of measurement $\simeq 100\ h$) are $7.2\ s^{-1}$, $4 \cdot 10^{-2}\ s^{-1}$ and $5 \cdot 10^{-2}\ s^{-1}$ respectively.

The background fluctuations are described by a normal distribution with standard deviations of $0.2\ s^{-1}$, $5.2 \cdot 10^{-3}\ s^{-1}$ and $5.5 \cdot 10^{-3}\ s^{-1}$ for the detectors 1, 2, 3 respectively. The procedure of processing the experimental data obtained both during a working exposure (with a neutron source or in experiments investigating processes with neutron production) and a background exposure is based on the analysis of distributions of time intervals between events either consecutively registered by the thermal neutron detectors 2, 3 or registered by the detector 1 and the detectors 2, 3.

It should be noted that the distributions of time intervals may be analyzed separately for the detectors 2 and 3. It makes sense to break up the whole range of time intervals into three subranges by duration: microsecond, millisecond and second $((\Delta t)_1, (\Delta t)_2, (\Delta t)_3)$. For example, $(\Delta t)_1 = 0$ - $1\ \mu s$; $(\Delta t)_2 = 1\ \mu s$ - $1\ s$; $(\Delta t)_3$ $1\ s$ - $1000\ s$. This is caused by the following circumstances:

1) Comparison of working and background time interval distributions over the $(\Delta t)_1$ and $(\Delta t)_2$ ranges both by form and by number of events can provide answers to such questions as: a) whether the emission of neutrons generated by the processes under investigation is of pulse nature; b) what the duration of neutron pulses is and what the frequency of their recurring is; c) what the time structure of a background is and whether it changes in the course of measurement.

2) If the neutron emission does not manifest its pulse character the comparison of working and background time interval distributions corresponding to the whole time range of measurement $(\Delta t) = (\Delta t)_1 + (\Delta t)_2 + (\Delta t)_3$ let us determine characteristics of the process with generation of neutrons (the rate of the process, its cross-section) or characteristics of the neutron source under study with the necessary accuracy.

3) Comparison of time interval distributions between signals coming from the scintillation and neutron detectors obtained during working and background exposures makes it possible to obtain unambiguous information not only supporting the evidence for occurrence of neutron emission with the energy exceeding the threshold value for channel 1 but also on the characteristics of the given process.

Figure 5 gives, as an example, distributions of time intervals between events registered by the detectors 2, 3 and obtained when measuring the background for $\simeq 100\ h$ for the $(\Delta t)_1 = 0$ - $10\ ms$, $(\Delta t)_2 = 10\ ms$ - $2\ s$ and $(\Delta t)_3 = 2$ - $200\ s$ ranges.

The created setup has been employed for searching investigation [7,8] for a long time. The reliability of the obtained results is guaranteed by the steady operation of both the detecting system and the registering electronics.

In conclusion we can say that the setup is attractive for use in experiments on measurement of neutron multiplicity and for determination of small quantities of fissionable substance.

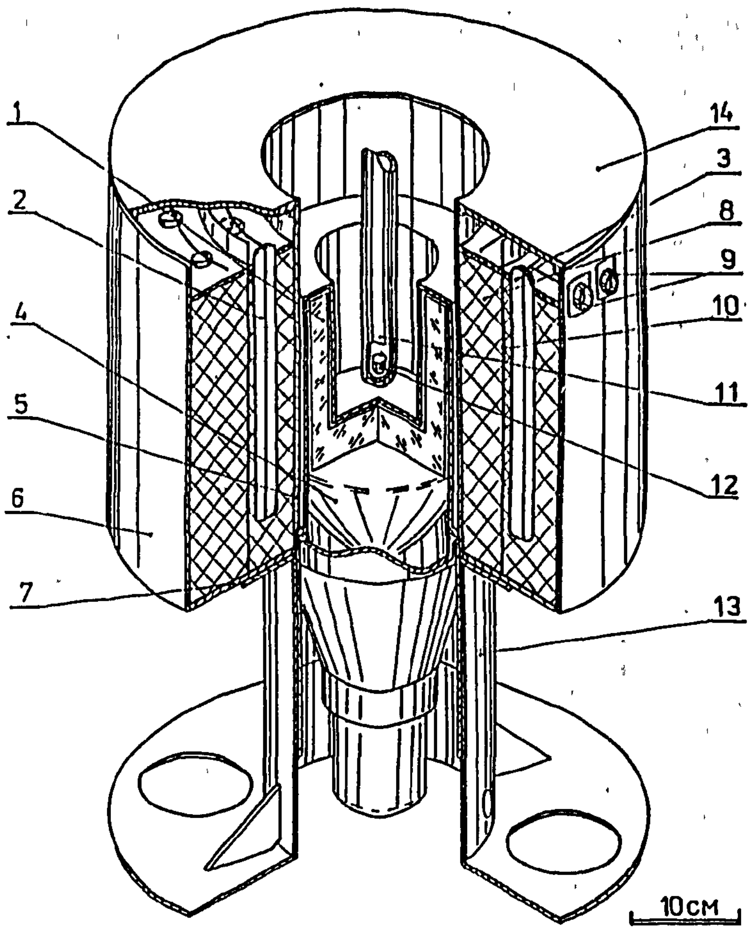

Fig.1 The detecting system of the experimental setup:

1 - scintillation detector; 2, 3 - thermal neutron detectors; 4 - photomultiplier; 5, 6 - shells of the neutron detector body; 7 - bottom; 8 - paraffin; 9 - high-voltage and high-frequency connectors; 10 - electromagnetic copper screen; 11 - stainless steel vessel; 12 - neutron source; 13 - support; 14 - cover with a copper screen.

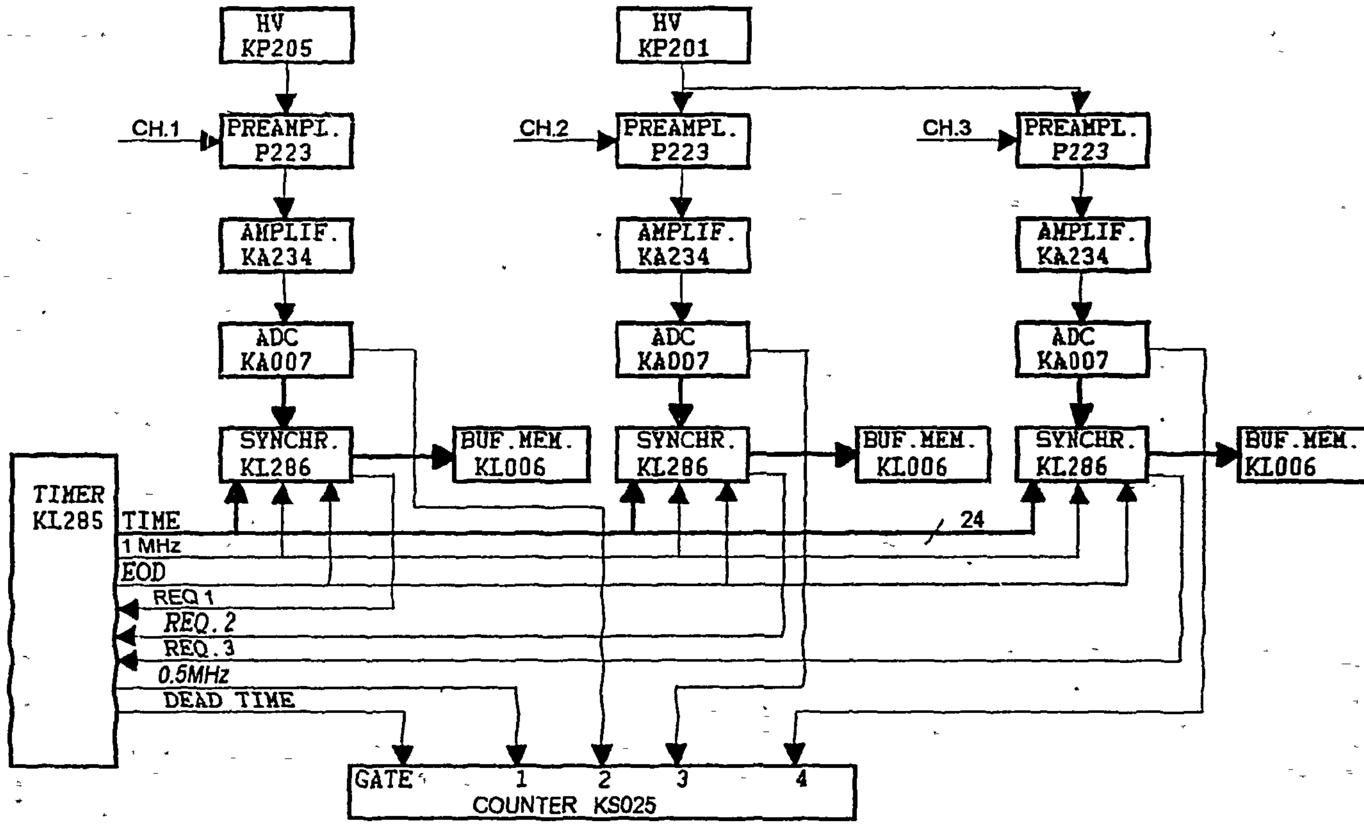

Fig.2 Block-diagram of the registering electronics.

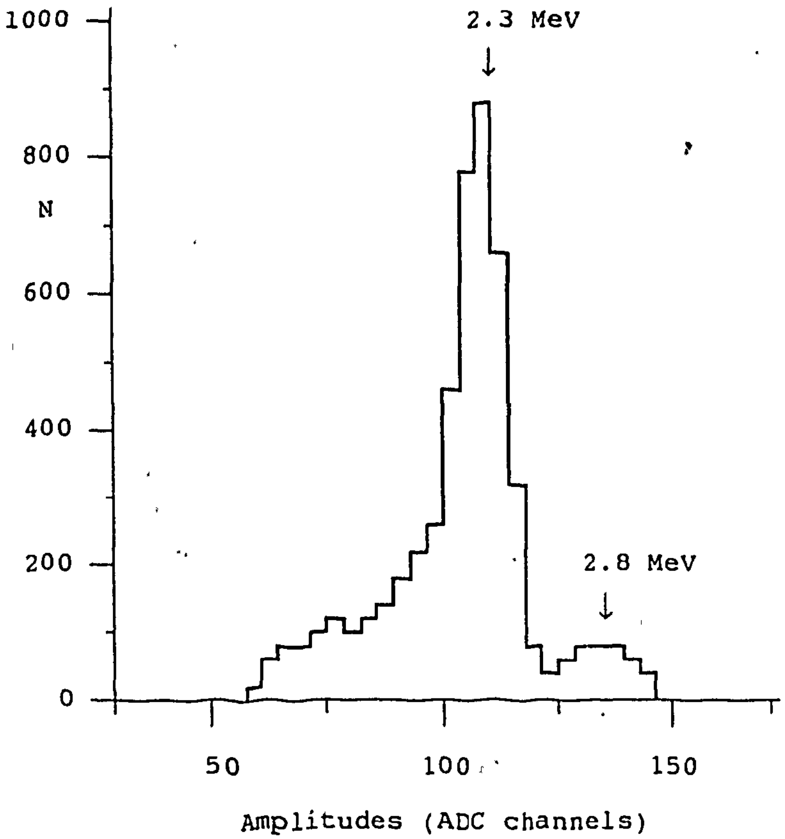

Fig.3 Amplitude distribution of signals coming from the BF_3-counter in calibration by the ^{252}Cf neutron source.

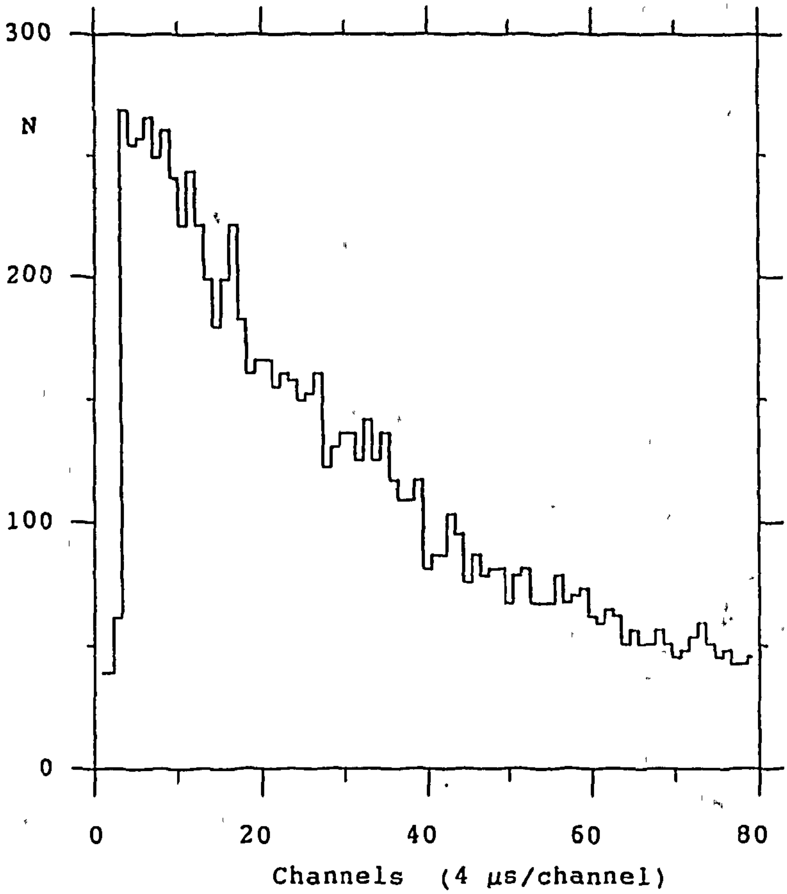

Fig.4 Distribution of time intervals between events consecutively registered by the detectors 2, 3 obtained by means of ^{252}Cf source.

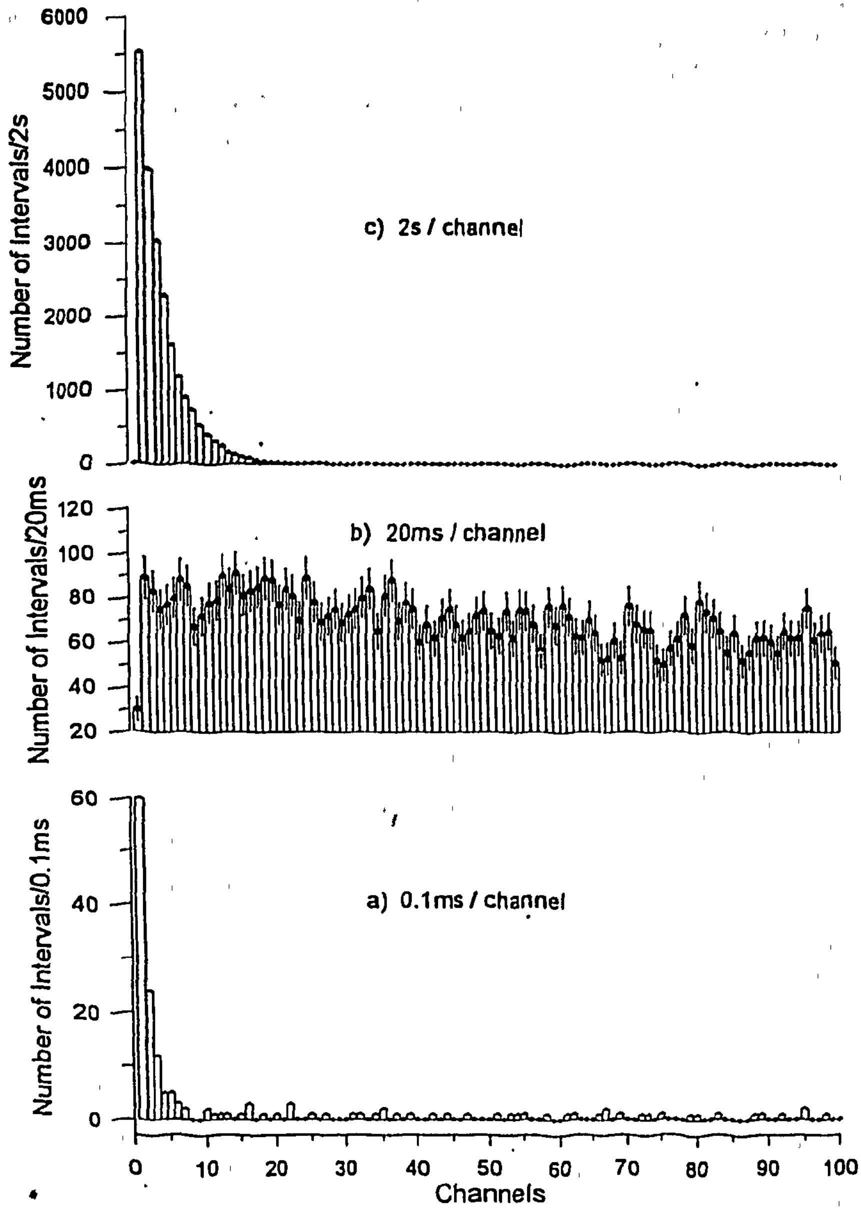

Fig.5 Distribution of time intervals between events registered by the detectors 2, 3 corresponding to different ranges of interval duration measurement:

a) 0 - 10 *ms*; b) 10 *ms* - 2 *s*; c) 2 - 200 *s*.

Distributions a, b and c correspond to the total number of events registered by the detectors 2 and 3 in background measurement.

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Быстрицкий В.М. и др. Д13-95-243
Установка для исследования редких процессов
с образованием нейтронов

Создана экспериментальная установка, предназначенная для изучения редких процессов с образованием нейтронов. Детектирующая система включает в себя сцинтилляционный детектор в виде полого стакана, вокруг которого по образующим двух коаксиальных цилиндров расположены детекторы тепловых нейтронов (BF_3-счетчики), помещенные в парафин. Детектирующая система и регистрирующая электроника позволяют получать временную и амплитудную информацию о каждом зарегистрированном событии.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1995

Bystritsky V.M. et al. D13-95-243
The Setup to Investigate Rare Processes
with Neutron Producing

An experimental setup has been created to study rare processes with neutron production. The detecting system comprises a scintillation detector in the form of a cup around which thermal neutron detectors (BF_3-counters) set in paraffin are placed parallel to the common axis in two concentric circles. The detecting system and registering electronics make it possible to obtain time and amplitude information for each registered event.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1995

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