Краткие сообщения ОИЯИ 6[57]-92 *JINR Rapid Communications 6[57]-92*
УДК 539.1.074.8

POSITION-SENSITIVE NEUTRON DETECTOR AS A MODULE OF NEUTRON MULTIDETECTOR SYSTEM

I.D.Alkhazov*, A.V.Daniel*, V.D.Dmitriev*, E.M.Kozulin, A.V.Kuznetsov*, Yu.E.Penionzhkevich, V.A.Rubchenya*

The position-sensitive neutron scintillation detector has been made. The detector consists of two photomultipliers and quartz tube filled with liquid scintillator (∅ 6x100 cm) with n-γ separation properties. The properties of the detector have been measured and calculated by SITHA code. The position resolution is 10 cm and time resolution is 1.4 ns. The neutron efficiency varies between 31% and 26% for neutron energy between 2 and 7 MeV, for neutron energy threshold — 1 MeV, respectively.

The investigation has been performed at Radium Institute (St.Petersburg, Russia) and at the Laboratory of Nuclear Reactions, JINR.

Позиционно-чувствительный нейтронный детектор как модуль нейтронной многодетекторной системы

И.Д.Алхазов и др.

Создан позиционно-чувствительный нейтронный сцинтилляционный детектор. Детектор состоит из двух фотоумножителей и кварцевой трубы, заполненной жидким сцинтиллятором (диам. 6x100 см) с n-γ разделяющими свойствами. Характеристики детектора были измерены и рассчитаны по программе SITHA. Позиционное разрешение составило 10 см при временном разрешении 1,4 нс. Эффективность регистрации нейтронов меняется между 31% и 26% для энергии нейтронов от 2 до 7 МэВ, соответственно для энергетического порога регистрации нейтронов — 1 МэВ.

Работа выполнена в Радиевом институте (Санкт-Петербург, Россия) и в Лаборатории ядерных реакций ОИЯИ.

1. Introduction

In the past few years the interest for neutron multidetector systems in low and medium energy of heavy-ion physics greatly raised. The so-called «Neutron Balls» allow one to measure the neutron multiplicity and don't give information on the angular distribution and the energy spectra of the

*Radium Institute, St.Petersburg, Russia detected neutrons. One needs multidetector system which gives simultaneously the energy spectra, the angular distribution, the mean multiplicity value (or multiplicity distribution of neutrons). The measurement of these characteristics can be performed by a number of small detectors, such as DEMON project [1]. The number of photomultipliers, however, leads to a sharp increase of the usage of electronics. Besides, a lot of calibration is necessary for their relative normalization. These problems can be reduced by means of large position-sensitive neutron detectors. A few types of such detectors had been studied in [2,3,4]. Each of these detectors is intended to solve a specific task: the detection of high-energy neutrons (up to 200 MeV) at a large solid angle [2], observation of neutron emission from fast moving fragments or from preequilibrium components for deep-inelastic heavy-ion reactions [3], scattering measurements of fast neutrons at small angles [4]. We designed the position-sensitive neutron detectors as the modules of neutron multidetector system [5]. The geometry of this multidetector system can be changed, for example, either near 4π solid angle neutron detector system or «neutron wall» system. The latter can consist of a few layers of position-sensitive neutron detectors for increasing the efficiency of high neutron energy measurements.

2. Construction and Principle of Operation of Position-Sensitive Neutron Detector (PSND)

The neutron detector consists of a quartz tube 100 cm long with 6 cm diameter (thickness of the walls: 2.5 mm) and two photomultipliers PM-30 with 50 mm dia. of photocathode. The tube is filled with liquid scintillator LS-13 [6] (analog of NE-213, with n-γ separation properties). The photomultipliers are coupled directly to the liquid scintillator in order to avoid light attenuation. Between PM and both ends of quartz tube there is a collapsible conjunction which consists of flanges and a special rubber. Tests have shown that this rubber is resistant to the liquid scintillator. The construction of the expansion chamber allows horizontal as well as vertical mounting of the detector. The detector is shielded against light with a titanium envelope. The scheme of the PSND is presented in fig.1.

Principle of time and position determination is shown in fig.2. The position information is obtained from the difference between the light travelling times (τ_L and τ_R) to two PMs at both ends of neutron detector. The position-independent time-of-flight is given by equation (see fig.2), with c — velocity of light, n_r — refractive index of liquid scintillator, t —

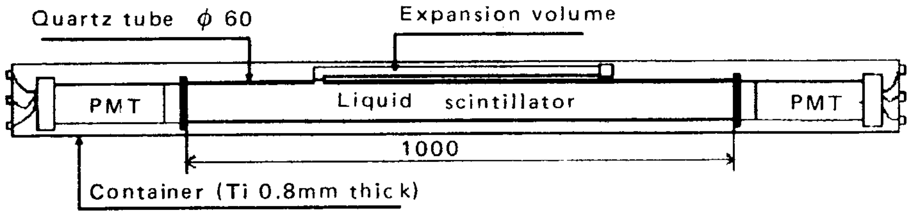


Fig.1. The scheme of position-sensitive neutron detector (PSND)

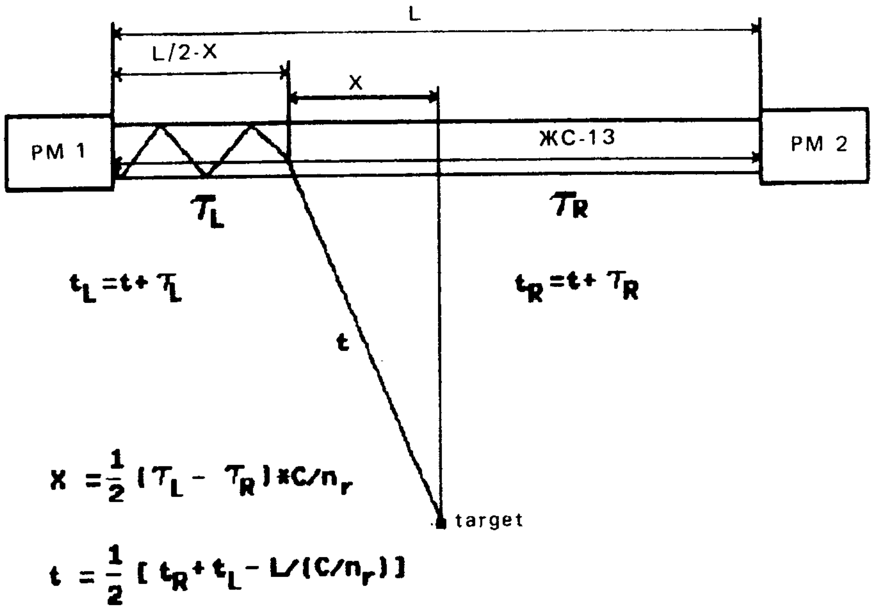


Fig.2. Principle of time and position determination. t — time-of-flight, x — position of an incident neutron, τ_L, τ_R — mean light travelling times, n_r — refractive index of liquid scintillator

time-of-flight, l — the length of detector (1m), τ_L and τ_R — mean light travelling times. The energy of a neutron is calculated by the time-of-flight method.

In figure 3 there is shown the electronic set-up for measurement of detector properties with the ^{252}Cf source and γ-source. The electronic set-up includes two constant fraction discriminators (CFD) and two time-to-pulse-height converters (TAC) for measurements of the times of flight and the difference light travelling times in the scintillator, two fast commutators for

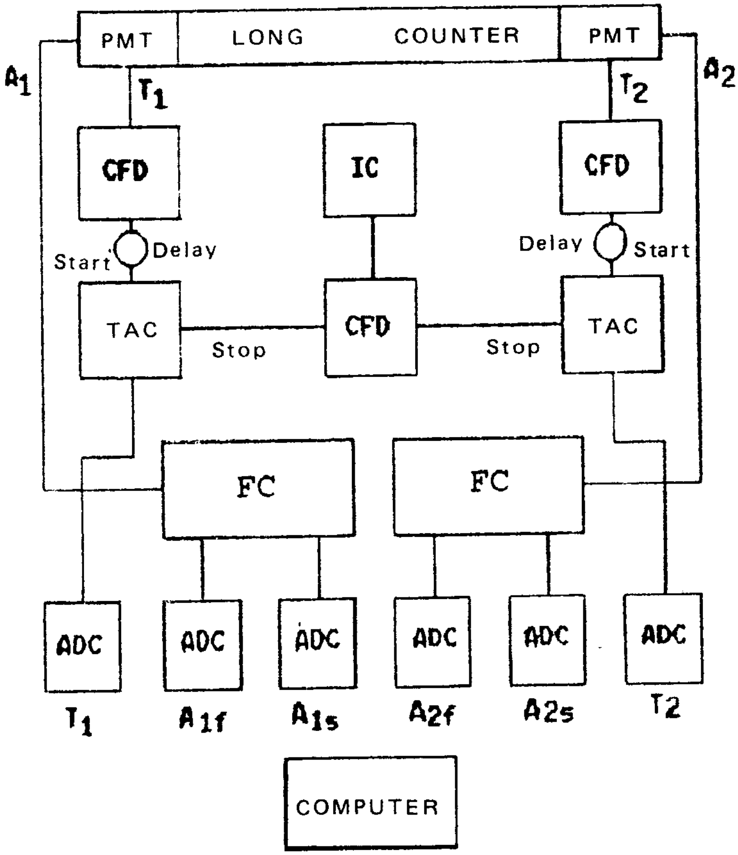


Fig.3. Electronic set-up for testing PSND. PMT — photomultiplier, CFD — constant fraction discriminator, TAC — time-to-pulse-height converter, FC — fast commutator, IC — ionization chamber, ADC — analog-to-digital converter

division of the PMs signal by fast (with time 50 ns) and slow (with time of 300 ns) components and block of coincidence and strobes. Six ADCs (analog-to-digital converters) are connected by the IBM COMPUTER. Ionization chamber with ^{252}Cf source and constant fraction discriminator forms the «stop» signal for the time-of-flight measurements.

In figure 4 there is shown necessary data for obtaining energy and angular information from position-sensitive neutron detector:

1. Half of a sum of times gives us the time-of-flight.

2. Difference of times gives us a position of an incident neutron. Time-of-flight and position give us neutron energy.

ADC 1	ADC 2	ADC 3	ADC 4	ADC 5	ADC 6
▿	▿	▿	▿	▿	▿
T_1	A_{1f}	A_{1s}	A_{2s}	A_{2f}	T_2

1. $(T_1 + T_2)/2 \Rightarrow T$ (time of flight)
2. $T_1 - T_2 \Rightarrow X$ (position)

} $\Rightarrow E_n$ (neutron energy)

3. $A_{1t}/A_{2t} \Rightarrow X^c$ (additional position information)
4. $A_{1t} + A_{2t} \Rightarrow E_n^c$ (additional position information)
5. $\left.\begin{matrix}(A_1, A_2)_{\text{fast}} \\ (A_1, A_2)_{\text{slow}}\end{matrix}\right\} \Rightarrow n - \gamma$ separation

$$A_{1t} = A_{1f} + A_{1s},\ A_{2t} = A_{2f} + A_{2s}$$

Fig.4. Necessary data for obtaining the energy and angular information from PSND

3. The ratio between the pulse heights of fast signals gives us additional position information.

4. Sum of the pulse heights defines the recoil energy of proton and also gives us additional information on neutron energy.

5. The relation between two fast and slow components of PM charge signal allows one to realize n-γ separation.

Therefore the data from position-sensitive neutron detector include six values and occupy 12 bytes of memory. For the system of neutron detectors we must add yet one byte in order to remember the number of neutron detectors.

In figure 5 there is shown the electronic set-up for serving of two (or more) PSNDs. This scheme explains the logic of work in the case of a few PSND, where the multi-input CDC (charge-to-digital converter 4300B «Le Croy») and the multi-input TDC (time-to-digital converter 4300B+4303 «Le Croy») are used.

3. Calculation Methods

The efficiencies of our set-up irradiated by neutrons with the energies less than 20 MeV and neutrons cross talk have been calculated by the program package SITHA (Simulation Transport Hadron) [7]. This package

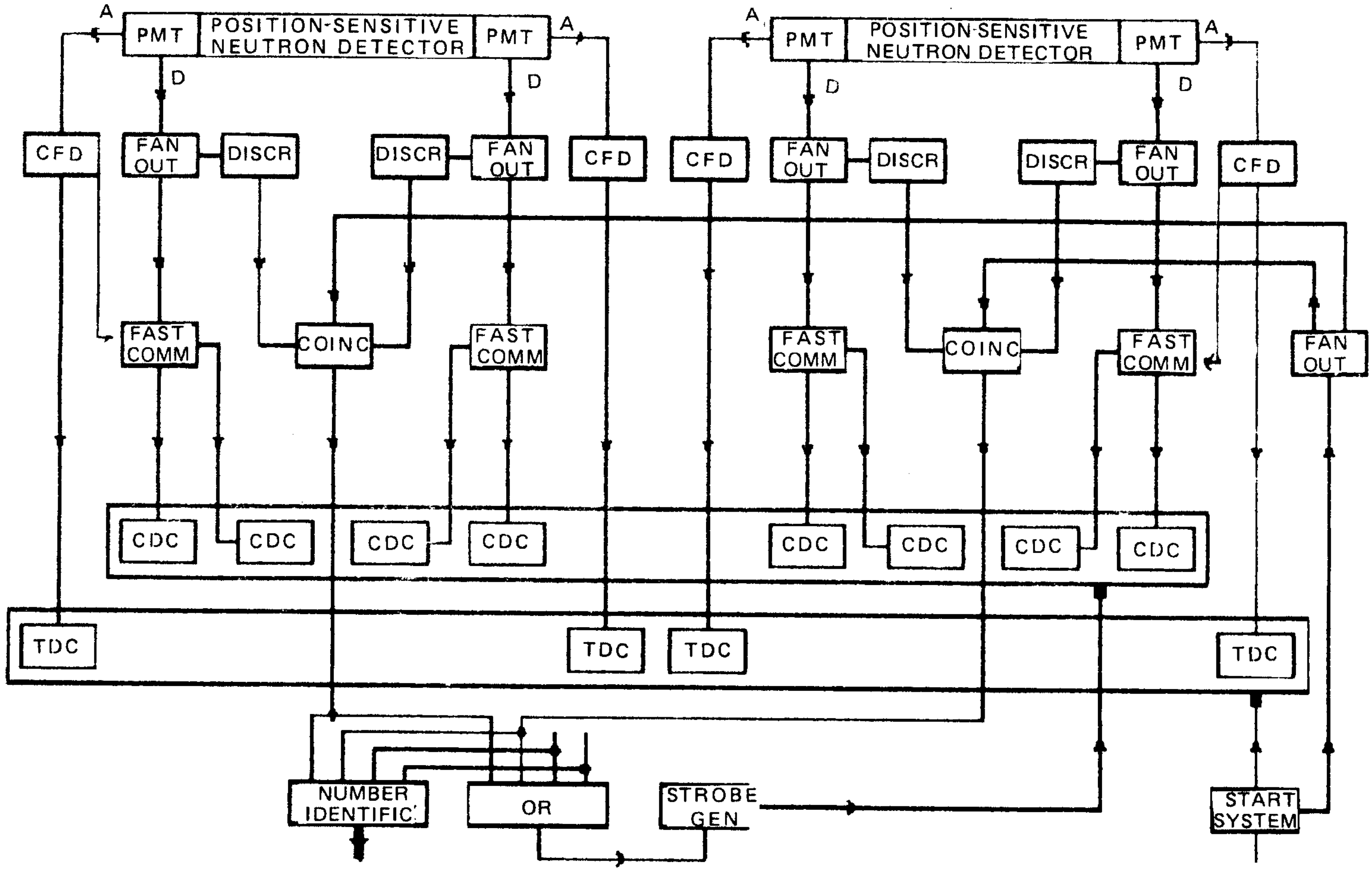


Fig.5. Block-scheme of electronics for serving of two (or more) PSNDs

was created in Radium Institute and its development goes on last years [8]. The package SITHA is used to calculate hadron transport in matter blocks of a complex geometry.

The nucleon and pion transport was carried out for the energy interval from 10 MeV to 10 GeV; and neutron transport, for the energies less than 20 MeV. In the last case multigroup approaches based on the neutron cross section library GR175-V1 [8] are used. The package SITHA includes different modules for calculation of the response function of the neutron detectors based on liquid organic scintillator irradiated by the neutrons with the energies less than 20 MeV. These modules have been carefully tested [9] and we use them for calculations of the characteristics of our long position-sensitive neutron detector.

Light output to protons, alpha particles and recoil nuclei were taken from Dekempeneer et al. [10]. Light attenuation in the long tubes has been taken into account.

4. Results and Discussion

The position resolution is presented in fig.6. The highly collimated ^{252}Cf source was displaced in steps of 10 cm in front of the detector. In the upper part of the figure the difference time (ΔT) between both the ends of the detector is shown. This value (14 ns) is equal to double mean light travelling time along the whole length of the detector. The position resolution depends on the time resolution of the detector. The time resolution has been optimized by the choice of voltage between cathode and the focusing electrodes of PM. The time resolution of the whole detector system including electronics is 1.4 ns. Therefore the position resolution is 10 cm. In the lower part of the figure one can see the position resolution as a function of the neutron energy loss in the scintillator. The energy scale was obtained by means of calibrating of γ-sources and ^{252}Cf source. In the lower energy region the position resolution is mainly determined by the signal-to-noise ratio. This poor resolution may be improved, however, using additional information on the time-amplitude rejection and on the ratio between the pulse height of signals from both PMs.

In fig.7 there is shown the light output versus the position on the detector. The lines are drawn via measured values. For a single PM the pulse height varies three times, but the sum of light output is nearly constant (20%) along the scintillator. The light output variation from single PM may be used for an additional position information. The sum of light output from

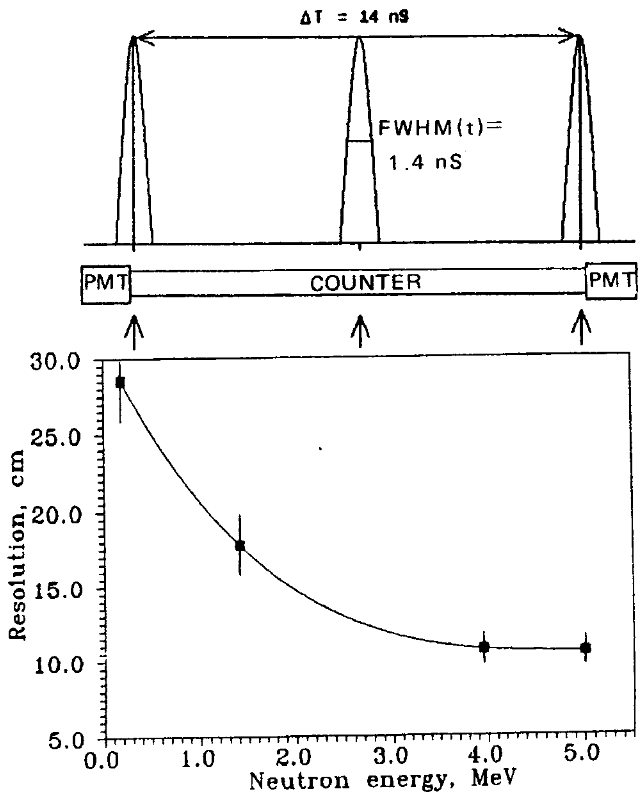


Fig.6. Upper part: the illustration of position resolution. Lower part: position resolution vs. neutron energy loss in the scintillator

both PMs gives an additional energy information which is almost independent of the position.

In figure 8 there is given the time-of-flight spectrum of PSND sector ($x = 20$—30 cm — position of detector relative to its end) for 0.5 m flight path as measured with a ^{252}Cf source. The quality of the time-of-flight separation between neutrons and γ is demonstrated in this figure. For n-γ pulse-shape discrimination we use the digital integration method: comparison of fast and slow components of PM signal. The combination of the time-of-flight and pulse-shape methodics enables a good n-γ discrimination for neutron energy threshold of 1 MeV.

The absolute neutron efficiency has been measured by means of ^{252}Cf source. The source was displaced at a distance of either 0.5 or 1 m from the

Fig.7. Light output vs.position. □ — photomultiplier 1, ■ — photomultiplier 2, ★ — sum of PM1 and PM2

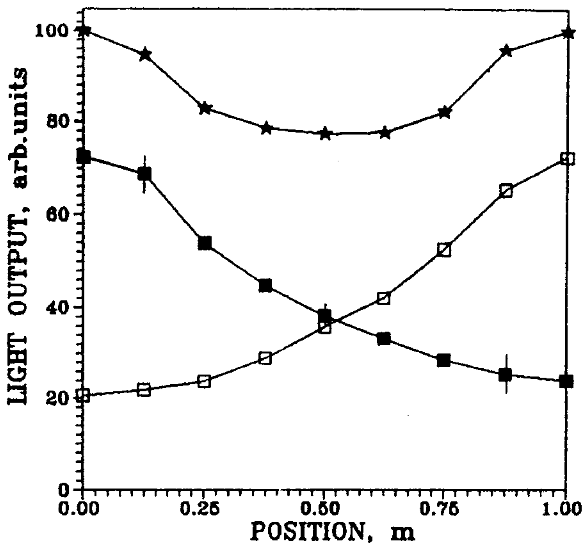
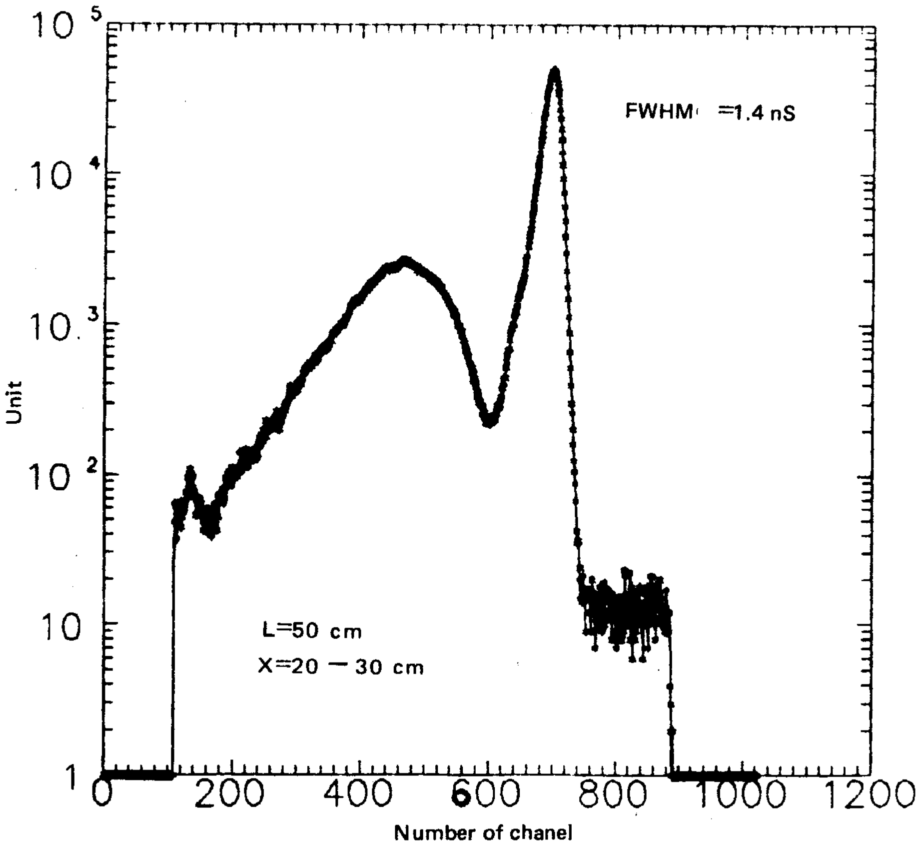


Fig.8. Time-of-flight spectrum for 0.5 m flight path (^{252}Cf). L — path of flight in the middle of detector, x — position of detector relative to its end



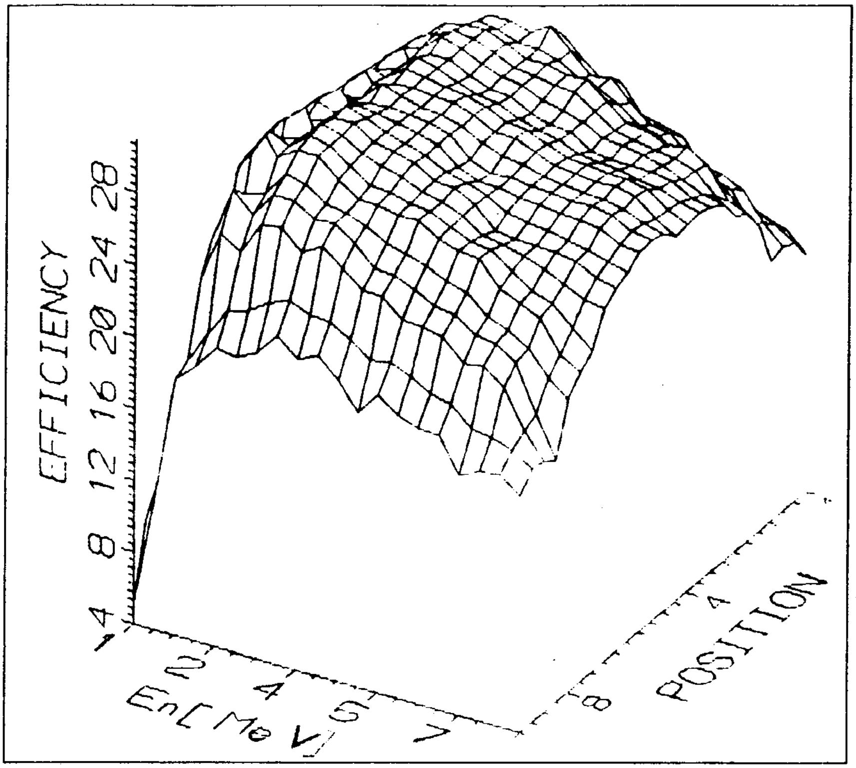


Fig.9. The measured neutron efficiency of PSND as a function of neutron energy and position of detector

center of a detector. The measurements have been made for energy threshold — 1 MeV recoil proton energy in the middle of detector. Ten positioned time-of-flight spectra for various time intervals between signals from PMs have been collected simultaneously. The neutron efficiency registration for different detector sectors (position) as a function of neutron energy has been obtained from neutrons number ratio detected in coincidence with fission fragments and total neutrons number emitted in solid angle of the given detector sector. In figure 9 there is presented the isometric plot of efficiency as a function of neutron energy and position of neutron detector for neutron energy threshold of 1 MeV. This efficiency has been also calculated by code SITHA for the same geometry and different energy threshold of neutron registration. In figure 10 there is shown the comparison between measured neutron efficiency and calculated one for 2 and 7 MeV neutron energy. The calculated and measured values of

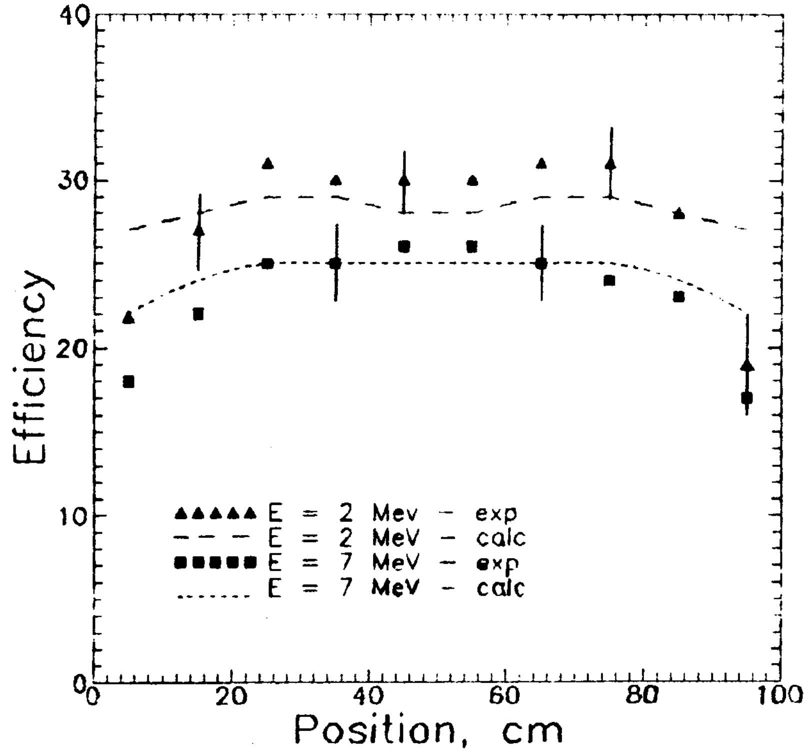


Fig.10. Comparison between measured neutron efficiency and calculated one by SITHA code values (curves) for 2 and 7 MeV neutron energy

efficiency are in good agreement. The efficiency is nearly independent of the position in the region of 80 cm. Therefore the detector may be used over an effective length of 80 cm (± 40 cm regarding the middle of detector). PSND has been tested on measurements of neutron emission from heavy-ion reactions on DEMAS-N set-up of the U-400 accelerator, LNR (JINR, Dubna). ^{20}Ne beam with energy of 144 MeV and current of 100 nA bombarded ^{197}Au target of 200 μg/cm^2 thickness. Neutron detector was placed parallel to the beam axis at a distance of 0.5 m. Counting rate from each PM was 10^5 per second. The neutrons were detected in coincidence with fragments. The avalanche fragment counter was used for «start» at measuring the energetic neutron spectrum by the time-of-flight method. The time resolution was 1.6 ns; the position resolution, 10 cm, at energy threshold of 1 MeV.

5. Conclusion

The test measurements on ^{252}Cf source, γ-sources and heavy-ion beam have shown that PSND can be used for investigation of the angular distribution and energy spectrum of neutron low energy range (0.5—10 MeV). This detector can also be used as a module of multidetector near 4π solid angle system which allows one to measure simultaneously multiplicity, the angular and energy distribution of neutrons with high efficiency. PSND can be used for construction of «neutron wall» which includes a few (5—10) layers of PSND for measurements in the large solid angle with high efficiency of high-energy neutrons (up to 500 MeV). However, in case of using PSND as a module of multidetector closely packed system there is a «cross talk» effect (this occurs when a detected neutron is scattered by a neighbouring detector). In accordance with investigation of this effect by Desesquelles et al. [11] with the multidetector AMPHORA, the main consequences of the «cross talk» are: an enhancement of the measured multiplicity and a smoothing of the laboratory angular distribution.

We calculated the values of the «cross talk» for various geometry configurations of some position-sensitive neutron detectors by means of simulation using the SITHA code. We began test measurements of this effect using two PSNDs. The preliminary results show that in case when two PSND were placed close to each other (the distance between axes of detector was 12 cm) only 5% of detected neutrons were due to the «cross talk» for neutron energy threshold of 1 MeV of spontaneous fission spectrum of neutrons. Taking into account the importance of distortions connected with the «cross talk» effect we are going to publish experimental and calculated results of this effect in the next article.

We thank Prof. Yu.Oganessian for permanent interest and large support of this work, colleagues S.Voronin and A.Veschikov for help in creation of neutron detector, V.Salamatin, A.Tonchev, G.Chubarian and the team of the U-400 accelerator for assistance in testing PSND on heavy-ion beam at LNR, Dubna.

Reference

1. Nuclear Physics News, 1991, vol.1, no.5, p.15.
2. Hourani E. et al. — Nucl. Inst. and Meth., 1976, v.134, p.513.
3. Netter P. et al. — Nucl. Inst. and Meth., 1981, v.185, p.165.
4. Qi H.Q. et al. — Comm. INDC(CPR)-005/G. 1985, p.1—7.

5. Alkhazov I.D. et al. — In: Scientific Report LNR, JINR 1989—1990 «Heavy Ion Physics», Dubna, 1991, E7-91-75, Dubna, p.182.
6. Afanasiadi L.Sh. et al. — Sov. Jour. «Pribory i Tekhnika». 1986, v.6, p.58.
7. Daniel A.V. — Preprint RI-181, Moscow, 1984.
8. Daniel A.V., Perov V.Yu., Sokol E.A. — JINR Comm. P3-91-320, Dubna, 1991.
9. Daniel A.V., Kozulin E.M., Kuznetsov A.V. — JINR Comm. (to be published), Dubna, 1992.
10. Dekempeneer E. et al. — Nucl. Inst. and Meth., 1987, v. A256, p.489.
11. Desesquelles P. et al. — Nucl. Inst. and Meth., 1991, v.A307, p.366.

Received on October 29, 1992.