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PAPERS ON THE MEASUREMENT OF THE SPONTANEOUS-FISSION NEUTRON SPECTRUM FOR CF-252

M.V. Blinov, V.A. Vitenko, V.I. Jurevich
V.G. Khlopin Radium Institute, Leningrad, USSR

English translation by IAEA, January 1983

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  M.V. Blinov, G.S. Boykov, V.A. Vitenko

  Paper in English presented at the International Conference on Nuclear Data for Science and Technology, Antwerp (Belgium), 6-10 Sept. 1982

- Study of the influence of scattering effects on the shape of the fission neutron spectrum

  M.V. Blinov, V.A. Vitenko, V.N. Dushin, V.I. Jurevich

  Voprosy Atomnoj Nauki i Tekhniki, Serija: Jadernye Konstanty, Nr. 1(40), Moskva (March 1981), p. 81-83, in Russian. English translation see IAEA report INDC(CCP)-177, April 1982, p. 53-58

THE SPONTANEOUS FISSION NEUTRON SPECTRUM FOR ^{252}Cf IN THE $3 \times 10^{2}-2 \times 10^{6}$ eV ENERGY RANGE[*/]

M.V. Blinov, V.A. Vitenko and V.I. Yurevich
(V.G. Khlopin Radium Institute)

ABSTRACT

This paper sets forth the results of precision measurements performed with an improved spectrometer. The energy range of the measurements is considerably extended. Within the limits of experimental error and indeterminacy in the calculation of the ^{6}Li(n,α) reaction cross-section, the neutron spectrum in the given range may be approximated to a one-parameter Maxwellian distribution (T = 1.42 MeV).

The spontaneous fission neutron spectrum for ^{252}Cf is used rather widely as a standard, but its application is often limited to the region above 1 MeV since the low-energy part has not been determined with sufficient accuracy. The spread of data obtained by various authors [1-6] is shown in Fig. 1.

The authors of this paper used a low-background time-of-flight spectrometer to measure the spectrum from 300 eV to 2 MeV. The spectrometer has been described in a separate paper. The neutron detector consisted of a ^{6}LiI(Eu) crystal coupled with a photomultiplier (crystals measuring 18 mm in diameter and 2 and 4 mm thick were used), and to detect the fission fragment we used a gas scintillation counter. The design of the detectors was described in Ref. [4]. Two layers of californium were used with a fission rate, at the beginning of the measurements, of 20.1×10^{3} and 98.3×10^{3} fissions/s, respectively. The spontaneous fission contribution from other fissile nuclides did not exceed 10^{-2}%. Delay lines were used to calibrate the spectrometer's time-scale with an accuracy of ± 0.5 ns. The time resolution for neutrons was 1 ns. The zero time

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[*/] The paper was prepared with the support of the International Atomic Energy Agency (Research Contract No. 2048/R3).

was defined by comparing neutron spectra measured at various path lengths. Four path lengths were used for the measurements, i.e. 6.25, 12.5, 25.0 and 50.0 cm. Different path lengths were used to verify the operation of the instrument and to check the measurement conditions, as well as to overcome the practical difficulties associated with measuring the spectra over a wide energy range using one path length. The 6.25 cm path length was used for the measurements in the 300 eV-50 keV region, the 12.5 cm length for the 5-200 keV region, the 25 cm length for the 70 keV-1 MeV region and the 50 cm length for the 150 keV-2 MeV region. The energy resolution at the upper limits of the ranges was not worse than 10%. A correction for energy resolution was made for all the path lengths.

In the given energy range the efficiency of the neutron detector was determined only by the ^{6}Li(n,α) reaction cross-section. This is because the other reactions on ^{6}Li and ^{7}Li nuclei which produce charged particles are endothermic, and the spectrometer's energy threshold for detection was set at approximately 4 MeV. The contribution from the I(n,γ) reaction was heavily suppressed by using thin crystals with a high gamma equivalent and small thickness, and this contribution was taken into account by performing measurements with a ^{7}LiI(Eu) crystal. The ^{6}Li(n,γ) reaction cross-section is negligible. The efficiency of the detector was calculated by the Monte Carlo method using the ^{6}Li(n,α) reaction cross-section values from the ENDF/B-V file. Allowance was made for multiple scattering in the crystal and for the time of flight of the neutrons up to detection.

The random coincidence background accounted for 0.07% of the effect at 100 keV, and 6% at 5 keV for the 6.25 cm path length. The spectrometer electronic circuit reduced the true random coincidence background by two orders of magnitude. The screening of the neutron spectrum by γ-rays was estimated to be no more than 0.5% for the 6.25 cm path length. The corrections for neutron scattering from the particle detectors, structural materials, ambient air and walls of the room were determined both experimentally and theoretically. The method of determining the corrections is described in a separate report. Figure 2 shows the energy dependence of the main corrections for the 6.25 cm path length. The total spectrum measurement time was 110 days. To check stability, the spectrometer was monitored from the position of the gamma peak, the value of the channel and the energy threshold for detection. Sets of measurements performed at different times for different path lengths, targets and crystal sizes were compared, allowing for the decay of the californium. The results of the measurements were in agreement within the limits of experimental error.

Figure 3 shows the equipment spectra for the < 200 keV region. The same figure gives the background spectra measured with a ^{7}LiI(Eu) crystal. The energy spectra, allowing for all the corrections for the four path lengths, are shown in Fig. 4 as deviations from the Maxwellian distribution with $T = 1.42$ MeV. As in Fig. 1, there is normalization for the 1 MeV region. The figure includes both the statistical and systematic errors. No allowance was made for the indeterminacy of the ^{6}Li(n,α) reaction cross-section when calculating the errors. They are greatest in the 243 keV resonance region and above 1 MeV. We find that the data obtained previously [7] are in agreement with the present results, taking into account the new estimates with the ^{6}Li(n,α) reaction cross-section, the introduction of corrections for multiple scattering in the crystal and the energy resolution of the spectrometer.

The results indicate that the deviation of the spontaneous fission neutron spectrum for ^{252}Cf from the Maxwellian distribution in the given energy region lies within the error limits for the experiment and for the determination of the reaction cross-section.

REFERENCES

[1] MEADOWS, J.W., Phys. Rev. 157 4 (1967) 1076.

[2] JEKI, L., KLUGE, Gy., LAJTAI, A., DYACHENKO, P.P., KUZMINOV, B.D., Prompt Fission Neutron Spectra, IAEA, Vienna (1972) 81.

[3] WERLE, H., BLUHM, H., J. Nucl. Energ. 26 (1972) 165.

[4] BLINOV, M.V., VITENKO, V.A., TOUSE, V.T., "Neutron Standards and Applications", Gaithersburg (1977) 194.

[5] NEFEDOV, V.N., STAROSTOV, B.I., SEMENOV, A.F., Nejtronnaya Fizika, Moscow 3 (1977) 205.

[6] NEFEDOV, V.N., STAROSTOV, B.I., SEMENOV, A.F., NIJAR Preprint P-22 (356) Dimitrovgrad (1978).

[7] BATENKOV, O.I., BLINOV, M.V., VITENKO, V.A., KRISYUK, I.T., TUZ, V.T., Nejtronnaya Fizika, Moscow 5 (1976) 114.

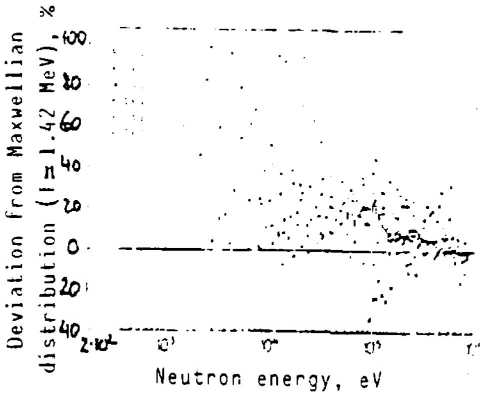
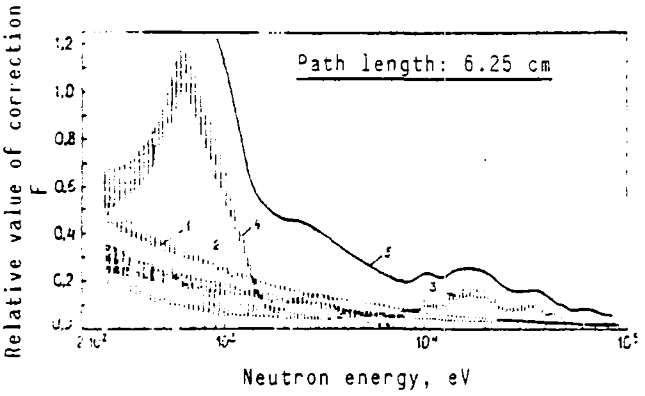


Fig. 1

Fig. 2 Main correction values as a function of neutron energy for a path length of 6.25 cm. The vertical shading denotes the indeterminacy of the corrections.



1 - Air scattering
2 - Background caused by side reactions and gamma rays
3 - Scattering on detectors
4 - Scattering on walls
5 - Total errors

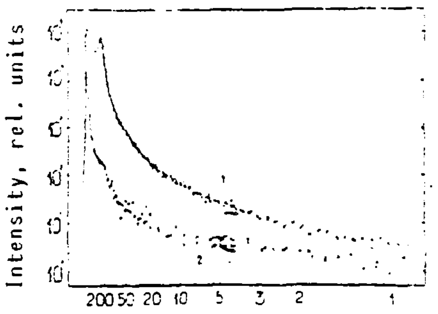


Fig. 3 Equipment spectra in the low-energy region for path lengths of 6.25 and 12.5 cm, measured using a ^{6}LiI(Eu) (1) and ^{7}LiI(Eu) (2) crystal

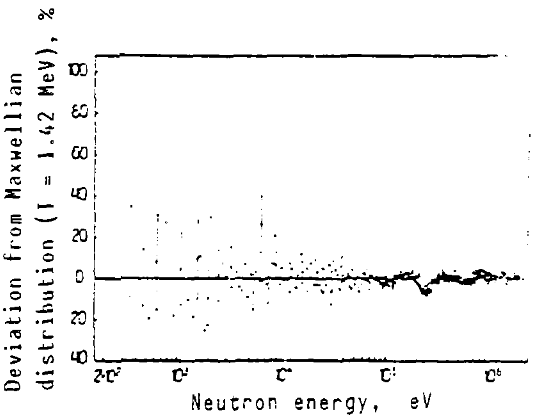


Fig. 4 Measurement of ^{252}Cf spontaneous fission neutron spectrum in the 300 eV–2 MeV region for path lengths of: • - 6.25 cm, o - 12.5 cm, █ - 25 cm and ☐ - 50 cm. The total errors are shown.

A LOW-BACKGROUND METHOD FOR PRECISION MEASUREMENTS OF NEUTRON SPECTRA IN THE kV ENERGY REGION[*/]

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ABSTRACT

The paper describes a ^{6}LiI(Eu) crystal spectrometer for performing time-of-flight measurements on intermediate-energy neutrons. The design of the spectrometer makes for a considerable improvement in background conditions compared to the fast-slow coincidence technique which is normally used. With this spectrometer, it is possible to measure neutron spectra in rather intense gamma fields and at heavy loads.

The measurement of neutron spectra below 100 keV presents considerable difficulties. This is due, above all, to the lack of proper high-efficiency and fast-response neutron detectors which are insensitive to gamma radiation. Moreover, the intermediate-energy neutrons emitted from excited nuclei are of low intensity, and as a rule the background effects are large, thus adding considerably to the difficulty of obtaining reliable data. Lithium glass and fission chambers consisting of ^{235}U layers are often used as detectors in this energy region, and their efficiency is poor. What is more, lithium glass is highly sensitive to gamma irradiation. The authors of Refs [1, 2] described a ^{6}LiI(Eu) crystal spectrometer (offering high time resolution) in which the above shortcomings were to a large extent eliminated. This spectrometer provided reliable data on the fission neutron spectrum down to 20-30 keV [3]. Progress to lower energies was barred by the true-random coincidence background (two fission events overlapping during the measured time interval). Furthermore, in the fast-slow coincidence circuit employed in this spectrometer, a high background level was caused by the high probability of γ-γ and γ-n overlaps during pulse integration ($\tau_{int} \sim 10^{-6}$ s) in the slow channel (curve 4 in Fig. 1).

[*/] Paper prepared with the support of the International Atomic Energy Agency (Research Contract No. 2049/RI/RB).

The authors of this paper have developed this spectrometer with a view to substantially improving the background characteristics. A distinctive feature of the spectrometer circuit design (Fig. 2) was the fast analysis of pulse heights and widths in the neutron channel and the analysis of pulse heights and intervals between pulses in the fission fragment channel. Pulse selection in the neutron channel is based on the following principle. An amplified input signal (a' in Figs 2 and 3) was transmitted to an integrator (RC filter) and to the delay line DL_3 (t delay = τ_{int} = 40 ns). An electronic key discharged the energy stored in a capacitor "C" when the input signal reached a certain amplitude (~ 0.2 of the Schmidt trigger threshold). The possibility of several pulses overlapping in the integration circuit was thus eliminated. The trigger threshold was set below the thermal neutron pulse value. In the linear gates, the signal delayed in DL_3 was strobed by a pulse from the trigger (c'). When a neutron or gamma-ray of > 3 MeV was detected, a pulse (d') of standard width (t_u ~ 5 ns) was transmitted to a shaper with a "tracking threshold".

The method used to eliminate the background caused by the overlapping of two fission events in the measured time interval was as follows (Figs 2 and 4). A fast signal, amplified and shaped to a given width (t_u ~ 5 ns), was triggered by a univibrator, the threshold of which was set higher than the height of the pulse generated by α particles. Summing of pulses from a single fission event was excluded by delaying the pulse in the univibrator and DL_1 for ~ 10 ns. If two fission events occurred in an interval of ~ 300 ns, a linear summator integrated the pulse from the univibrator generated by the first event (t_u ~ 300 ns) and the pulse generated by the second event originating from the amplifier-shaper (c). The linear signal delayed in DL_2 (t delay ~ 300 ns) was strobed by a pulse from an integral discriminator in order to prevent the first event from being recorded.

In order to compare the background characteristics of the present spectrometer with the instrument previously used [1, 2], we measured the ^{252}Cf fission neutron spectrum under identical experimental conditions. The results (see Table) showed that the random coincidence background was reduced by more than a factor of 10, the true random coincidence background became negligible, and the background caused by γ-γ and γ-n overlaps dropped by more than a factor of 50.

Table

En, keV	Background effect, %					
	Random coincidences		True random coincidences		γ-γ and γ-n overlaps	
	A	B	A	B	A	B
100	5.5	0.42	5.0	< 0.001	3.3	< 0.05
25	41.6	3.2	37.4	< 0.08	25	< 0.5
5	429	33	386	< 0.64	258	< 2

Note: A - Fast-slow electronics, B - Present spectrometer; the measurements were made over a path length of 12.5 cm and the ^{252}Cf source strength was 20.1 x 10^3 fissions/sec.

The results show that this spectrometer can be used for a wide range of theoretical and applied physics experiments in the intermediate neutron energy region. It allows measurements to be performed in rather intense gamma fields and at heavy loads.

REFERENCES

[1] BLINOV, M.V., VITENKO, V.A., KRISYUK, I.T., Dokl. Akad. Nauk SSSR 224 4 (1975) 802.

[2] BLINOV, M.V., VITENKO, V.A., Nejtronnaya Fizika, Moscow 6 (1976) 160.

[3] BATENKOV, O.I., BLINOV, M.V., VITENKO, V.A., KRISYUK, I.T., TUZ, V.T., Nejtronnaya Fizika, Moscow 5 (1976) 114.

FIGURE CAPTIONS

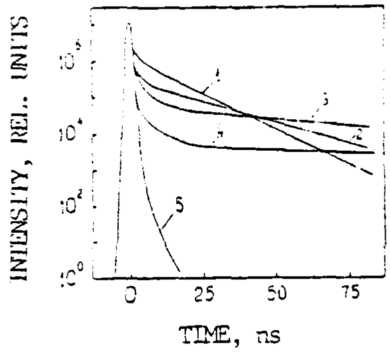

Fig. 1. Shape of γ plot allowing for γ-γ and γ-n overlaps:

1, 2, 3 - fast channel only (threshold 1 > threshold 2 > threshold 3);

4 - fast-slow electronics;

5 - present spectrometer.

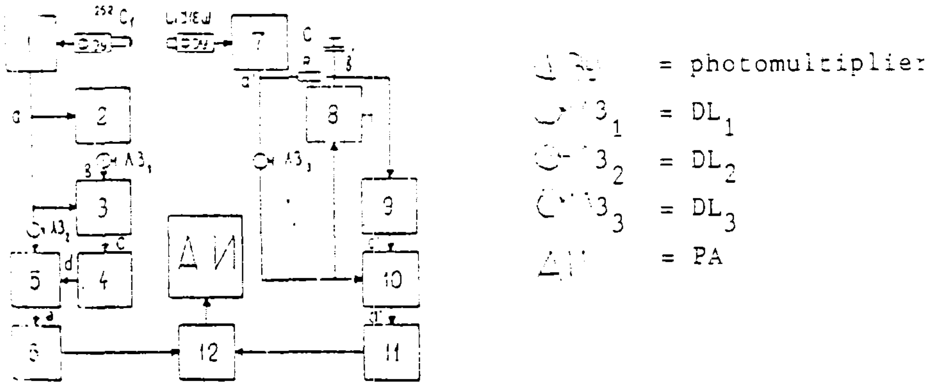

Fig. 2. Spectrometer block diagram:

1 - Fast amplifier-shaper;

2 - Univibrator;

3 - Linear summator;

4 - Integral discriminator;

5 - Gate circuit;

6, 11 - Shaper with "tracking threshold";

7 - Fast amplifier;

8 - Electronic key;

9 - Schmidt trigger;

10 - Linear gates;

12 - Time-amplitude convertor;

PA - Multichannel pulse analyser.

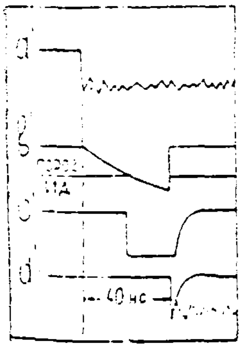

Fig. 3. порог = threshold
ИД = PA
НС = ns

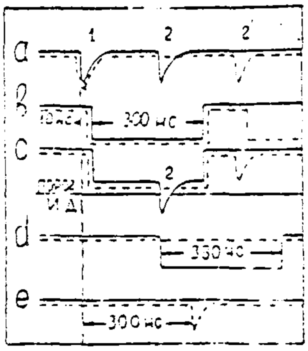

Fig. 4. порог = threshold PA
ИД = PA
НС = ns

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MEASUREMENT OF THE ^{252}Cf SPONTANEOUS FISSION NEUTRON SPECTRUM IN THE LOW-ENERGY REGION*/

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ABSTRACT

The shape of the ^{252}Cf spontaneous fission neutron spectrum in the 1 keV-1 MeV energy region was studied by the time-of-flight technique using a ^{6}LiI(Eu) crystal as the neutron detector. Particular attention was devoted to the region below 200 keV. The measurement data obtained indicate that the spectrum in the whole region studied can be described by a one-parameter Maxwellian distribution with T = 1.42 MeV.

(Fission neutron spectrum, neutron standard, californium-252.)

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*/ The work is being carried out with the support of the International Atomic Energy Agency (Research Contract 2046/RB).

The reason for determining the exact shape of the ^{252}Cf spontaneous fission neutron energy spectrum is that it has been recommended by the IAEA for use as the standard fission neutron spectrum. This energy distribution can be used extensively in various neutron spectrometric studies for performing relative measurements. The value of this standard spectrum depends on the accuracy with which it is known; however, it is quite a complicated matter to measure this spectrum with precision. This is due partly to the fact that the spectrum in question occupies a very wide energy range. At present, the results of several studies in the region from 0.5 to 8 MeV are in satisfactory agreement although the data of Refs [1,2] still require substantial refinement. In the region below 0.5 MeV the position remains unsatisfactory since the scatter of data in the different studies exceeds 30-50% [3-6], which is quite unacceptable for a standard. Measurements in the low-energy region present particular difficulties, which are associated primarily with the effect of the scattering of higher-energy neutrons and with unsatisfactory background conditions in the experiments.

This paper presents the results of measurements of the ^{252}Cf spontaneous fission neutron spectrum in the region from 1 keV to 1 MeV. The most detailed study was made of the region below 200 keV. For the purpose of improving the measuring accuracy the effect of neutrons scattered by the spectrometer detectors and by the environment was determined both by experiment and calculation. The random-coincidence background was considerably reduced in the work.

The neutron energy was measured by the time-of-flight technique. Neutrons were recorded by a ^{6}LiI(Eu) crystal 17 mm in diameter and 2 or 4 mm thick. A gas scintillation counter attached directly to a miniature FEhU-71 photomultiplier was used for fragment detection. A californium layer was applied by vacuum spraying on the bottom of the gas counter. Two californium layers were used (1×10^5 fissions/s and 2×10^4 fissions/s). The electronic part of the spectrometer was modified substantially in comparison with that employed in previous work [5]. Thus, for example, we used a time-amplitude analysis of neutron detector pulses, which substantially reduced the random-coincidence background. The background associated with the occurrence of two fission events in the time interval measured was eliminated by amplitude selection in the fast fission-fragment recording channel. These improvements enabled us to perform measurements with high-intensity californium sources for small flight paths in the low-energy region. Since we were compelled to use neutron detectors with crystals of small size to reduce the influence of scattering from the photomultiplier, the neutron recording efficiency was low. This greatly lengthened the time needed for measurements and hence necessitated a high level of stability in spectrometer operation. One series of measurements with the corresponding control experiments took from one to two months of round-the-clock operation of the facility.

The measurements were conducted for several flight paths (62.5, 125, 250 and 500 mm) in order to compare the results obtained under different conditions and to improve the statistical accuracy of the measurements.

Figure 1 shows the experimental time-of-flight spectra. In order to illustrate the contribution from the reactions with iodine nuclei we have also shown here the spectra obtained with a ^{7}LiI(Eu) crystal having the same characteristics as the working crystal. The time resolution evaluated from the gamma half-peak width was 1.5 ns. The random-coincidence background at 10 keV was 10% of the effect. For comparison we can cite the Ref. [3] data on background, which is 300% for the same energy.

In our previous studies [5,7] we had tried to reduce the detector mass and developed counters which were highly miniaturized in comparison with similar detectors ordinarily used in other studies [3,4]. In the present work there was no change in the neutron and fragment detectors used. However, we considered it necessary to determine the effect of scattering from them with greater accuracy and over a wider energy range than before. We made an experimental evaluation of the effect of scattering on the gas counter by doubling its mass, while approximately retaining the geometric arrangement. It was more difficult to evaluate the contribution of scattering from the neutron detector since it is an extremely complex matter to retain the geometry while doubling the mass because of the close proximity of the crystal to the photomultiplier. For this reason we carried out measurements as well as calculations in order to assess the contribution of neutrons scattered from the photomultiplier. The corrections so obtained correlated satisfactorily with one another. Multiple scattering in the crystal and in its packing not only changes the efficiency of recording neutrons of the given energy but also brings about a shift in the instant of recording. In order to correct these distortions, V.N. Dushin prepared a program, which solves the equation of neutron transfer under the geometric conditions of the detector by the Monte Carlo method [10]. A 40-group approximation was used. For neutrons of each group the time response of the scintillator was calculated and then used to calculate the correction function. Analysing the possible sources of neutron scattering, we came to the conclusion that air can also make a noticeable contribution. Calculations showed that this effect depends substantially on the energy region being measured and the flight path (for example, for a 6.25 cm flight path the correction is 7% at 10 keV).

Figure 2 shows the energy dependences of some corrections for scattering and for interaction of neutrons with iodine nuclei. The total correction in the 1-10 keV region amounts to tenths of the effect. If this is not taken into account, the intensity in this region naturally increases considerably.

Figure 3 shows the ^{252}Cf spontaneous fission neutron spectrum in the 1 keV-1 MeV region obtained in the present study with allowance for all corrections. In the calculation of the efficiency we used the ^{6}Li(n,α) reaction cross-section values taken from the ENDF/B-V file, which agree satisfactorily with the recent experimental data [8,9]. In Fig. 3 the solid line denotes a Maxwellian distribution with T = 1.42 MeV. The experimental points are located sufficiently close to this curve in the entire region measured. The scatter of points lies mainly within the statistical errors indicated. The small (~5%) systematic deviation of points in the vicinity of 250 keV is evidently due to the error of the ^{6}Li(n,α) reaction cross-section values used. Thus, the ^{252}Cf fission neutron spectrum in the 1 keV-1 MeV region can be approximated by a one-parameter Maxwellian distribution.

REFERENCES

[1] SMITH, A.B., Prompt Fission Neutron Spectra (Proc. Cons. Meeting) IAEA, Vienna (1972) 3.

[2] STEWART, L., EISENHAUER, C., Neutron Standards and Applications (Proc. Symposium) NBS Special Publication 493 (1977) 198.

[3] MEADOWS, J.W., Phys. Rev. 157 (1967) 1076.

[4] JEKI, L., KLUGE, Gy., LAJTAI, A., DJACHENKO, P.P., KUZMINOV, V.D., Prompt Fission Neutron Spectra (Proc. Meeting) IAEA, Vienna (1972) 81.

[5] BLINOV, M.V., VITENKO, V.A., TOUSE, V.T., Neutron Standards and Applications (Proc. Symposium) NBS Special Publication 493 (1977) 194.

[6] NEFEDOV, V.N., STAROSTOV, B.I., SEMENOV, A.F., Neutron Physics (Proceedings of the Fourth All-Union Conference on Neutron Physics) Moscow (1977) 205 [in Russian].

[7] BLINOV, M.V., VITENKO, V.A., KRISYUK, I.T., The Time Characteristics of Low-energy Neutron Emission in ^{252}Cf Spontaneous Fission, Report RI-30, Leningrad (1974) [in Russian].

[8] GAYTHER, D.B., Annals of Nuclear Energy 4 N 11/12 (1977) 515.

[9] LAMAZE, G.P., SCHRACK, R.A., WASSON, O.A., Nucl. Sci. and Eng., 62 N 2 (1978) 183.

[10] DUSHIN, V.N., in: Proceedings of the VIII International Symposium on the Interaction of Fast Neutrons with Nuclei, Nuclear Reaction Mechanisms, Gaussig (German Democratic Republic) (1979) 153 [in Russian].

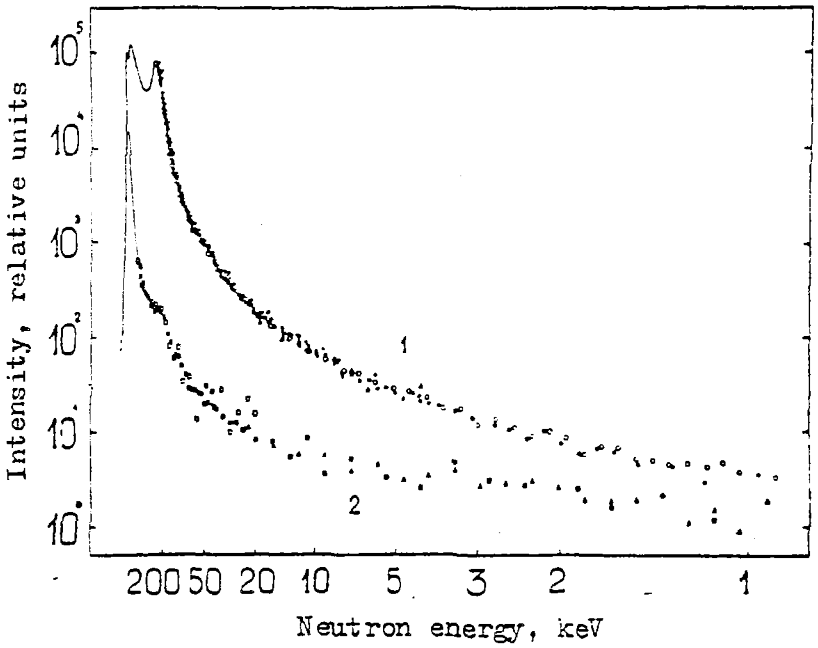

Fig. 1: Neutron spectrograms (the low-energy region is shown) obtained with crystals:

(1) ^{6}LiI(Eu) (△ , ▽ - data of various series of measurements for a 125 mm flight path; ●, ○, + - data for a 62.5 mm flight path);

(2) ^{7}LiI(Eu) (□ - data for a 125 mm flight path; ■, ▲ - data for a 62.5 mm flight path).

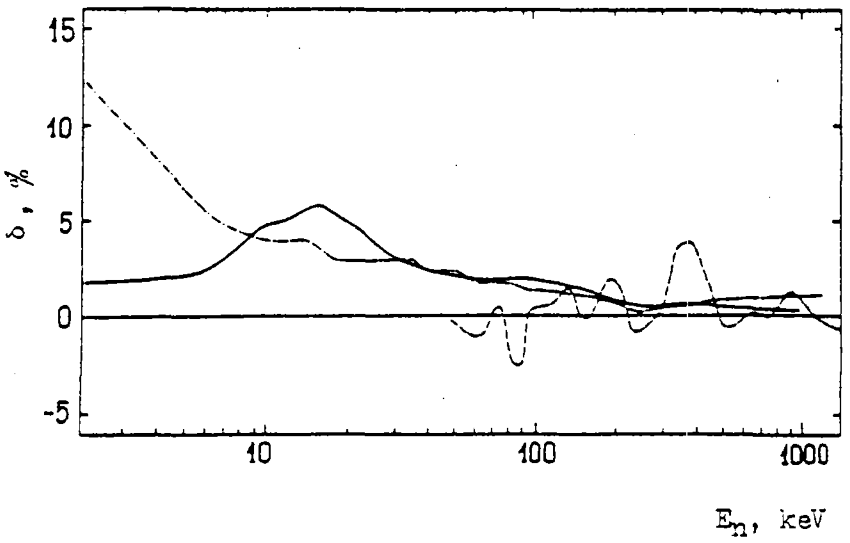

Fig. 2: Energy dependence of the corrections for neutron multiple scattering: in crystal for a 250 mm flight path, calculation (- - -); in neutron detector photomultiplier for a 62.5 mm flight path, calculation (———); and correction for interaction of neutrons with iodine nuclei in crystal for a 62.5 mm flight path, experiment (- · - ·).

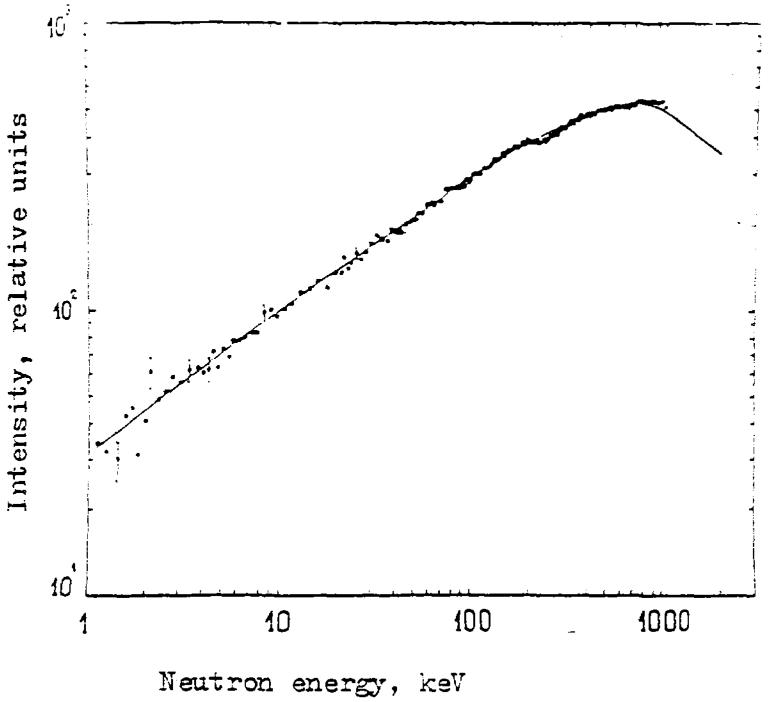

Fig. 3: The ^{252}Cf spontaneous fission neutron spectrum obtained in the present study (•). The solid line denotes Maxwellian distribution (T = 1.42 MeV). The data are normalized in the 0.4–0.8 MeV region. The errors indicated are statistical.