Measurement of the beta spectrum of ^{235}U fission fragments and the problem of reactor $\tilde{\nu}_e$ spectra

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The results of a measurement of the beta spectra of the products of ^{235}U fission by thermal neutrons are presented. The conflicting situation, which arises in comparing the calculated β^- and $\tilde{\nu}_e$ spectra with the experimental β^- spectra and $\tilde{\nu}_e$ spectra that are obtained in neutrino experiments in nuclear reactors, is discussed.

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Knowledge of the reactor ν_e spectra is required for basic research in nuclear reactors and for neutrino diagnostics of processes occurring in reactors.[1] Interest in this area has increased dramatically recently because of the ongoing search[2,3] and the future search[4] for Pontecorvo oscillations.[5]

For several years, two groups—an American group (AG) and a Soviet group—have been engaged in the calculations of $\tilde{\nu}_e$ spectra, using fission-fragment yields and decay schemes; they have been joined recently by a new group (DV) in the USA. The most recent data obtained by these groups have been published in 1978 through 1980.[6–8]

Despite the fact that the authors have used fission-product data that differ little, their results do not agree. The major differences can apparently be attributed to the fact that about 30% of the decay schemes and the yields of certain fragments are unknown, and the authors had to make various hypotheses concerning them.

Under these conditions all the data cause certain doubts, and an additional criterion is required to ascertain what data are true. Such a criterion is the degree of agreement of the calculated spectra of β^-electrons, which are obtained simultaneously, with the $\tilde{\nu}_e$ spectrum and with the β^-spectra of the fission fragments, which are obtained experimentally.

During the last ten years, there has been only one paper[9] published, in which the results of the measurements of the β^-spectra of ^{235}U fission fragments, have been reported. We have therefore carried out new measurements of the spectra of electrons produced as a result of fission of ^{235}U and ^{239}Pu by thermal neutrons. We are not going to discuss the methodological problems since we are now interested only in comparing the β^-spectra obtained by calculation with those obtained experimentally and the $\tilde{\nu}_e$ spectra corresponding to them.

The calculated and experimental results for the β^-spectra are shown in Fig. 1. The calculated values of the Soviet group[7] are assumed to be unity. It can be seen in Fig. 1 that our data in the energy range 1.5 to 7 MeV are in good agreement with the experiment[9] and with the calculations of the Soviet and the American (AG)

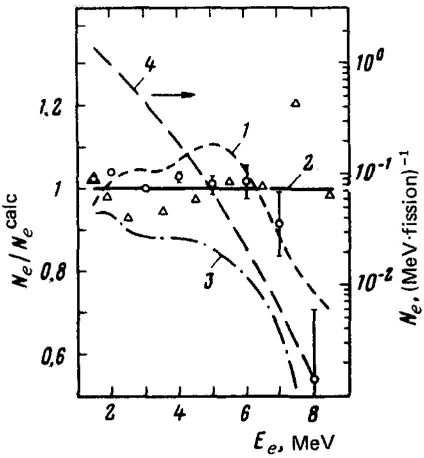

FIG. 1. Ratio of the spectra of electrons from ^{235}U fission fragments for calculations (curves) and experiments (points) to the data of Ref. 7. Curves: 1–Ref. 6 (AG), 2–Ref. 7, 3–Ref. 8 (DV). Points: ○–our paper, △–Ref. 9, 4–spectrum of electrons from fragments of ^{235}U fission by thermal neutrons.[7]

groups.

The calculated spectrum of the (DV) group lies below ours and the discrepancies increase with increasing energy. The errors and the difference between all the spectra increase at energies higher than 7 MeV; however, this is not of great importance now because of the small contribution of this energy region to the cross section.

Qualitatively, the same picture is observed in the $\tilde{\nu}_e$ spectra shown in Fig. 2: the spectrum proposed by the DV group is significantly softer.

Based on the presented discussion, we conclude that the data of Refs. 6 and 7

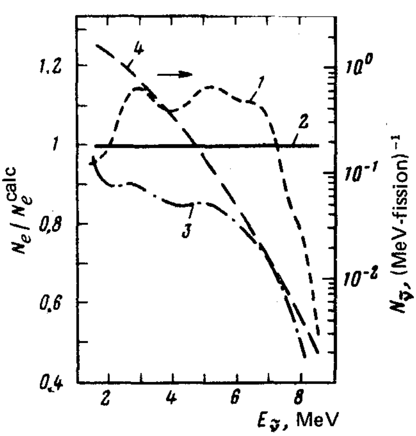

FIG. 2. Ratio of the spectra of antineutrinos from ^{235}U fission fragments to the data of Ref. 7. Curves: 1–Ref. 6 (AG), 2–Ref. 7, 3–Ref. 8 (DV), 4–spectrum of antineutrinos from fragments of ^{235}U fission by thermal neutrons.[7]

must be used to calculate the predicted effects in the higher region of $\tilde{\nu}_e$ energies (up to 7 MeV).

We turn now to the results of an investigation of the reaction

$$\tilde{\nu}_e + p \to n + e^+ \quad (1)$$

in reactors.

The results of the paper by Nezrick and Reines[11] were analyzed[10] and a conclusion was reached that the predicted cross section, which was calculated from the spectra of the Soviet group (1.27×10^{-43} cm^2), lies about 35% above the experimental value of $(0.94 \pm 0.13) \times 10^{-43}$ cm^2.

The e^+ spectrum of the reaction (1), which was obtained at Grenoble[2] in an experiment aimed at finding Pontecorvo oscillations, was published at the end of 1980. This spectrum, as well as the total cross section, agrees within the error limits with the calculated $\tilde{\nu}_e$ spectrum of the DV group and is 30-40% below that predicted from the spectra of Refs. 6 and 7.

Thus, the data discussed above are in poor agreement with each other. On the one hand, the calculations of the Soviet and American (AG) groups confirm satisfactorily the measurements of the β^-spectra of the fragments and do not support the data of reactor experiments, whereas the calculations of the American (DV) group are consistent with the results of the reactor experiment at Grenoble and inconsistent with the experimental β^-spectra of the fragments.

The Grenoble experimenters assumed with certain reservations that the $\tilde{\nu}_e$ spectra of the American (DV) group are preferable to the others and concluded that their results are consistent with the absence of Pontecorvo oscillations (at a distance of 8.7 m from the reactor). We wish to point out that another point of view is possible. If the data presented above do not contain unaccounted for errors, then the experimental situation is consistent with the fact that (a) the $\tilde{\nu}_e$ spectra obtained by the Soviet and American (AG) groups are close to the true spectra and (b) Pontecorvo oscillations, which cannot be resolved in the observed e^+ spectrum in the reactor experiment, although they appear in the decreasing total cross section, are valid.

1. A. A. Borovoĭ and L. A. Mikaelyan, At. Energiya **44**, 508 (1978).
2. F. Boehm, J. F. Cavaignac *et al*., Phys. Lett. B **97**, 310 (1980).
3. F. Reines, H. W. Sobel, and E. Pasierb, Phys. Rev. Lett. **45**, 1307 (1980).
4. A. A. Borovoĭ, S. N. Ketov, L. A. Mikaelyan, A. V. Perfilov, and A. N. Kheruvimov, Preprint IAE-3317/2, 1980.
5. S. M. Bilen'kii and B. M. Pontecorvo, Usp. Fiz. Nauk **123**, 181 (1977) [Sov. Phys. Usp. **20**, 776 (1977)].
6. F. T. Avignone, III and Z. D. Greenwood, Phys. Rev. C **22**, 594 (1980).
7. V. I. Kopeĭkin, Yad. Fiz. **32**, 1203 (1980) [Sov. J. Nucl. Phys. **32**, (to be published)].
8. B. R. Davis, P. Vogel *et al*., Phys. Rev. C **19**, 2259 (1978).
9. N. Tsoulfanidis, B. W. Wehring, and M. E. Wyman, Nucl. Sci. Eng. **43**, 42 (1971).
10. A. A. Borovoĭ, S. N. Ketov, V. I. Kopeĭkin, A. N. Kheruvimov, and K. D. Shkol'nik, Yad. Fiz. **30**, 149 (1979) [Sov. J. Nucl. Phys. **30**, 77 (1979)].
11. F. A. Nezrick and F. Reines, Phys. Rev. **142**, 852 (1966).

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