PHYSICAL REVIEW C VOLUME 21, NUMBER 3 MARCH 1980

Emission of long-range alpha particles in the photofission of ^{235}U with 20-MeV bremsstrahlung

P. D'hondt, E. Jacobs, A. De Clercq, D. De Frenne, H. Thierens, P. De Gelder, and A. J. Deruytter
Nuclear Physics Laboratory, Proeftuinstraat 86, B-9000 Gent, Belgium
(Received 15 October 1979)

Long-range alpha particles emitted in the photofission of ^{235}U with 20-MeV bremsstrahlung were measured. The binary to long-range alpha particle ratio, $\langle E_\alpha \rangle$, and full width at half maximum (E_α) were deduced.

[NUCLEAR REACTIONS, FISSION $^{235}U(\gamma, F)$, $E_{\gamma max}=20$ MeV, measured: Long-range α spectrum.]

The long-range alpha accompanied fission (LRA fission) has been extensively studied for the thermal neutron induced fission of fissile nuclei (e.g., ^{233}U, ^{235}U) and for the spontaneous fission of ^{252}Cf.[1-3] From the detailed similarities of the characteristics of the heavy fragments and of the neutrons evaporated from them[4-6] in the fission modes with and without emission of LRA particles, we learn that we do not deal with two different channels and that information obtained from one of these modes can be applied to the other.

Since the characteristics of the LRA particles are determined by the initial conditions at the moment of scission, the study of LRA fission can yield interesting information on the dynamics of the scission configuration (e.g., on the distance and velocities of the fission fragments at the moment of scission).

As no information on the LRA-particle energy distribution is known and only one value of the binary to LRA-particle accompanied fission probability (B/LRA) has been reported[7] for photofission, a two-parameter study of the LRA photofission of ^{235}U with 20-MeV bremsstrahlung was performed. (Binary fission indicates those events in which, besides the two heavier fragments, no other light particles than neutrons are emitted.)

The bremsstrahlung was produced by 20-MeV electrons in a 0.1 mm thick gold foil. The photon beam was cleared of electrons with a magnet and collimated to a diameter of 1.5 cm at the target location. The target, prepared at the Central Bureau for Nuclear Measurements, Euratom-Geel, consisted of a 416 $\mu g/cm^2$ ^{235}U layer (UF_4 form, enriched up to 97% ^{235}U) on a 50 $\mu g/cm^2$ VYNS backing with 10 $\mu g/cm^2$ Au.

A detector telescope particle identification system had to be used to separate the LRA particles from a high proton background, which was predominantly produced by (γ, p) reaction in the carbon of the target backing and the F of the target. The photofission cross section has a maximum value of ~180 mb at 14 MeV photon energy.[8] If a B/LRA ratio of about 600 is assumed, the expected LRA photofission cross section is thus of the order of 0.3 mb. The $^{12}C(\gamma, p)$ cross section on the other hand, reaches a maximum of ~13 mb at 22.5 MeV photon energy and has a value of ~5 mb at 20 MeV,[9] while the $^{19}F(\gamma, p)$ cross section reaches a maximum of ~5 mb at 20 MeV photon energy.[10] The counter telescope consisted of two Au-Si surface barrier detectors, a totally depleted ΔE detector of 32.1 μm thickness, followed by an E detector depleted to a depth of 500 μm. The active area of the detectors was 150 mm^2 in order to minimize the γ pile-up in the detectors.[11] The ΔE detector was shielded by a 20 μm Al absorber in order to stop the fission fragments and the natural alpha particles of the target and to reduce the background due to secondary electrons, produced in the target by the bremsstrahlung. A 10 mm diameter collimator in front of the ΔE detector defined a more homogeneous region of this detector. Based on the difference in energy loss in the thin ΔE detector for different light particles with the same initial energy, identification is possible.[12]

The amplified pulses from the detectors were fed into two Northern NS623 analog-to-digital convertors. The coded coincident signals were stored event by event on a digital cassette recorder by means of a microprocessor system (INTEL 8080) in a 4096 by 4096 channel configuration. The detectors were calibrated using well known natural α lines from the target and from a ^{228}Th source. The stability of the two detectors chains was checked with a pulser. The γ-flash pulses were measured continuously. The coincident signals of the telescope system were registered after on-line correction by subtraction of an average value of the γ-flash pulses. The two-dimensional ΔE-E data are handled off-line with a PDP-15 computer system.

The fission fragments are counted in a third

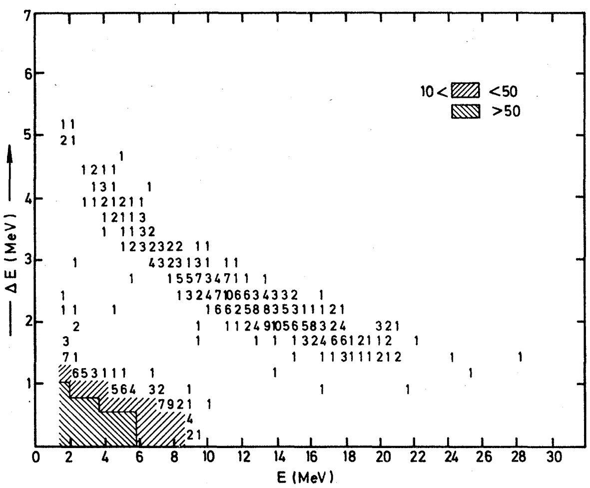

FIG. 1. Two-dimensional E-ΔE spectrum of the LRA particles for the photofission of ^{235}U with 20-MeV bremsstrahlung. In each channel the number of counts is indicated.

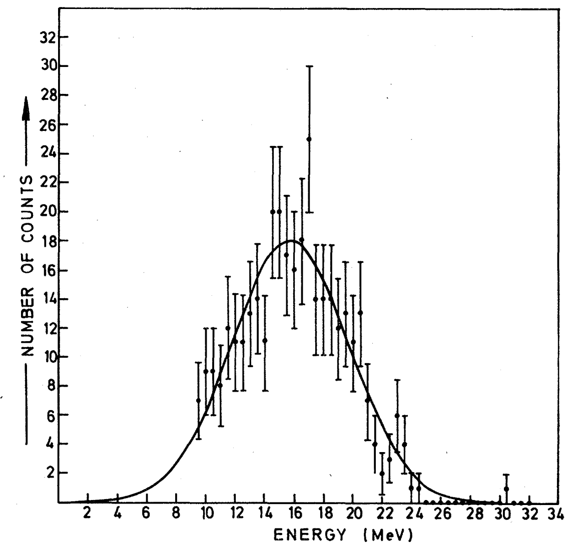

FIG. 2. The spectrum, corrected for energy losses, of the LRA particles emitted in the photofission of ^{235}U with 20-MeV bremsstrahlung.

detector, placed on the opposite side of the target. The geometry factor between this detector and the telescope system was determined by counting in both detector systems the natural α particles of the ^{235}U target used. Coincidence losses in the telescope were less than 1%; this was checked with the 8.785 MeV ^{212}Po α particles from a ^{228}Th source.

Three independent experimental runs, each of about 24 hours, were performed under the same experimental conditions. The results of the three runs were in agreement within the statistical accuracy. The total number of recorded LRA particles was 346. The overall two-dimensional E-ΔE spectrum is shown in Fig. 1. In each $(E, \Delta E)$ channel the number of counts is plotted. It is clear that the LRA particles are very well separated from the high background in the low-energy part of the spectrum. The particle spectrum corrected for energy losses in the aluminium absorber is shown in Fig. 2. A Gaussian was fitted through the data points. The peak of the energy distribution is 15.8 ± 0.5 MeV and its full width at half maximum (FWHM) is 9.6 ± 0.8 MeV. The binary to LRA-particle emission probability B/LRA is 580 ± 50. The uncertainty takes into account the statistical error, a possible error introduced by the extrapolation of the LRA data to low-energy values and the uncertainty introduced by performing a correction for the emission of ^{6}He particles. The value 1.91%, as observed for thermal neutron induced fission of ^{235}U, was taken[13] for the ratio of the ^{6}He to LRA emission probability.

The B/LRA value, deduced from our experiments can be compared only with the tentative value 400 ± 200, obtained by Titterton and Goward[7] for the photofission of ^{235}U with 23-MeV bremsstrahlung. In these experiments only 4 LRA events were observed. No other B/LRA values have been reported in the literature for photofission.

The B/LRA ratio expected for the fission of the compound nucleus ^{235}U from the semiempirical relation

$$Y(Z,A) = [b(4Z - A) + a] \times 10^{-3}$$

given by Halpern[2] for the LRA/B ratio $Y(Z,A)$, for the fission of the compound nucleus with mass number A and charge number Z, is 560. For the coefficients a and b we used the values -15.51 and 0.13, respectively, calculated by Wagemans *et al.*[14] for the thermal neutron induced fission of several nuclei. The calculated B/LRA value is in very good agreement with our measured value for 20-MeV bremsstrahlung induced fission of ^{235}U, indicating the nearly (compound nucleus) excitation energy independence of the B/LRA ratio. The relative insensitivity of the light charged particle emission probability to excitation energy confirms once more that these particles are not evaporated from the accelerated fragments but that they must be emitted from the neck region close to the moment of scission.

This research was supported by the Interuniversitair Instituut voor Kernwetenschappen—Nationaal Fonds voor Wetenschappelijk Onderzoek. Thanks are expressed to the linac team of the Nuclear Physics Laboratory for operating the accelerator.

[1]N. Feather, in *Proceedings of the Second International Atomic Energy Symposium on Physics and Chemistry of Fission, Vienna, Austria, 1969* (International Atomic Energy Agency, Vienna, 1969), p. 83.
[2]I. Halpern, Annu. Rev. Nucl. Sci. 21, 245 (1971).
[3]R. Vandenbosch and J. Huizinga, *Nuclear Fission* (Academic, New York, 1973).
[4]H. W. Schmitt, J. H. Neiler, F. J. Walter, and A. Chetham-Strode, Phys. Rev. Lett. 9, 427 (1962).
[5]E. Nardi and Z. Fraenkel, Phys. Rev. Lett. 20, 1248 (1968).
[6]E. Nardi and Z. Fraenkel, Phys. Rev. C 2, 1156 (1970).
[7]E. W. Titterton and F. K. Goward, Phys. Rev. 76, 142 (1949).
[8]C. D. Bowman, G. F. Auchampaugh, and S. C. Fultz, Phys. Rev. 133, B676 (1964).
[9]R. Carchon, R. Van De Vijver, H. Ferdinande, J. Devos, and E. Van Camp, Phys. Rev. C 14, 456 (1976).
[10]E. Kerkhove, private communication and Annual Report Nuclear Physics Laboratory Ghent, 1978.
[11]A. De Clercq, E. Jacobs, D. De Frenne, H. Thierens, P. D'hondt, and A. J. Deruytter, Phys. Rev. C 13, 1536 (1976).
[12]F. S. Goulding, D. A. Landis, J. Cerny, and P. H. Pehl, Nucl. Instrum. Methods 31, 1 (1964).
[13]A. A. Vorob̆yov, D. M. Seleverstov, V. T. Grachov, I. A. Kondurov, A. M. Nikitin, N. N. Smirnov, and Yu. K. Zalite, Phys. Lett., B40, 102 (1972).
[14]C. Wagemans, M. Asghar, P. D'hondt, A. J. Deruytter, and A. Emsallem, Nucl. Phys. A285, 32 (1977).