SEARCH FOR H^5 *AMONG THE PRODUCTS OF* U^{235} *THERMAL NEUTRON FISSION*

V. N. ANDREEV and S. M. SIROTKIN

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The isotopic content of the long range particles emitted in thermal neutron fission of U^{235} is investigated. Besides the α-particles, tritium was found. For H^5 the upper limit of 2×10^{-5} nuclei per fission was obtained. This value is far less than the yield of the most short-lived group of delayed neutrons for which H^5 could be a precursor.

THE emission of long range α-particles in nuclear fission is well known. In 1959 Albenesius[1] separated tritium from the fission products of uranium and the transuranium elements by radiochemical means. According to the data of Albenesius and Ondrejcin[2] and of Sloth et al.[3] the tritium yield is only one nucleus in $(1.10 \pm 0.08) \times 10^4$ fissions. Watson[4] and Wegner[5] have observed the emission of tritium nuclei in the spontaneous fission of Cf^{252} and measured their energy spectra. The spectrum of the tritium nuclei had a maximum at 8 MeV and a half-width of ~ 7 MeV.

It is possible that, besides tritium and He^4, other isotopes of hydrogen, helium, and other light elements are also emitted in the fission of nuclei. Since fission fragments are formed with an excess of neutrons, we can expect that the heaviest isotopes of each element will be formed preferentially.

We have been interested in the possible emission of the hydrogen isotope H^5 in fission. In 1963 Nefkens[6] irradiated lithium with high energy γ-rays and observed a β-activity with a lifetime of 110 msec and with $E\beta_{\max} > 15$ MeV. He assigned this to a new isotope of hydrogen formed and decaying according to the reaction

$$Li^7(\gamma, 2p)H^5 \xrightarrow[\beta^-]{} He^5.$$

If H^5 is formed in fission, it should be the precursor of delayed neutrons with a half-life of 0.11 ± 0.03 sec, since He^5 is unstable and decays with a nuclear lifetime, emitting a neutron.[1)] Actually, delayed neutrons are emitted in fission with small half-lives, according to various authors, from 0.13 to 0.23 sec, and with an absolute yield (in the case of U^{235}) of ~ $(6.6 \pm 0.8) \times 10^{-4}$ neutrons per fission[11]. Since the yield of short-lived groups of delayed neutrons is greatest in U^{235}, we have chosen it as a subject for study.

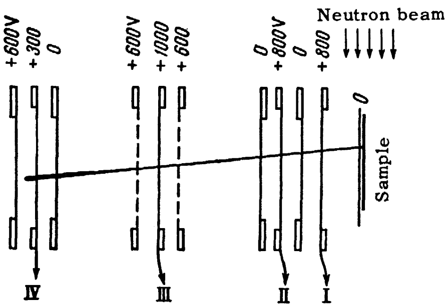

FIG. 1

Figure 1 shows a drawing of the experimental apparatus. A sample of U^{235} ~ 20 mg in weight was irradiated by thermal neutrons in a beam from the thermal column of a reactor. The long range particles passed through a 28-μ aluminum foil, two ionization chambers I and II, a double grid-chamber III, an aluminum absorber, and a differential ionization chamber IV. Chambers I, II, and IV were connected in coincidence and selected particles emitted from the sample and stopping in chamber IV. The coincidence pulse triggered a multi-channel pulse height analyzer connected to the output of an amplifier fed by the double grid-chamber III. Thus we could determine dE/dx for particles with a fixed range. By changing the thickness of the absorber placed in front of chamber IV, we could study particles with different ranges. The range resolution was determined by the thickness of the gas in chamber IV and by the thickness of the center electrode. The resolution was 1 cm of range with a center electrode of 0.8 micron aluminum foil, and 2 cm of range with a center electrode of 6 micron aluminum foil.

Figure 2 shows the measured spectrum of parti-

[1)] Cence and Waddell[7] attempted to observe H^5 by means of delayed neutrons; Schwarzschild, Poskanzer, Emery, and Goldhaber irradiated lithium by high energy protons with the same purpose. In both experiments negative results were obtained. The questions of the production and the stability of H^5 are discussed also in the papers of Baz', Gol'danskiĭ, and Zel'dovich[9], and Gol'danskiĭ[10].

Isotope	E_{av}, MeV	ΔE, MeV	dN/dE, MeV^{-1}	No. of particles per fission
H^3	6.7 8.6	0.16 0.28	$(4,9\pm1.5)\cdot10^{-6}$ $(2.7\pm0.8)\cdot10^{-6}$	$(2,4\pm0.7)\cdot10^{-5}$
H^5	8.2 10.5	0.19 0.31	$<1.5\cdot10^{-6}$ $<10^{-6}$	$<7\cdot10^{-6}$
He^3	15.5 18.8	0.33 0.53	$<8\cdot10^{-6}$ $<5\cdot10^{-6}$	$<6\cdot10^{-5}$
He^4	17.3 21.3	0,38 0,63	$(1.44\pm0.15)\cdot10^{-4}$ $(5.46\pm0.55)\cdot10^{-5}$	$(1,9\pm0,2)\cdot10^{-3}$
He^6	25.3	0.73	$<2\cdot10^{-6}$	—

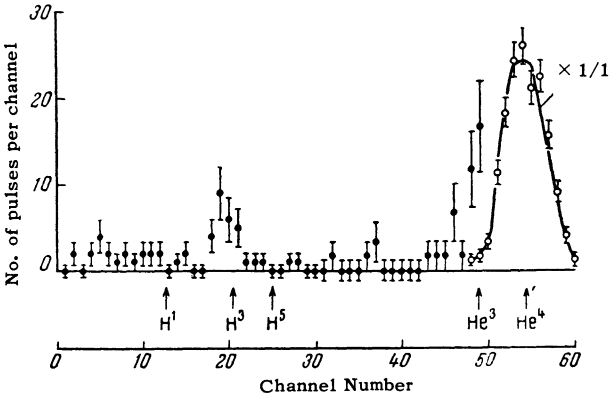

FIG. 2

cles with a range of 27 cm in air. The main peak corresponds to α particles. Also shown are the calculated locations for other particles which we would be able to observe. Figure 3 shows the spectrum of particles with a range of 38 cm in air. Besides α particles we have observed only tritium nuclei among the long range particles from U^{235}.

The discriminator settings for chambers I, II, and IV were chosen to count helium isotopes and H^5 with only a small loss of efficiency. The efficiency for counting tritium nuclei was already appreciably reduced. The loss of efficiency was estimated from the variation of the α-particle coincidence rate with discriminator setting in each of the coincidence channels.

The results of our measurements are listed in the table. In the second column is shown the mean energy of the particles, calculated from their range; in the third column is the energy interval corresponding to the spread in range. In the fourth column is listed the relative number of particles observed by us for one fission and in a 1 MeV energy interval of the spectrum. In these calculations we used the observed particle counting rates, the weight of the U^{235} sample, the value of the neutron flux, and the geometrical efficiency for counting long range particles. The errors shown correspond to the uncertainty in these quantities. In the fifth column is listed the total number of particles for one fission, calculated on the assumption that the spectrum of the helium isotopes is identical with the spectrum of the α-particles and that the spectrum of the hydrogen isotopes is similar to that of the α-particles but with half the mean energy.

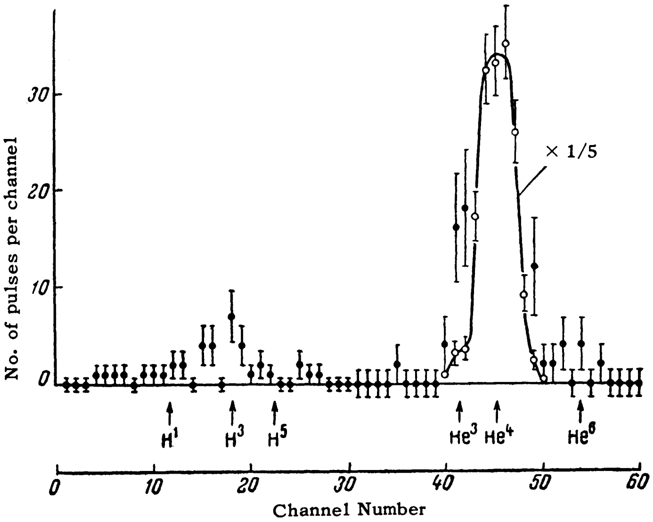

FIG. 3

The measured value for α-particles agrees well with the data in the literature. Comparison of our results with the radiochemical yield of tritium shows that the counting efficiency for tritium was reduced in our apparatus by roughly a factor of three or four. Assuming, with some margin, that the counting of H^5 nuclei was suppressed by a factor of three, we obtained, with a probability of better than 95%, an upper limit of 2×10^{-5} for the probability of emission of H^5 in fission of U^{235} by thermal neutrons. This is thirty times less than the yield of the shortest lifetime group of delayed neutrons in U^{235} fission.

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