Searches for superdense nuclei in the active zone of a reactor

V. G. Nikolenko, A. B. Popov, G. S. Samosvat, and
Khvan Cher Gu

Joint Institute for Nuclear Research

We searched for a transition, accompanied by large energy release, of a nucleus into a superdense state. It is established that the yields of γ quanta of energy $\sim$30–100 MeV and of neutrons with $\sim$40–200 MeV do not exceed, respectively, 3×10^{-8} and 9×10^{-7} per fission event in the IBR-30 pulsed reactor.

PACS numbers: 25.85.Ec, 21.10.Dr, 27.90.+b, 28.40.Nw

1. Despite the negative results of experimental searches[1–8] of hypothetical superdense nuclei (SPD), this task is fundamental enough to seek new ways of their observation. In the present paper we describe an attempt to observe SPD with increased binding energy in the active zone of a reactor by observing the γ quanta and neutrons of anomalously high energy emitted from the reactor. This experiment provides an estimate of the probability of nuclear fission in the zone (75% ^{239}Pu and 25% ^{235}U), such that one or both fragments are in the superdense state. In such a fission, the
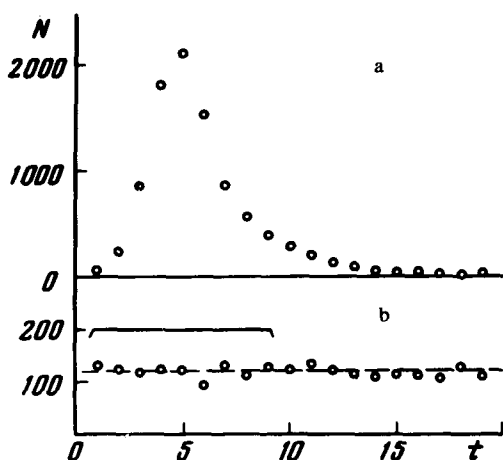
FIG. 1

excess energy can increase the energies of the fission neutrons and γ quanta. Nor is a possibility excluded of a delayed high-energy γ emission from radioactive superdense fragments.[8] We note that the advisability of searching for superdense nuclei among the fission fragments is mentioned in[9].

2. The search for hard γ quanta was carried out at an average IBR-30 pulsed-reactor power ~ 20 kW and at a half width of its bursts ~ 100 μsec, using two NaI(Tl) crystal measuring 10×10 cm, placed 70 meters away from the reactor. At the registration threshold 30 MeV, to suppress the superposition of pulses from soft γ rays, it was necessary to place in the beam a water filter 275 cm thick. The first measurement run consisted of 120-hour accumulation of the temporal spectrum of the pulses under fixed conditions. In the second run, we registered 160 pairs of spectra corresponding to alternating 15-minute exposures with the detector inside and outside the beam.[10] A segment of the spectrum of the first run is shown in Fig. 1(b) (t is the number of the channel of 32 μsec width; N is the number of counts in the channel); Fig. 1(a) shows for comparison the spectrum obtained at the detector threshold 10 MeV.

3. The fission-neutron spectrum was investigated by a time of flight method using a base of 1000 meters, a power ~ 6 kW, and a burst half-width ~ 3 μsec, with the aid of a plastic scintillator of 10 cm diameter and 9 cm thickness. To lower the γ background, a lead filter 12.5 cm thick was placed in the beam. Figure 2 shows the temporal spectra of the pulse obtained at different amplitude thresholds after 175 hours at a channel width 0.5 μsec. Against a flat cosmic background, a flash of bremsstrahlung γ radiation from the booster is seen in channels 32–37, followed by the fission γ rays (on the spectrum of Fig. 2(c) they are suppressed by the threshold; a neutron peak is located in the channels from ~ 55 on. The E_n scale on Fig. 2 represents the neutron energy.

4. An estimate of the particle yield δ per fission act is obtained from the relation

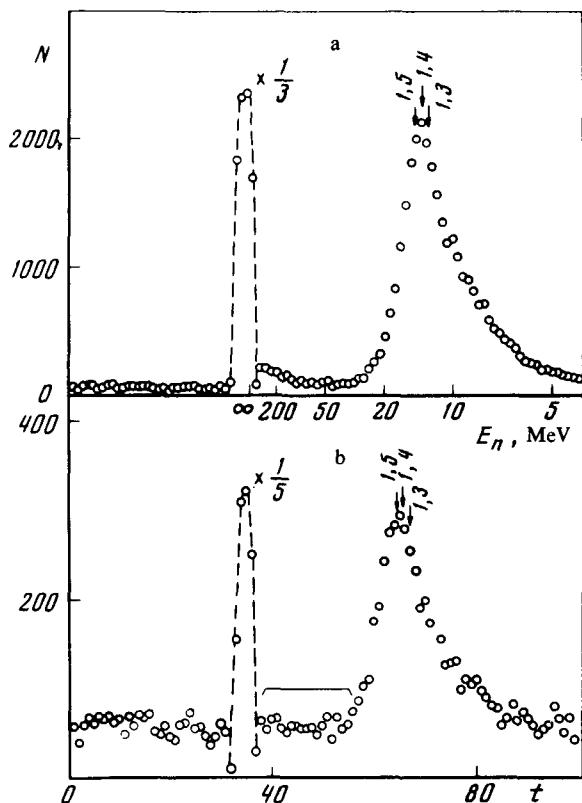$$A = 3 \times 10^{13} W T \delta \kappa \epsilon \frac{\omega}{4\pi} \,, \tag{1}$$

FIG. 2.

where A is the detector count, W is the reactor power in kW, κ is the transmission of the medium separating the production point and the particle detector, ω and ϵ are the solid angle and the efficiency of the detector, and T is the measurement time in seconds. For prompt γ quanta ($\tau_{1/2} < 100$ μsec) we took A to be the difference between the counts in the first 9 channels of the spectrum on Fig. 1(b) and the average background over the succeeding 4000 channels, which amounted to 3 ± 33. At $A < 33$ and $\kappa \approx 2 \times 10^{-5}$ (with allowance for the reactor construction) we obtain from (1) δ_γ ($\tau_{1/2} < 100$ μsec) $< 3 \times 10^{-8}$. The fact that the spectrum is flat in the entire analyzer range ~ 0.13 sec enables us to estimate the yield and the delayed radiation. Thus, δ_γ ($100 < \tau_{1/2} < 10\,000$) $< 3 \times 10^{-9} \sqrt{\tau_{1/2}}$, where $\tau_{1/2}$ is in microseconds. The reults of the second measurement run $A = -650 \pm 780$, obtained as the difference between the counts of the detector in the beam and outside the beam, yields an estimate δ_γ (1 sec $< \tau_{1/2} < 1$ day) $< 3 \times 10^{-6}$ of even more delayed γ quanta.

5. The neutron registration efficiency was determined by comparing the area and the position of the peak with the calculation at acceptable temperatures θ of the evaporation spectrum (the arrows on Fig. 2 mark the calculated positions of the maxima for $\theta = 1.3$, 1.4, and 1.5 MeV). The average neutron yield $\delta_n < 9 \times 10^{-7}$ in the interval 40–200 MeV was obtained from (1) at $A < 39$ (the difference in the counting

rate in the channels 38–54 of the spectrum on Fig. 2(b) and the background was 2$+$39), and at mean values $\kappa \approx 0.02$ and $\epsilon \approx 0.03$.

6. The results of the first run allow us to estimate the maximum content of the superdense nuclei, assuming the (n,γ) reaction on these nuclei. Since thermal neutrons are contained only in the IBR-30 moderator, we used in the calculation of the reaction intensity inside the reactor not the cross section 1000 b[4] but the cross section 0.1 b for the fission spectrum. It turned out that the atomic concentrations of the superdense nuclei in the water moderator, in the tungsten reflector, and in the fissioning material of the reactor do not exceed 2×10^{-12}, 2×10^{-8}, and 5×10^{-7}, respectively.

[1]P.B. Price and J. Stevenson, Phys. Rev. Lett. **34**, 409 (1975).
[2]P.B. Price, Bull. Am. Phys. Soc. **20**, 594 (1975).
[3]S. Frankel *et al.*, Phys. Rev. C **13**, 737 (1976).
[4]R.J. Holt *et al.*, Phys. Rev. Lett. **36**, 183 (1976).
[5]K. Frankel and J. Stevenson, Phys. Rev. C **14**, 1455 (1976).
[6]V.I. Aleshin *et al.*, Pisma Zh. Eksp. Teor. Fiz. **24**, 114 (1976) [JETP Lett. **24**, 100 (1976)].
[7]A.P. Bugorskiĭ *et al.*, Soobshch. JINR 13-10216, Dubna, 1976.
[8]A. Kulikov and B. Pontecorvo, Phys. Lett. B **66**, 136 (1977).
[9]A.B. Migdal *et al.*, Phys. Lett. B **65**, 423 (1976).
[10]V.A. Vagov, G.P. Zhukov, and Sh. Salan, in: I Vseosyuzonoe soveshchanie po automatizatskii nauchnykh issledovanii va yadernoi fizike (First All-Union Conference on the Automation of Nuclear Physics Research), p. 19, Nuc. Res. Inst. Ukr. Acad. Sci., Kiev, 1976, p. 19.