Search for neutron activity in targets irradiated by 70-GeV protons

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The γ-ray and neutron activities in targets were measured two years after they had been irradiated by 70-GeV protons. The limit of the cross section for production of neutron emitters in proton-nuclear collisions was determined.

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This investigation was initiated by the problem of superdense nuclei. The theory of pion condensation developed by Migdal[1,2] draws attention to the fact that nuclear matter, beginning with a certain density, can be converted to a state with a pion condensate. The existing uncertainty in selecting certain constants does not allow us to determine the binding energy per nucleon unambiguously for anomalous nuclei as compared with ordinary nuclei. Most of the experimental studies of superdense nuclei (see review article[3]) were targeted on the search for anomalous nuclei with a larger

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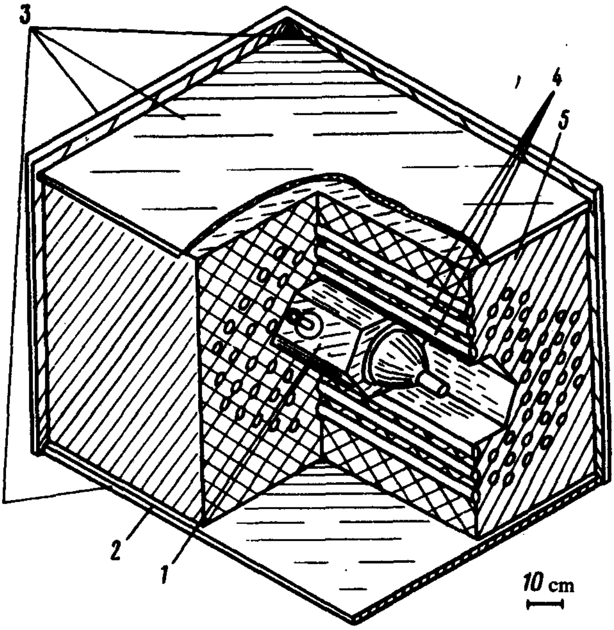

FIG. 1. General view of the combined detector. 1, Scintillation detector; 2, irradiated target; 3, plates of the active shield against cosmic μ rays; 4, neutron (He^3) counters; 5, neutron moderator.

binding energy (sometimes much larger) than that of ordinary nuclei. In this experiment we searched for metastable, superdense nuclei in spontaneous transitions to ordinary nuclei.

To obtain superdense nuclei, we irradiated Al, Cu, and Sn targets each having $\sim 10^{23}$ nuclei per cm^2 and a Pb target (5×10^{22} cm^{-2}) by 70-GeV protons at an integral intensity of $\approx 1.1 \times 10^{16}$. Although irradiation by energetic, heavy ions is more promising from the viewpoint of fusion of superdense nuclei,[4] we should not exclude their production in a proton beam due to less probable reaction channels and secondary processes, especially if the large, integral intensities of proton beams are taken into account.

The experiment was based on observation of neutron and γ-ray activities of the irradiated samples, assuming that the lifetime of the produced superdense metastable nuclei is $\gtrsim 1$ year.

The experiment was performed using a combined setup (Fig. 1) consisting of a neutron detector and a scintillation detector. The latter contained about 15 kg of scintillation fluorobenzene C_6F_6. The recording efficiency of the fission-spectrum neutrons was equal to ~ 0.5. In the experiment, we measured the γ-ray energy and the number (multiplicity) of neutrons recorded during the presence of a time window whose start was the pulse from the scintillation detector (γ-ray start) or the pulse from the first neutron. The starting pulse could be produced only when there were no pulses preceding it during a time not less than the time window for recording of neutrons.

The operating regime with a γ-ray start was used on the assumption that there are

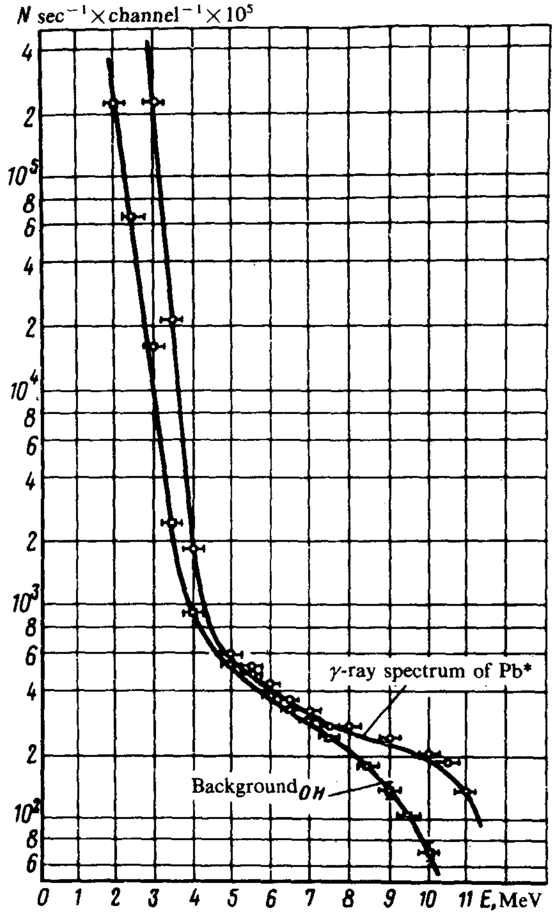

FIG. 2. Differential γ-ray spectra of Pb* and of the background for zero neutron multiplicity. ● represents the γ-ray spectrum of Pb* and □ denotes the γ-ray spectrum of the background; the channel width is 0.5 MeV.

TABLE I. Effect. Neutron Activity (events $sec^{-1} \times 10^5$)

Target \ Neutron multiplicity	1	2	3	4	5
Al*	−164 ± 88	8 ± 21	5.7 ± 10.4	5.4 ± 5.0	2.7 ± 2.0
Cu*	9 ± 91	51 ± 22	−4.3 ± 10.5	2.9 ± 4.9	−0.3 ± 1.6
Sn*	162 ± 91	58 ± 21	1.4 ± 10.5	−4.3 ± 4.6	−0.7 ± 1.6
Pb*	104 ± 90	43 ± 22	8.9 ± 10.4	−5.9 ± 4.3	3.7 ± 2.1

correlated "γ-n" events (analogous to spontaneous fission of nuclei), which give a more comprehensive picture of the investigated transitions.

The range of measured γ-ray energies (~ 1.5–10 MeV) was determined primarily by instrumental loading (600–700 pulses$\cdot$sec^{-1}). The duration of the time window for recording of neutrons was 200 μsec. To allow for random coincidences, we used the generator technique whose starts were statistically added to the neutron and γ-ray starts. The measurements were performed separately for each irradiated metal (Al*, Cu*, Sn*, and Pb*); the time required to collect the statistical data in each case was 2×10^5 sec of the "live time." The background measurements of nonirradiated samples of 3.6×10^5-sec total duration were carried out periodically during the experiment.

Figure 2 shows the results of measurements with a correction for random coincidences reduced to a time of 10^5 sec. Table I gives the results of measurement of the neutron activity, irrespective of the type of start.

The results obtained for each element taken separately do not indicate that there is a positive effect with a sufficient degree of certainty. The upper limit of the cross section for production of metastable, superdense nuclei at the 95% confidence level is estimated as

$$\frac{\sigma}{\tau} \lesssim 3\cdot10^{-34}\ \mathrm{cm}^2/\mathrm{yr}$$

where τ is the lifetime in years of an anomalous nucleus.

The observed difference in the γ-ray spectra of Pb* and the background in the energy interval 5–10 MeV (Fig. 2) must be measured more carefully under low-background conditions using a total-absorption spectrometer.

It should be noted that although the existence of superdense nuclei cannot be determined unambiguously even from a reliable observation of neutron activity, such an attempt would certainly be of interest, considering the relatively large interval of time after the irradiation in the accelerator (2 years).

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