"Explosion" of nuclei induced by 1-GeV protons in ^{238}U, ^{232}Th, and ^{197}Au targets

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Nuclear fission induced by 1-GeV protons in ^{238}U, ^{232}Th, and ^{197}Au targets has been studied in a double-arm time-of-flight spectrometer. An "explosion" of nuclei was observed: a reaction with extensive nucleon emission and with two fragments whose kinematics differs sharply from fission kinematics.

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A double-arm time-of-flight spectrometer,[1] with the block diagram shown in Fig. 1, has been used to study how the mechanism for the fission of ^{238}U, ^{232}Th, ^{197}Au, and ^{184}W nuclei induced by 1-GeV protons depends on the nucleon loss. The additional fragments emitted perpendicular to the proton beam direction are detected by two semiconductor-detector mosaics. The time evolution was studied with the help of an independent starting-signal apparatus. The target thickness was varied from 100 to 500 $\mu g/cm^2$, and the baseline for the fragment flight was 70 cm. The energy and time calibration of the apparatus was carried out with the help of a thin source of the spontaneous-fission isotope ^{252}Cf. In the experiments we determined the energies E, the masses $M \sim ET^2$, and the momenta $P \sim ET$ of the additional fragments emitted collinearly; here T is the time of flight across the specified baseline for each of the

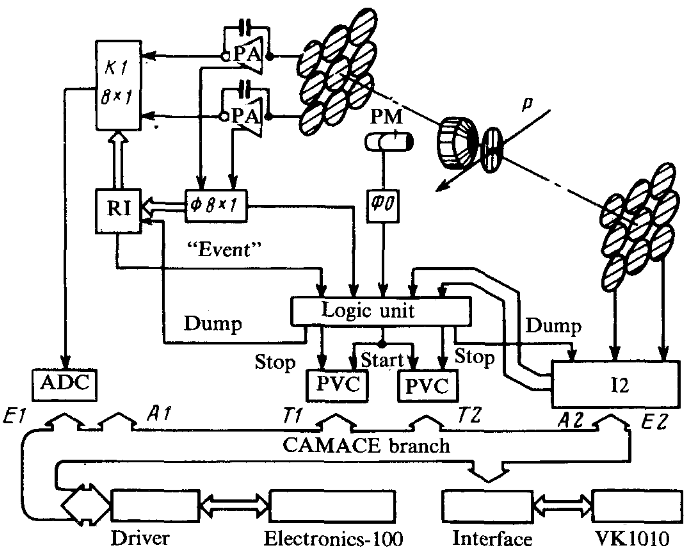

FIG. 1. Block diagram of the double-arm time-of-flight spectrometer.

fragments. The instrumental resolution corresponds to the standard deviations $\sigma_M = 4.0 \pm 0.7$ amu for the mass of the individual fragments and $\sigma_{M_L + M_H} = 6.0 \pm 1.0$ amu for the sum of the masses of the additional fragments. Figure 2 shows the distribution of events in the magnitude of the sum of the fragment masses; this sum is equivalent to the magnitude of the nucleon loss. In addition to the nuclear-fission events with an average nucleon loss of about 20 amu, we see events for which the nucleon loss is much higher than the fission loss, nearly reaching half the original mass of the target nucleus. These events are shown by the histograms in Fig. 2; they lie five or more standard deviations from the bulk distributions. The effect can be seen most clearly for the ^{238}U nuclei, and it fades gradually with decreasing mass number of the target nucleus.

The events with a large nucleon loss also have a distinctive emission kinematics. The total kinetic energy in these events exceeds the fission energy for a given fragment-mass sum. A second distinctive feature of the kinematics of the two fragments with a large nucleon loss is a redistribution of the kinetic energy between the fragments, with the result that for most of the events the relationship $E_H M_H = E_L M_L$ is completely disrupted. This relationship is characteristic of the decay of a nucleus at rest into two parts. In order to explain this aspect of the kinematics of the additional fragments, it is necessary to assume that there is a perpendicular transport momentum P_T comparable in magnitude to the fission-fragment momentum. Figure 3 shows histograms of the difference between the momenta of the heavy and light fragments, $P_T = P_H - P_L$, for events in which the nucleon loss exceeds 60 amu. Also shown here are corresponding distributions for fission events with a low nucleon loss. These histograms suggest that

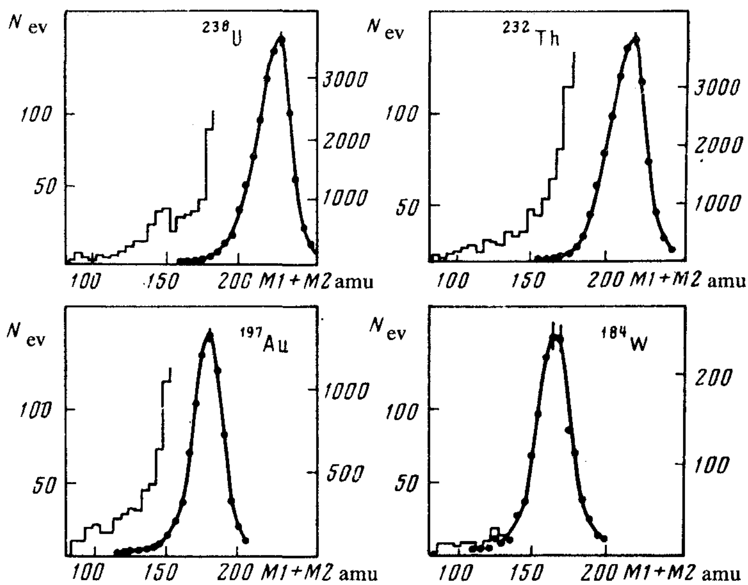

FIG. 2. Distribution of events in the magnitude of the sum of the fragment masses. The points and the scale at the left correspond to the fission process; the histograms correspond to the "explosion" of nuclei.

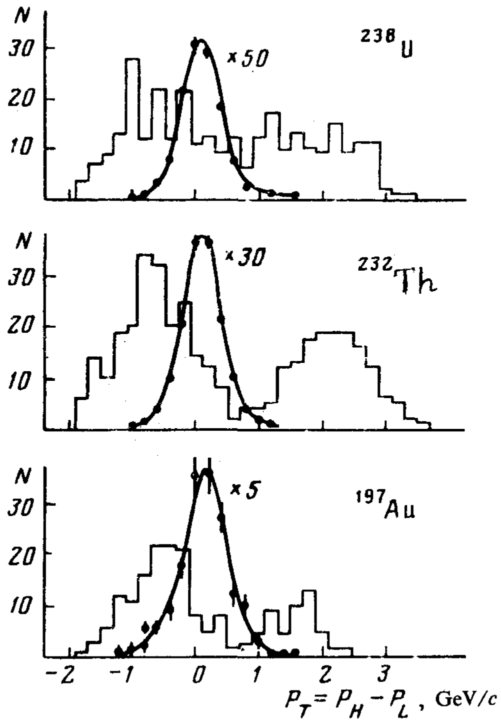

FIG. 3. Distributions in the magnitude of the momentum, $P_T = P_H - P_L$, for events with a nucleon loss exceeding 60 amu (histograms). The experimental points and the solid curves correspond to fission events with a low nucleon loss.

a transverse momentum of up to 3 GeV/c may be transferred during the interaction of the 1-GeV proton with the heavy nucleus.

Since this process is markedly different from nuclear fission, it might be called the "explosion" of a nucleus. We believe that the same process has been observed elsewhere[2] during the bombardment of ^{238}U nuclei by 11.5-GeV protons. Wilkins *et al.*[2] attributed the entire increase in the kinetic energy to a decrease in the distance between the fragments at the time of their production. The momentum distributions of the additional fragments found in the present experiments, however, indicate that the increase in the resultant kinetic energy is attributable at least in part to a transport motion in the direction perpendicular to the primary beam. This motion apparently results from the summation of the recoil momenta during the emission of a large number of nucleons, deuterons, α particles, and other light nuclei, with a total mass equal to the observed nucleon loss. Reactions induced by fast particles in which a large number of secondary nuclear particles have been observed—up to the point of the complete disintegration of the nuclei—have been observed experimentally.[3] The relationship between the momentum transferred to one of the products of the nuclear reaction and the total multiplicity of the product particles may prove important in explaining reactions in which there is an apparent anomalous momentum transfer.

[1]M. N. Andronenko, I. N. Sinogeev, G. E. Solyakin, Yu. A. Chestnov, and V. E. Shashmin, Prib. Tekh. Eksp. No. 4, **51** (1977); No. 4, **53** (1977); No. 4, **41** (1977).
[2]B. D. Wilkins, S. B. Kaufman, E. P. Steinberg, J. A. Urbon, and D. J. Henderson, Phys. Rev. Lett. **43**, 1080 (1979).
[3]O. Akhrorov, B. P. Bannik, A. K. Popova, Dzh. A. Salomov, K. D. Tolstov, G. S. Shabratova, M. Sherif, and A. El Nagy, Preprint JINR R1-9963, 1976.

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