Investigation of deuteron beams generated in a plasma focus

N. V. Filippov and T. I. Filippova

I. V. Kurchatov Institute of Atomic Energy
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Time of flight spectroscopy using the method of comparative activation of Al-C targets is used to investigate the generation conditions and the parameters of the "hard" (1–5 MeV) components of deuteron beams produced in systems of the "plasma focus" type in the regime with "runaway" of the current sheaths.

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Operation of installations of the "plasma focus" (PF) type in the so called "runaway" regime of the current sheath were reported earlier.[1] In this regime, a current exceeding 1 MA, with a channel transverse dimension of approximately 1 mm is focused on the axis of a non-cylindrical z-pinch. As a result, a powerful electron beam (EB) is produced in the cumulation zone and is fed by the energy of the magnetic field that is stored in the space bounded by the plasma sheath and the electrode. At an initial energy 60—100 kJ, in regimes with shell runaway, it is possible to convert into EB energy up to 20% of the initial energy of the capacitor bank.

The plasma-"gap" electric field that produces the EB should effectively accelerate the ion component of the plasma. By special choice of the construction of the central part of the anode and of the initial discharge conditions, we obtained in the present study regimes in which a noticeable fraction of the total current J went to the ion component. The produced ion beam has a sharply pronounced angular anisotropy and an energy distribution with end-point energy $E_d \sim 5$—8 MeV. To analyze the deuteron beam we used the method of comparative activation of a combined Al-C target and the principle of time-of-flight spectrometry with oscillography and subsequent reduction of the signal from a scintillation detector that registered the neutron radiation of the reaction $C^{12}(d,n)N^{13}$.

The experimental setup is shown in Fig. 1. The experiments were performed with an "MG" setup of the "plasma focus" type[1] at an initial voltage 15—16 kV and a working-gas pressure 0.6—0.8 Torr of D_2 to which 20 mTorr of Xe was added. In the discharge chamber (1) we installed a drift tube (2), through which the fast-neutron beam produced near the anode (3) was incident on a target (4) made up of aluminum foil and carbonized fabric. The aluminum ribbon was

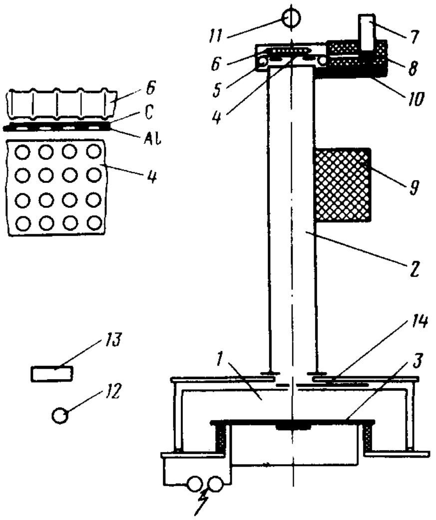

FIG. 1. Experimental setup and arrangement of the measuring apparatus.

perforated and the deuterons were able to interact with the carbonized fabric through the perforations. The deuteron beam produced in the carbon the reaction $C^{12}(d;n)N^{13}$, with production of the position-active isotope N^{13}, and produced on the aluminum foil the reaction $Al^{27}(d,p)\,Al^{28}$, where Al^{28} is an inactive aluminum isotope. The resultant activity of the targets was measured with the aid of an STS-6 Geiger counter (6). The ribbon targets could be moved with the aim of drums (5) to a new non-activated position. This design made it possible to work with three types of targets—aluminum, carbon, and their combination with a chosen area ratio.

A comparison of the radioactivity induced in the targets makes it possible to estimate the effective hardness of the beam and its power. These measurements are carried out already after the discharge, thus ensuring stability of the method with respect to noise accompanying the discharge. The strong difference between the rates of decay of Al^{28} and N^{13} makes it possible to determine with sufficient accuracy, by expanding the sum of the exponentials, the values of $P_{Al^{28}}$ and $P_{N^{13}}$, which are proportional to the initial number of atoms of each element. This method of comparative activation of two targets, which yields the information rapidly, was used to determine discharge regimes accompanied by generation of strong-current deuteron beams. A procedure similar to that

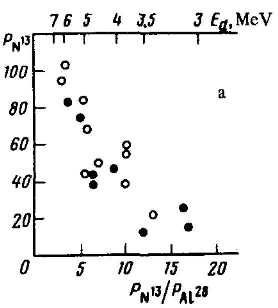

FIG. 2. Comparison of the method of activation of two targets with the activation-flight method.

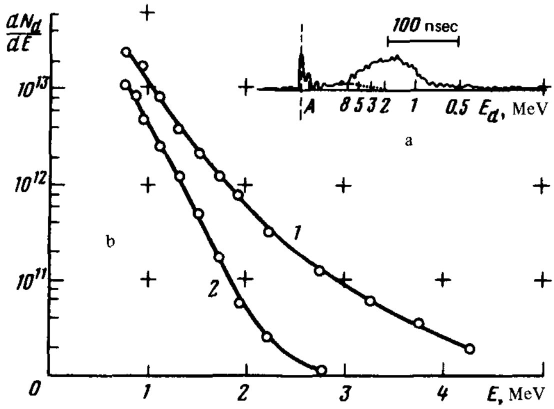

FIG. 3. Oscillogram of neutron pulse from the reaction (a) and typical spectra of fast deuterons (b).

described here was used for a similar purpose earlier at the Livermore Laboratory. Figure 2 (light circles) shows for a group of 10 discharges with strongly differing radioactivities of the targets, the dependence of the ratio $P_{N^{13}}/P_{Al^{28}}$ on the value of $P_{N^{13}}$. The upper scale is the energy of the equivalent monochromatic deuteron beam in MeV, for which the ratio of the corresponding reactions should have yielded the given ratio of the induced activities.[2] It is seen that when the absolute value of the target activity is increased, the energy of the accelerated deuterons is increased (up to 7—8 MeV).

Absolute calibration of the apparatus was carried out to determine the efficiency of the measurements of the lack of activity of the targets. The calibration was carried out with the aid of a standard β emitter (Au^{198} foil) and made it possible to determine the total number of radioactive nuclei N^{13} and Al^{28} produced under the influence of the deuteron beam.

To obtain the time characteristics of the beam (the instant of the appearance of accelerated deuterons, the duration of the generation, the spectral composition) we used the analysis of the neutron radiation produced when deuterons interact with a carbon target. A photomultiplier (7, Fig. 1) with an organic scintillator was placed inside a collimating unit of polyethylene and registered the pulse of neutron radiation from the target under conditions that ensure (with the aid of screens 9 and 10) a lowering of the background due to the neutrons from the PF and to the hard radiation produced in the discharge.

A number of preliminary experiments, particularly experiments in which the distance S from the anode to the cathode was varied, revealed that the instant at which the high-energy deuterons are produced coincides with the instant when the EB is generated, and the generation time does not exceed 10—15 nsec.

Figure 3 shows a typical oscillogram of a neutron pulse produced by a carbon target measuring 6×8 cm after incidence of a beam of fast neutrons that have traveled 150 cm from the point of generation. The figure shows also the scale of the deuteron energy E_D, corresponding to each section of the pulse dN_n/dt. Knowing the effectiveness of the nuclear reactions on carbon as a function of E_d, we calculated from the oscillogram shown in Fig. 2a the energy distribution of the deuterons in the beam (1, Fig. 2b). We calculated analogously the spectral distributions of the deuterons for discharges that differ strongly in the measured value $P_{N^{13}}$. All the obtained distributions turned out to lie between the curves 1 and 2 (Fig. 3b). The curve shown in Fig. 3b was used to calculated the aluminum-target activity that whould be produced by bombardment with a deuteron beam having the same composition. The obtained calculated ratio $P_{N^{13}}/P_{Al^{28}}$ is shown by the dark circles on the plot with the experimental values (Fig. 2). Both groups show a similar dependence of the ratio of the activities on the absolute value of $P_{N^{13}}$, with equality of the calculated and measured values of this ratio. We see therefore that the use of the method of comparitive activation of combined targets for the analysis of non-monochromatic beams singles out the "hard" part of the spectrum and by the same token overestimates the average energy of the particles in the beam. However, this method is useful in exploratory experiments aimed at optimizing the design and operating regimes of the apparatus.

The application of the developed procedures to the analysis of deuteron beams produced in regimes with "runaway" of the current sheath has made it possible to establish the following parameters of the hard component of the beam.

1. The duration of the generation of high-energy deuterons ($E_d > 0.7$ MeV) is 10—15 nsec.

2. The beam has a broad spectral distribution extending up to 5—8 MeV.

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