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Study DD-Neutrons in the Experiments on S-300 Pulsed Power Machine

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1. INTRODUCTION

Z-pinch discharges with deuterium in the load have been investigated as the source of neutrons. The deuterium has been used in the loads in different forms. The results with cryogenic deuterium or deuterized fibre with small diameter were presented e.g. in [1,2], the results with deuterium as the gas filling in the plasma focus devices were reported in [3-6], the compression of the deuterized plasma by the implosion of the symmetric wire array was described in [7] and the gas-puff configuration was studied in [8,9].

In spite of these activities and 50-years long research, the mechanism of high-energy electron and deuteron acceleration in z-pinches as well as the fusion reaction mechanisms are still under discussion.

2. EXPERIMENTAL SETUP

The experiments described in this paper were performed on the S-300 generator at the Kurchatov Institute in Moscow at a peak current of 3 MA with a rise time of about 100 ns [10]. The z-pinch load was formed from a deuterated $(CD_2)_n$ fibre of 100 μm diameter in the axis of an tungsten wire array of 60 wires with mass of 160 μg and 1 cm in diameter and in length.

A comprehensive information about the plasma behavior was obtained by a set of diagnostics positioned axially and side-on: visible photography with a streak camera, pinhole camera with the gated soft x-ray microchannel-plate detector (MCP) divided into 4 frames, shadow diagnostics (5 laser beams each 1 ns duration, 10 ns time separation), detector of Cerenkov radiation of fast electrons with energy above 50 and below 400 keV, 5-channel calibrated polychromator (VUV and XUV) with temporal resolving PIN detectors. 5 scintillation probes with photomultipliers were used for detailed time-resolved measurements of the hard X-ray above 100 keV and the neutron emission situated axially (at distances of 2.55 m and 7.42 m behind the cathode and at a distance of 2.55 m behind the anode) and side-on (at distances 2.95 m and 8.10 m) and indium-activation counter for estimation of the total neutron yield supposing isotropy distribution in the 4π solid angle.

3. EXPETIMENTAL AND SIMULATION RESULTS

The presented results were obtained from the detail analysis of the signals recorded mainly in the shot No. 0506082 with the total neutron yield amounting $2x10^9$. The time of neutron production was calculated using M-C simulations and the time-of-flight method supposing the Gaussian distribution of neutron energies and time of emission.

In Fig.1 (traces 1-4) one can see the signals of the current, voltage, fast electrons and hard X-rays.

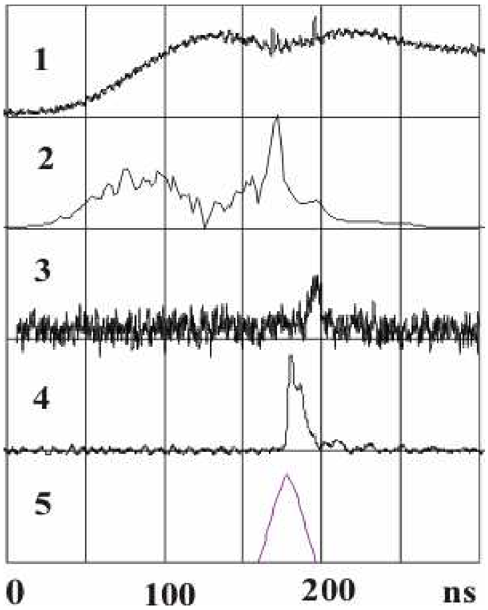
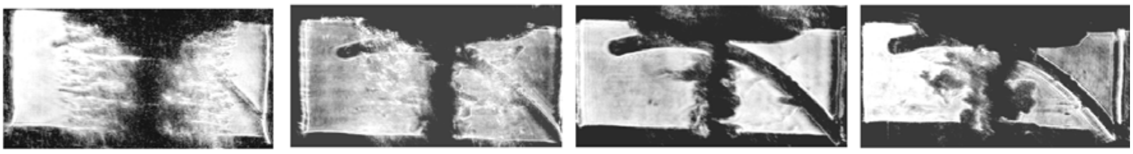


Fig. 1: Traces recorded in the shot No. 0506082: 1 – current, 2 – voltage, 3 – fast electrons above 50 keV detected axially behind the anode, 4 – hard X-rays above 100 keV, 5 – time of production of neutrons calculated using time-of-flight and MC methods.

The waveform of the discharge current shows a dip. The minimum of the dip of the current signal occurred in this shot 172 ns after the start of the discharge current (Fig.1, trace 1). This time correlates with the peak of voltage (trace 2) and minimum diameter of the pinch Fig. 2b. The fast electrons and hard X rays were emitted after the dip of the current and peak of the voltage. The high energy electrons were released from the pinch in the short range of 180 – 200 ns. These electrons with energies of 50-400 keV were recorded only in the z-direction behind the anode and only in some discharges. In other shots with detectors located axially behind the anode or side-on, the electron signals were in the level of noise. The electrons with these energies were probably confined by internal magnetic field with force lines oriented perpendicularly to the position of detectors, they could not escape the plasma and their energy might be continuously transformed into X-rays. The hard X-rays above hundreds keV showed very sharp increase of a few ns and the short FWHM of 15 ns. The temporal dependence of hard X-ray signals was very similar in all three investigated directions.



a 162 ns b 172 ns c 182 ns d 192 ns

Fig. 2: Temporal evolution of the pinch phase imaged with laser diagnostic beam.

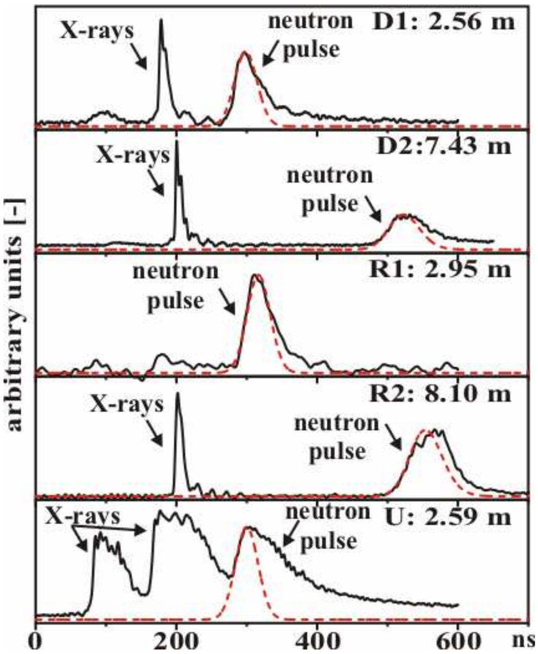


Fig. 3: The comparison of calculated (red) and measured neutron (black) signals detected behind the cathode (D), anode (U) and side-on (R).

The laser shadow beams in Fig. 2 recorded the pinch evolution: a - the final phase of implosion, b – phase of minimal diameter at the time of dip of current and maximum of the voltage, c and d – phase of development of instabilities. The arcade in the figures is the image of the cable situated behind the plasma (it was left in the chamber at the load installation) and it served as a probe of the opacity of the laser beam in wavelength 532 nm. The shadows show that at the time after the pinch phase with minimal diameter, the plasma of the liner has the density above the critical value with sharp decrease at the surface. The deuterium ions comprised only in 10% of the total ion mass and 30% of the particles in the pinch.

5 scintillation detectors (in three different directions, one radial and two axial) represent a low number for application of the time-of-light methods to determine a temporal distribution of neutron energy. Nevertheless, one can estimate some important qualities supposing two independent Gaussian distributions, namely neutron energy distribution with the maximum of 2.45 MeV and the time of neutron production. In this case, the FWHM of signals is the sum of the FWHM of the time (which is constant at different distances from the neutron source) and the FWHM given by neutron energy range (which is increasing with the detector distance from the source). Then it is possible to evaluate a contribution of each component and to calculate the time of neutron generation. This value was optimized in order to fit recorded signals. Because scattered and reflected neutrons could play an important role, we took into account in particular the increase and the peak of the neutron pulses where the influence of scattered neutrons is the lowest. The calculated parameters of neutron signals, the energy of 2.45 ± 0.23 MeV and the time of production of 181 ± 15 ns, are imaged. One can see that the

hard X-ray, fast electron and neutron emission culminated after the dip of the current. The comparison of calculated and recorded signals is shown in Fig. 3. The calculated values are the same for signals in all directions of detectors and covered 90% of surface of the signals. The rest 10 % is supposed to correspond to both (i) the deviation of the peak of the energy maximum and (ii) the scattered, reflected and moderated neutrons. The wide FWHM of the signal detected side-on was influenced by saturation of the photomultiplier supplied with a high voltage.

4. CONCLUSION

The z-pinch liner implosion toward the deuterated $(CD_2)_n$ fibre on the S-300 facility produced the neutrons with energy distribution of 2.45 ± 0.23 MeV in both axial and one side-on directions at the time of 181 ± 15 ns. The independent Gaussian distributions of energy spectra and the time of production were supposed. The hard X-rays with energies above hundreds of keV, fast electrons with energies 50-400 keV and neutrons were registered after the pinch phase at the time of plasma expansion.

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