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PLASMA FOCUS EXPERIMENT IN YUGOSLAVIA

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1. INTRODUCTION

Getting energy from the fission and fusion was achieved immediately after the II World War in destructive purposes ("atomic and hydrogen bomb") through the uncontrollable spreading of fission and fusion reactions. Controlled fission was achieved in nuclear reactors and the same is trying with thermonuclear reaction. Medium in which it can be realized is plasma, the fourth state of the matter in which 99,99% of the substances in Cosmos are created. The Sun, our nearest star, as well as all the other stars, is also in this state. As is known, in classic fuel, energy received from the Sun is synthesized through the energy that all living beings on our planet were sustained. With civilization development the reserves of that classic fuel will be spent (coal, oil, land gas, wood ...) faster then they will be repaired on natural way. Because of that it was necessary to find some more reliable source of energy. Electric energy from the hydrosystem is not enough for the energy derivation in quantity that human race needs today and it specially will not be enough in the imminent future.

Nuclear centers took very important part in one period. But keeping in mind limited reserves of uranium 235, and specially the coastlines of the method for natural uranium enriching with uranium 235, and the risk of radioactive residues from the exploited nuclear power stations, necessity for contrivance of more suitable energy resource was imposed. The chosen way was constructing of fusion machines where the fusion of light elements such as deuterium and tritium, deuterium and helium, hydrogen and boron etc. would be controlled in the plasma as a medium.

Today in the world prevails intention to chasten thermonuclear fusion in laboratory because it is considered for the basic energy creation process in all stars.

To obtain impacts in the plasma, leading to the fusion of light elements (e.g. deuterium and tritium), plasma must be heated over 100 000 000 K so that nucleus of light particles could be close enough to allow attraction prevailing the force of rejection. In this attraction the first creating intermediate state is one unstable nucleus and after that, in example of deuterium and tritium, there is an α particle and one neutron of high energy emitted, with releasing energy of 17,6 MeV:

$$D + T \rightarrow {}^4He + n + 17{,}6\ MeV \qquad (1)$$

This kind of plasma should be confined on high temperatures long enough to give more energy from the nuclear fusion than it is spent on the nuclear fusion. It is possible to be done with a fusion reactor that use deuterium from natural water as a fuel. Tritium will be created in reactor coating made of lithium after the neutron being captured from D,D reaction according to the following way:

$$^{6}Li + n \rightarrow {}^{4}He + T + 4{,}8\ MeV$$
$$^{7}Li + n \rightarrow {}^{4}He + T - 2{,}5\ MeV \qquad (2)$$

Returning the tritium created in a such way, the cycle has been closed and we can write it symbolically as a reaction:

$$D + {}^{6}Li \rightarrow 2\,{}^{4}He + energy \qquad (3)$$

The plasma can be confined in three ways, as it is known: gravitational, magnetic and inertial. Plasma in stars is confined by gravitational field. In laboratory conditions plasma is confined by magnetic field or inertialy. So far it has found that a most successful devices for magnetic confinement of plasma were tokamaks, stelerator and inverse pinches (so called closed systems), and magnetic mirrors and plasma focuses (open systems). Among all these devices, the best results achieved until now with different kinds of tokamaks are (JET in Culham, PLT and TFTR in Prinston, T-20 in Russia, JT-60 in Japan and ASDEX in Garhing). In experiments with inertial plasma confinement the most successful devices are those in which with laser radiation shaped deuterium "ball" is irradiated homogeneously and symmetrically by all sides (up to 1% asymmetric radiation) so that reached e densities of D, are big enough to overcome Columb's barrier for starting their fusion. The best known experiments in USA are NOVA in LLNL, and in Russia "Dolphin" in FIAN. Several years ago in USA have started the building of the latest device under the name NIF (National Ignition Facility). That device will use 1,8 MJ, 500 tW, 0,35-μm laser system for investigation of possibility of economical inertial fusion reactor exploitation.

Joining to these researches, the Faculty of Physics and Institute of Physics with mutual efforts built deuterium plasma focus, that gives high value of neutron contribution, the positive charged particles, X-rays, optical and electromagnetic radiation, in impulsive mode.

2. EXPERIMENTAL SET UP AND RESULTS

The first experiment with a modified plasma focus device up to 2kJ input energy was performed in the Laboratory for plasma spectroscopy at Faculty of Physics, University of Belgrade, in 1985. Analysis of the propagation of the current sheet and collapse of the plasma was studied. (Fig.1.) (Purić et al., 1986).

The experiments on the model of plasma focus device in the connection with nuclear aspects, in 1989 were provided when D^{+} ions of the energy about 1 MeV were detected using the NTD (CR-39) detectors. (Antanasijević et al., 1991).

During the next several years the new plasma focus device was built and is given in Fig 2.

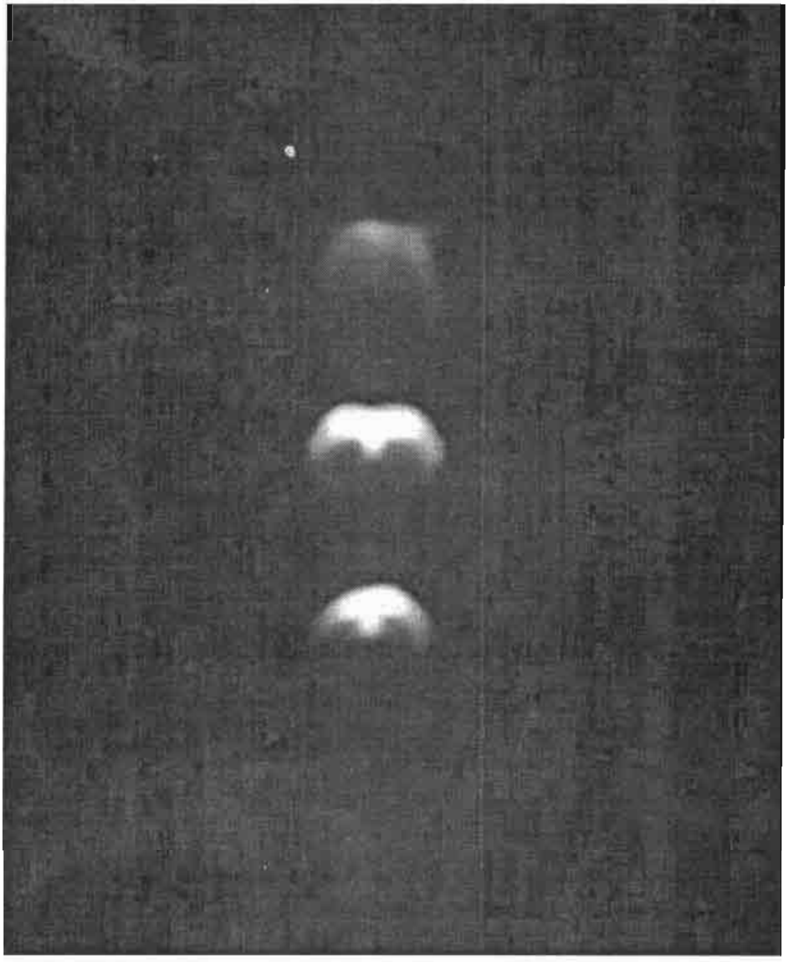

Fig. 1. p=1 Tor, time between snapshot 2 and 5 ns; f/22

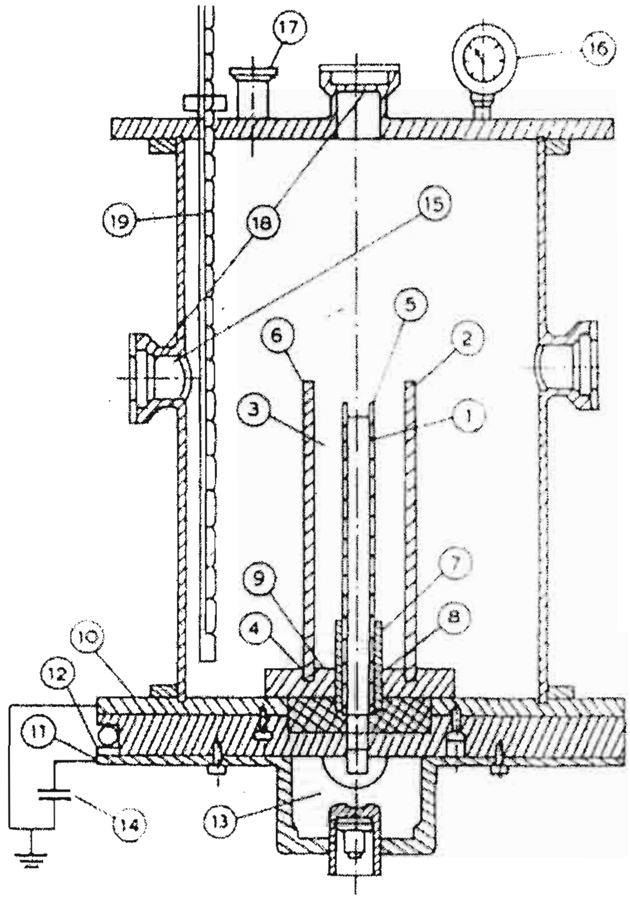

Fig. 2. Schematic sectional view of the plasma focus device. (1) Inner electrode; (2) outer electrode; (3) interelectrode gap; (4) breech wall; (5), (6) muzzle ends; (7) insulator sleeve; (8) field distortion element; (9) cylindrical brass knife edge; (10), (11) breech brass plates; (12) insulator layer; (13) switch; (14) power supply; (15) optical window flanges; (16) pressure control; (17) vacuum pump flange; (18) CR-39 or CA 80-15 with Al pinhole (diameter 1 mm); (19) optic cables, proportion: 1:3.

The plasma focus chamber is the Mather type and consist of two brass coaxial electrodes (the outer electrode consist of 9-18 cylindrically positioned brass roads). The chamber has been designed for current up to 1 MA and 10^{10} n/pulse.

For producing electrical discharges with a current up to 1MA and rise time at 1μs, a low inductance capacitor bank (C=45μF, L=62nH, R=15mΩ, M_{max}=40kV, E_{max}=36kJ) with triggered spark gap as a switching device is used as an energy source with a power supply and two coaxial electrodes.

The voltage measurement was performed with high voltage probes. A Rogovski coil monitoring the variations with time of electrode current was used.

Acceleration of the plasma focus current sheet has been measured using an appropriate photodiode with optic cables "looking" at certain spots inside the chamber (the item 19. on the Fig. 2).

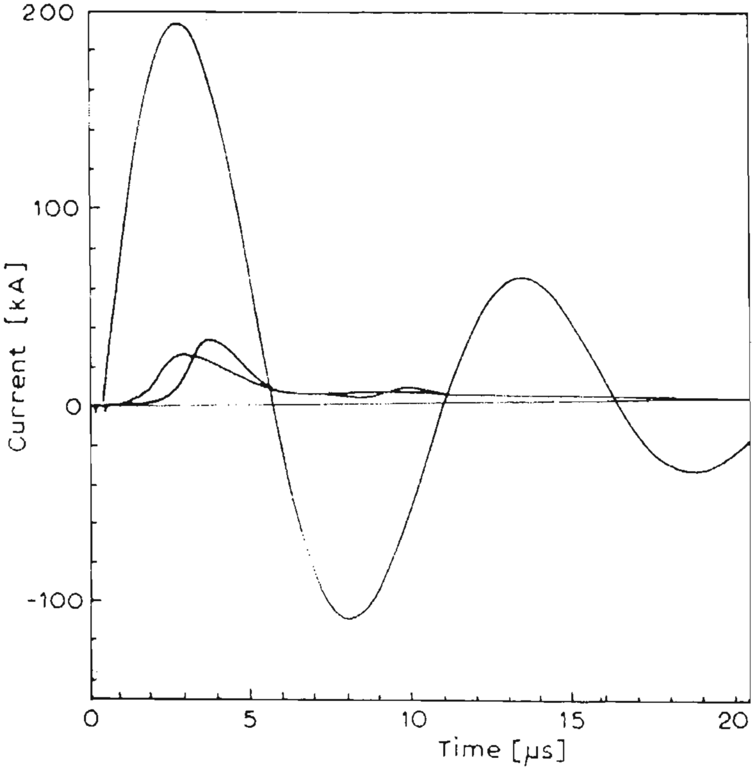

Fig. 3. PF current and photodiode signals (8 and 11 cm signals).
$V = 9.2$ kV, $P_0 = 1.3$ mbar, $V_{ex} = 2$ cm/μs.

In Fig. 3 the corresponding current and photodiode signals at 8 and 11cm position on the length of the inner electrode are given. The time of reaching the maximal value of the current has to correspond to the time of the current sheet coming to the top of the electrode.

For neutron yield measurements a large (600 *l*) liquid scinttilator (NE 343) surrounded with 12 photomultipliers with efficiency of 80% for unique neutron was used. (Fig. 4). (Antanasijević, R., et al., 1993).

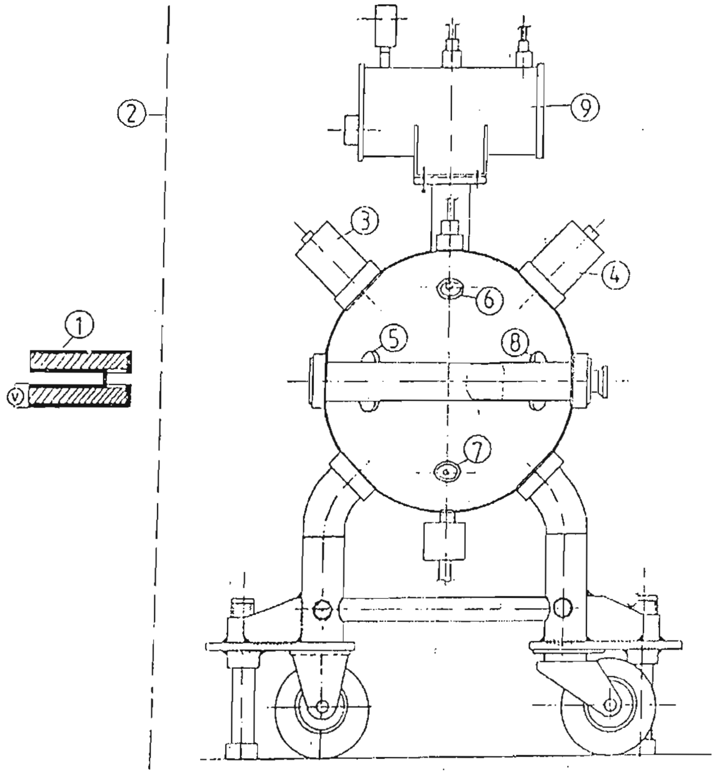

Fig. 4. The large volume gadolinium loaded liquid scintillator detector: 1 – plasma focus chamber, 2 – electromagnetic shield, (3 – 8) – photomultipliers and 9 – expansion tank.

Calibration of the detector using the ^{252}Cf placed in the center of the detector is shown on the Fig.5.

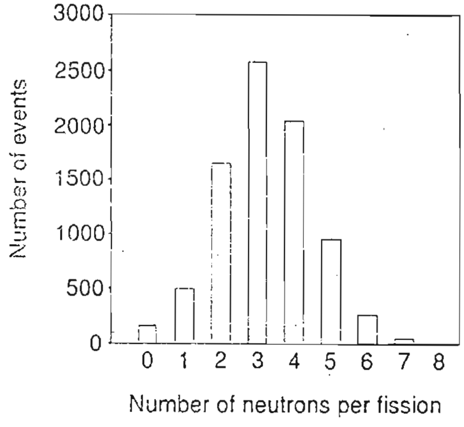

Fig. 5. Calibration of the scintilation detector with ^{252}Cf.

Plasma focus current and neutron yield are shown on the Fig. 6.

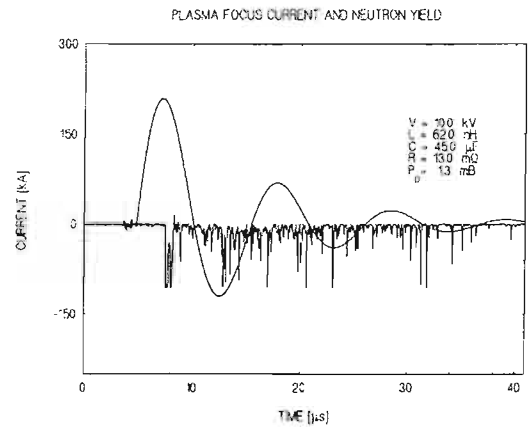

Fig.6. Plasma focus current and neutron yield.

Comparison of the neutron yield on the our PF with corresponding value obtained in the other laboratories is given in Fig.7.

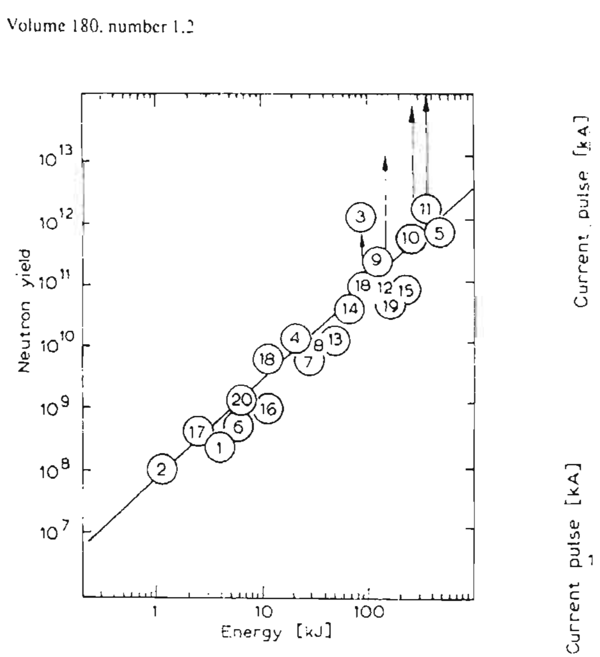

Fig.7. Our results on international scale. (1) Bucharest; (2) Darmstadt; (3) Düsseldorf; (4) El Sequndo; (5) Frascati; (6) Hoboken; (7) Jülich; (8) Langley; (9) Livermore; (10) Limeil; (11) Los Alamos; (12) Moscow; (13) Osaka; (14) Sandia; (15) Stuttgart; (16) Sukhurni; (17) Tokio; (18) Urbana; (19) Warsaw; (20) Zemun.

Device is designed so that we have 8 windows on the plasma focus chamber and we can investigate different processes during the single shot. Namely we can measure the number density of the:

a) positive particles produced from D-D reactions and its discrimination using the NTD (NC and CR-39), (Antanasijević et al., 1997) and Al foil of different thickness, (Vuković and Antanasijević, 1995). In the D-D fusion reactions ^{3}He, ^{2}H and ^{1}H as well as the neutrons are emitted. In the case of the appearance of the secondary reactions D+^{3}He, ^{4}He ions are also produced;

b) produced X-ray using appropriate "optics" based on the mica sheet where it was found that in the case of the used gases with low Z (^{1}H, ^{2}H) only the soft X-rays are emitted and it was found that the X-ray energy emitted from the PF depends only on the Z of the working gas (Fig.8.);

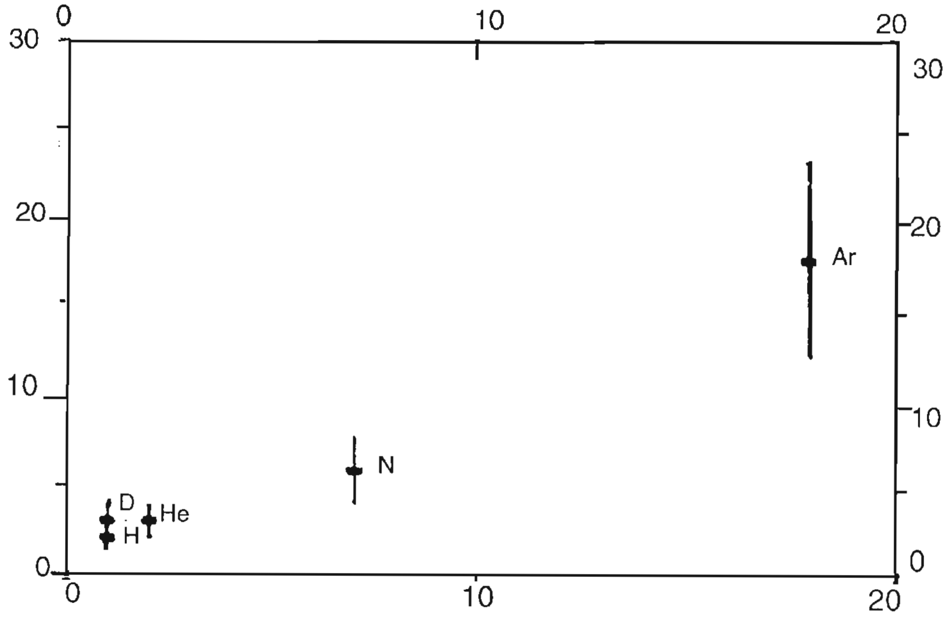

Fig.8. X-ray energy dependence on the gas atomic number Z.

c) angular distribution of deuterons and products of the D-D reactions (Antanasijević et al., 1996.), and was found that the angular distributions of the ^{4}He and X-ray are the isotopic; only the ^{2}H have the maximum distribution above the central electrode and,

d) to study the electromagnetic interference influence on the current profile; the maximum discharging current up to 640 rA was achieved so far, although using the same condenser battery was possible to achieve the current up to 1 MA; it was shown that there was no current interrupting, but electromagnetic interference influence on the current profile during the plasma focus collapse phase (Šević, et al., 1998), (Fig.9.)

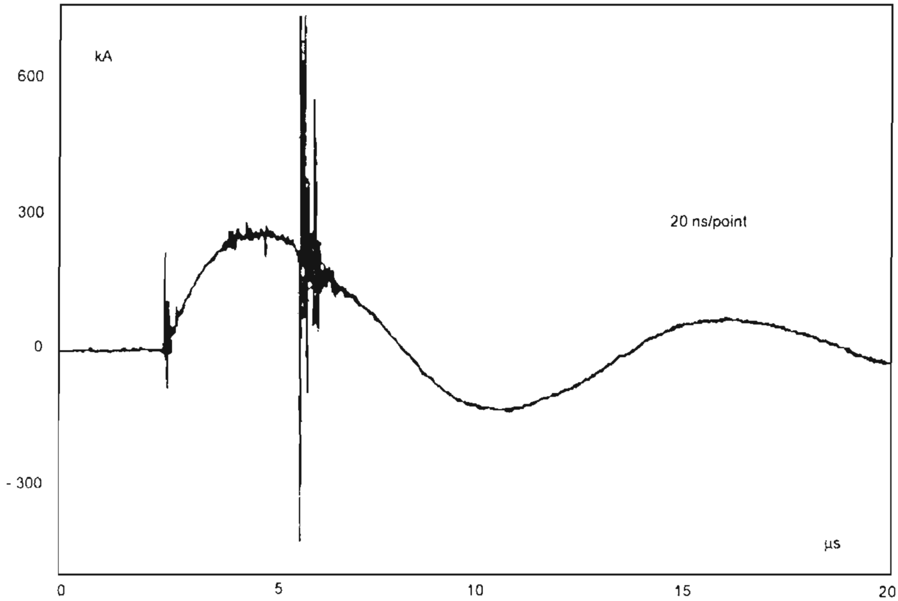

Fig.9. PF Current Signal

Finally, during this year, two new corresponding channels have been mounted on the appropriate windows, for optical measurements with spectrograph and X-ray radiography with soft X-ray. Also, a small liquid detector (NE 343) of 12 l volume for neutron angular distribution measurement from D-D reactions was completed.

Although the plasma focus experiment can be regarded as the simplest of all the fusion approaches based on self-magnetic field confinement there are a lot of unresolved problems intrinsic to such an approach. For instance, the plasma focus is considered as an impedance converter, which gives a fast rising high current at the final pinch phase. In spite of this, it is questionable whether the plasma focus depends or whether the leakage current, which increases with he discharge energy, is intrinsic in the plasma focus device. We have tried to analyze the process of selforganisation in the collapse phase of the plasma focus operation in which the neutrons begin to be emitted if the working gas is deuterium. Therefore the role of the radiation collapse in the plasma focus device and theoretical explanations to the scaling law obtained experimentally is still very important subjects to be studied (Miyamoto, 1996).

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