DD PRODUCT YIELD IN THE GDT CENTRAL CELL

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The report presents the recent results of experiments with deuterium neutral beam injection in the Gas Dynamic Trap (GDT) device. Neutron scintillation detector and single particle proton detector near fast ions mirror point allow to control DD activity in each shot. A system for spatial measurements of fusion protons is prepared. DD reaction yield measurements are needed to compare with the predictions of the theory based on two-body Coulomb collisions.

I. INTRODUCTION

Experiments with plasma heated by deuterium beams are carried out in the Gas Dynamic Trap (GDT) to simulate the fusion reaction intensity in the project 14 MeV neutron source based on GDT [1]. This project is developed for fusion materials testing. GDT is a long axially symmetric plasma confinement device with the high mirror ratio. The GDT plasma consists of two components. The first component is collisional target hydrogen or deuterium plasma with the electron temperature about 200 eV and density up to $5 \cdot 10^{19}$ m^{-3} . This thermal plasma is confined in a collisional regime that is characterized by the condition that a mirror-to-mirror distance considerably exceeds the effective ion mean free path of scattering into the loss cone. The second component is fast ions with mean energy of ~10 keV and density up to $5 \cdot 10^{19}$ m^{-3}. This component is produced by oblique neutral beam injection at the midplane of the device. These strongly anisotropic fast ions are confined in collisionless regime.

According to the estimates which involve classical mechanisms only, the fast ion relaxation in the target plasma of GDT neutron source is to be dominated by electron drag and therefore, their pitch-angle distribution remains quite narrow. As a result, the fast ion density has strong maximum near the turning points where longitudinal velocities of fast ions are close to zero. In case of deuterium neutral beam injection this effect increases neutron yield within those regions, which house the test zones in the prospective GDT-based neutron source (GDT-NS) (in which the injection of deuterium and tritium neutral beams is suggested). This picked axial profile of the fusion reactions intensity is the distinguishing features of the projecting neutron source.

There are two branches of the DD reaction:

$$D+D\begin{array}{l}\xrightarrow{50\%} T(1.01MeV)+p(3.02MeV)\\ \xrightarrow{50\%} He^{3}(0.82MeV)+n(2.45MeV)\end{array}$$

Usually 2.45 MeV neutron flux are measured, but 3.02 MeV proton flux measurement has some advantages. The difference in the DD product fluxes is less than 2 %. The measurements can supplement each other. DD product yield measurements are used for comparison between the experimental results and the theoretical predictions. It is important to prove that fast ion relaxation and scattering are basically determined by two−body Coulomb collisions. Here we present the results of recent experiments with increased magnetic field and improved injection system.

II. EXPERIMENTAL SETUP

The GDT device (fig. 1) comprises the central cell and two end cells. The mirror-to-mirror distance is 7 m, magnetic field at midplane was increased to 0.33 T (for most experiments), and a typical mirror ratio is about 40. The deuterium target plasma was produced by the plasma gun located in one of the end cells. In this experiment eight new injectors with the focused beams are used. The duration of the beam injection was increased up to 5 ms, energies of the injected particles were increased up to 25 keV, total beams power was about 5 MW. Neutral beam injectors were used for plasma heating and fast ions build-up. A material balance is supplied by extra gas injection near the magnetic plug with using gas-puffing system. MHD stability provides by differential rotation of edge plasma which is caused potential (300 V) between the plasma dump and limiter. Titanium evaporators provide vacuum condition.

To detect the product yield of the DD synthesis near the turning point of fast ions was used two detectors. The first detector is organic scintillator combined with a photo multiplier tube (PMT). Using the PMT of the “fine mesh” type (Hamamatsu) enabled to locate the photo multiplier

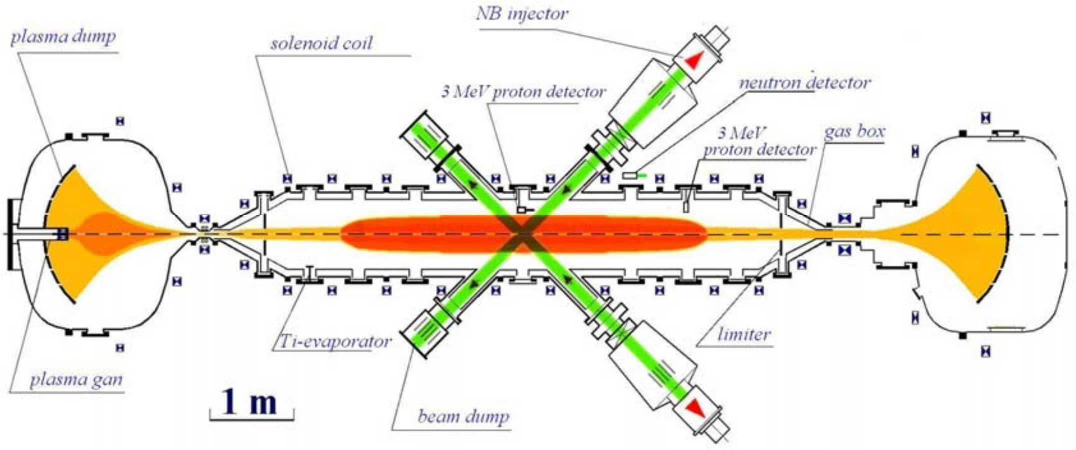

Fig. 1.The GDT layout.

tube in a magnetic field as strong as 1.5 T. This PMT can operate when located at an angle of up to 30º with the magnetic field lines. This detector was outside the vacuum chamber and used for registration time evolution of 2.45 MeV neutron flux. The second detector is a special counter based on PIN diode with sensitive area 0.5 cm^2 and the current preamplifier. It was installed inside the vacuum vessel on radius 23 cm. Detector is sensitive to protons and insensitive to neutrons and magnetic field. The magnetic field in GDT forces on trajectory of proton, but the gyroradius of a 3 MeV proton in 0.66 T magnetic field is 38 cm and this effect easy to take into account. The entrance window was protected by the 10 μm aluminum foil. Single 3 MeV protons were registered as 35 ns pulses. The average amplitude of the pulse corresponded to the 4 μA diode current. The single-particle counting regime permits to measure absolute 3 MeV proton flux. The ADC824a used allows to record 131 K points with the step 5 ns. One ADC allows to measure within 0.65 ms. Data of both detectors control DD product linear yield (number of DD reactions produced by 1 cm length of the plasma column) in maximum point during all shot. To calculate all DD product yield we used typical axial profile now [2].

A new 3 MeV protons detector was prepared for more detailed longitudinal distribution measurements. The detector has PIN diode with sensitive area 3.1 cm^2, current preamplifier and collimator to provide sufficient spatial resolution. It was installed inside the vacuum chamber. Design of detector allows shift it in four different positions in each port. The detector can be installed in one of the four upper GDT ports which required venting the device to air. So it is possible to get longitudinal distribution of proton flux in series of shots.

The perpendicular scanning of the 3 MeV proton flux in the fast ion mirror point was produced by the detector based on scintillator and PMT [2].

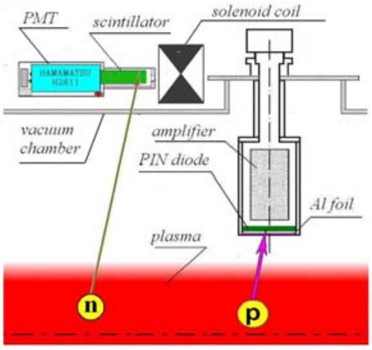

Fig. 2. System of 2.45 MeV neutron and 3.02 MeV proton detectors.

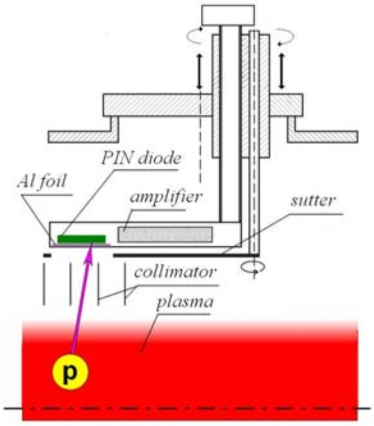

Fig. 3. Layout of 3 MeV proton detector for axial profile measurement.

Other GDT diagnostics were also used in the DD experiments to provide the data for comparison to the numerical simulations discussed below. The trapped neutral beam power was derived from the neutral beam attenuation detector data. The energy contents in the fast ions and target plasma were measured by an array of diamagnetic loops. Thomson scattering system based on a Nd laser was used to measure the radial profiles of electron temperature and density. Dispersion interferometer was used of linear density measurements.

III. EXPERIMENTAL RESULTS

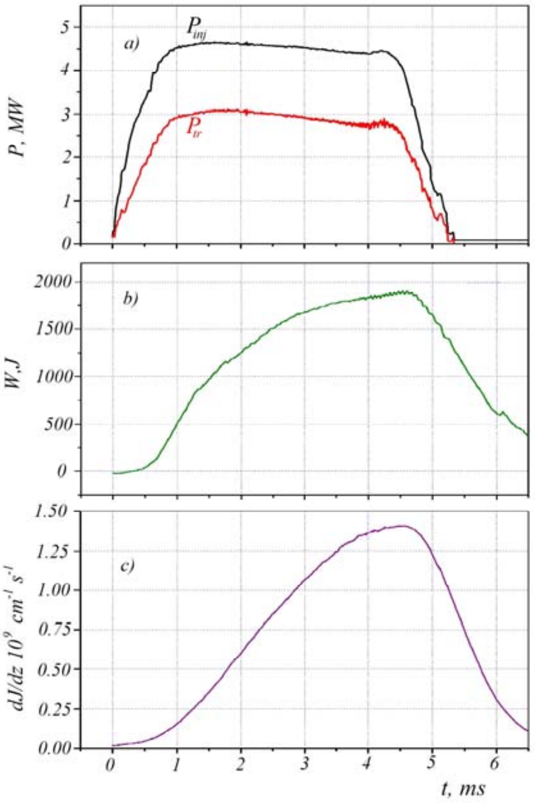

Fig. 4. Time evolution:
a) Injected (P_{inj}) and trapped (P_{tr}) NBI power
b) Fast ion energy content
c) Linear DD yield near fast ion the mirror point.

The trapped NBI power, fast ion energy content and DD reaction yield were controlled in each shot now. It was significant for optimization of the operating regime at GDT. Only fast ion energy content was not enough because of effects of the radial fast ion centre distribution and energy distribution. Typical oscillograms are presented in fig. 4. The maximal DD reaction yield presented on the fig.4(c) was measured by detector by 3 MeV proton detector installed at the position near fast ion mirror point (Z=173 cm).

The growth of neutral beam injection power, increasing the magnetic field and the optimization of the operating regime at GDT has led to the significant enhancement of DD reaction products flux. Near the mirror point the maximum linear DD reaction yield was $1.6{\cdot}10^9$ s^{-1} cm^{-1}, maximum neutron flux was $3{\cdot}10^{11}$ s^{-1}. GDT generates 10^9 neutrons per shot in experiments with deuterium injection and deuterium target plasma. This calculation used the previous axial distribution DD reaction yield [2]. The detailed axial distribution for new regime will be measured later.

The result of perpendicular scanning of the 3 MeV proton flux in the fast ion mirror point is presented in fig. 5.

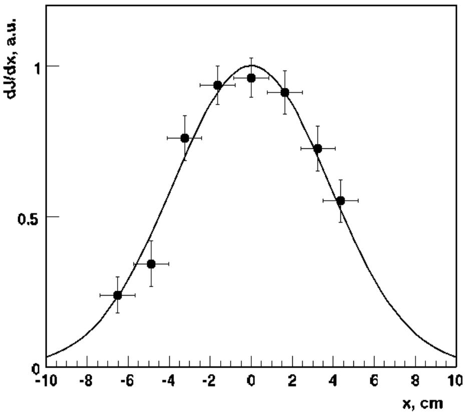

Fig. 5. Perpendicular profile of DD reaction yield in the fast ion mirror point.

IV. CONCLUSIONS

Analysis of DD reaction yield and diamagnetism of fast ions in the experiments with deuterium and hydrogen target plasma shows that fast ions collisions are defined with DD reactions. Fusion reactions between fast component and target plasma give low contribution into total number of reactions in comparison with previous experiments.

Presented results and detailed axial distribution will be compared with results of numerical simulation.

ACKNOWLEDGMENTS

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