*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-1.108 (2006)*

ITER RELATED MATERIALS STUDIES.

E.P.Kruglyakov A.V.Burdakov, A.A.Ivanov

Budker Institute of Nuclear Physics. 630090, Novosibirsk, Russia

Fusion program assumes end-of-life testing of all structural materials for future fusion reactor. Either resistance to irradiation by 14 MeV neutrons and stability of material properties under bombardment by power plasma fluxes should be studied. One of the confinement systems discussed below, namely, gas dynamic trap (GDT) has a good perspective as a volumetric neutron source. Multi-mirror trap GOL-3 operating in the Budker Institute even with present-day plasma parameters can be useful for studying plasma - wall interaction in the ITER divertor in any regimes of operations including ELMs, disruptions, etc.

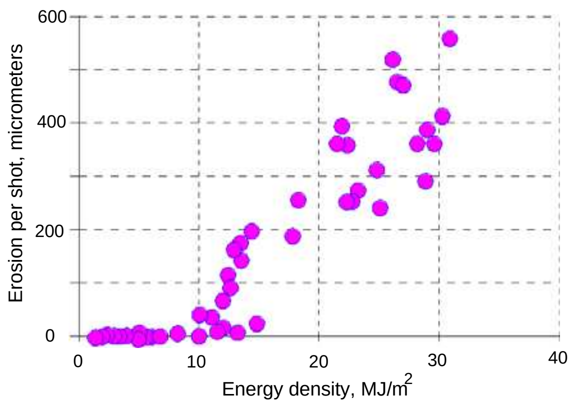

Fig.1 The erosion depth of the graphite vs energy density

Multi-mirror system GOL-3. The facility consists of 12 meter long solenoid with corrugated magnetic field (55 mirror cells with mirror ratio B_{max}/B_{min} = 4.8/3/2 T). High current relativistic electron beam with energy E_b = 1 MeV, current I_b =30 kA, and duration $t_b \approx 8\cdot10^{-6}$s injected through one of the ends to heat the plasma. Two important phenomena were discovered recently [1]. Firstly, strong suppression of electron heat conductivity was observed due to excitation of plasma micro turbulence. This effect leads to heating of plasma electrons up to T_e=2 keV in a dense ($n_e \sim 10^{21} m^{-3}$) plasma. Additionally, in the case of multi-mirror configuration of the magnetic field fast ion heating up to ~2 keV was observed within ten microseconds after the REB switching off. Conceivable mechanism of the ion heating is connected with strongly non-homogeneous electron heating along the axis. The most strong heating of plasma electrons takes place in the mirror throats where the REB current density is the highest. Consequently, the electron pressure here is maximal. This results in development of very steep pressure gradients which cause plasma acceleration. Expansion of these hot electron clouds together with ions produce the counter streams of plasma with subsequent conversion of their directed energy into the ion heating.

Plasma – wall interaction. High power plasma stream flowing out the ends of the GOL-3 solenoid has been already used in the ITER-related studies of plasma interaction with carbon materials [2]. The energy density in the pulse incident upon the targets was varied in the range of 0.5-50 MJ/m^2 that is similar to conditions of ITER ELM events. The presence of high-energy electrons together with Maxwellian ones in the GOL-3 enables to simulate the sample preheating up to ~ 1500^0K. It was shown that regimes with large erosion of the protective material (graphite, carbon fiber composite, etc) and dust particles formation are possible. It was experimentally shown that irradiation of the graphite target by plasma stream together with high energy electrons can lead to a destruction of the target. Macroscopic explosive erosion of the target begins at the level of 10 MJ/m^2 (see Fig.1). Similar behavior of the other materials can be observed at these conditions.

One more experiment was carried out on expansion of cold plasma cloud through hot hydrogen (deuterium) plasma. Before REB injection a small carbon target (~2 mm in diameter) was placed by a pellet injector in the center of solenoid (Fig.2). The expansion of created carbon cloud was studied by absolutely calibrated diagnostics including CCD-camera with ICT, etc. Irradiation of the target by plasma stream with hot electrons leads to explosive erosion of the graphite and formation of vapor cloud mixed with dust particles.

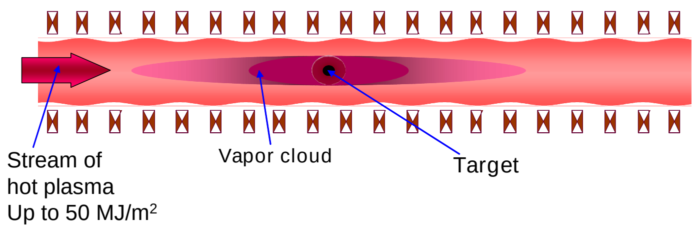

Fig.2 Scheme of the experiment of carbon pellet injection into GOL-3 device

Threshold of the volumetric graphite destruction (~10 kJ/g) was determined. It was observed that the vapor layer consists of graphite dust, vapor cloud and plasma corona. The conditions for long-lifetime operation of the graphite plasma dump were found. They corresponded to energy density ~1 MJ/m^2. Experiments on study of long-range carbon plasma propagation were carried out. At the distances up to 5 meters from the target there was not observed any significant transverse broadening of the carbon jet. Within 0.8-4.5 m from the pellet this plasma had a velocity of $(1\text{-}2)\cdot 10^4$ m/s at the distance 5 m.

Gas Dynamic Trap. A gas dynamic trap (GDT) for plasma confinement was first proposed in [3]. The experiments on study of the effects of gas dynamic plasma confinement are carried out on GDT device. The vacuum chamber of the GDT consists of a cylindrical central cell 7 meter long and 1 meter in diameter and two expander tanks attached at both ends. The device has an axisymmetric magnetic field configuration. Plasma radius at the midplane is 8-15 cm, plasma density is $3\text{-}20\cdot10^{19}$ m^{-3}, electron temperature after neutral beam injection is about 100 eV, magnetic field in the mirrors is up to 15 T, and at the midplane is 0.22 T. At present, the beam energy is 15-17 keV, total injection power is up to 4 MW, and the beam duration is 1.1 ms. The experiments on the GDT device have already enabled to obtain several principal results. In particular, it was shown, that even in the case of axially symmetric magnetic system MHD-stable plasma can be provided [4]. Besides, the most critical issues related to the problem of high electron heat losses due to direct plasma contact with the end wall was solved experimentally. As experiments have shown, if expansion of the magnetic field lines is large, i.e. $B_m/B_w >$ sqrt(M/m) (here B_m is the magnetic field at the end mirror and B_w is that at the wall) the electron temperature in the trap is not sensitive to the value of ratio B_m/B_w. In opposite case when $B_m/B_w <$ sqrt(M/m), the electron temperature significantly reduces due to the large heat losses to the end wall. This result is in a good agreement with the theory.

GDT based neutron source. An idea of a 14 MeV neutron source on the basis of GDT was proposed in [5]. After that the concept was revised (see, for instance, [6]. At present, the parameters of such a source are as follows. Primary neutron flux density is 2 MW/m^2 or 10^{18} neutrons /cm$^2\cdot$s, test zone size is 1m^2, maximum magnetic field strength is 13 T. These parameters are chosen to to make the source simpler and cheaper and, from the other hand, to meet the requirements of fusion materials testing.

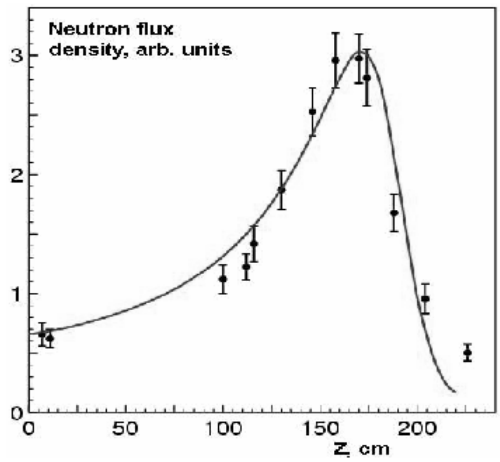

Fig.3 Axial profile of D-D neutron flux in GDT

In the recent years, several neutron source projects have been proposed (see, for instance, [7]). Among them the GDT-based source seems to be the most attractive because of very moderate power (60MW) and tritium (150g per year) consumptions. The main idea of the neutron source on the basis of GDT involves an oblique injection of deuterium and tritium neutral beams with an energy of order of 100 keV into a ''warm'' collisional target plasma confined in the central solenoid. Injection of the neutral beams forms an anisotropic population of high energy ions with a density profile being strongly inhomogeneous along the system axis. The maxima of the fast ions density appear in the vicinities of turning points and the minimum – at the center of solenoid. The effect of neutron flux peaking was demonstrated in the experiments on the GDT [8] (see Fig.3) with injection of deuterium neutral beams.

One of the most important parameters of the neutron source is the electron temperature which determines the fast ion losses. At the moment, it amounts to ~100 eV, which is quite far from that required for full-scale neutron source. According to simulations, an increase of T_e up to 300 eV would make feasible the neutron source with the flux of 0.5 MW/m^2. To demonstrate feasibility of this "moderate flux" neutron source, at least from physical point of view, the program of the GDT upgrade was initiated. The simulations have shown, that six new NB injectors with total power of 10 MW would increase T_e up to 300 eV. It is worthwhile to note that during 5 milliseconds injection a steady state regime will be established. Thus, the GDT-Upgrade could really demonstrate feasibility of the "moderate flux" neutron source. All the works on the GDT-U are close to completion. The experiments on checking up the concept will begin within nearest months.

REFERENCES

1. Koidan V.S., Arzhannikov A.V., Astrelin V.T., et al, 30th EPS Conf. On Controlled Fusion and Plasma Physics, St.Petersburg, July 7-11, (2003)
2. Astrelin V.T., Burdakov A.V., Chebotaev P.Z., et al, Nuclear Fusion, Vol. 37, #11, (1997), p.1541-1558.
3. Mirnov V.V., Ryutov D.D., *Sov. Journ. Techn. Phys.Letters,* 5, p. 279, (1979)
4. Anikeev A.V., et al, Phys. Plasmas, 1(5), p.1529 (1995)
5. I.A.Kotelnikov, V.V.Mirnov, V.P.Nagornyj, D.D.Ryutov, in: Plasma Physics and Controlled Fusion Research, 2, IAEA, Vienna, p.309, (1985).
6. A.A.Ivanov et al, 16th IAEA Fusion Energy Conf., Montreal, Canada, 7-11 October, 1996
7. Kruglyakov E.P., *Journ of Appl. Mech. and Techn. Physics*, 38 (4), pp 566-577, (1997). Translated from Prikladnaya Mekhanika i Tekhnicheskaya Physika, 38 (4), pp 77-89, (1997)
8. Maximov V.V., et al, *Nuclear Fusion*, 44 (4), p.542, (2004)