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BOOK OF ABSTRACTS

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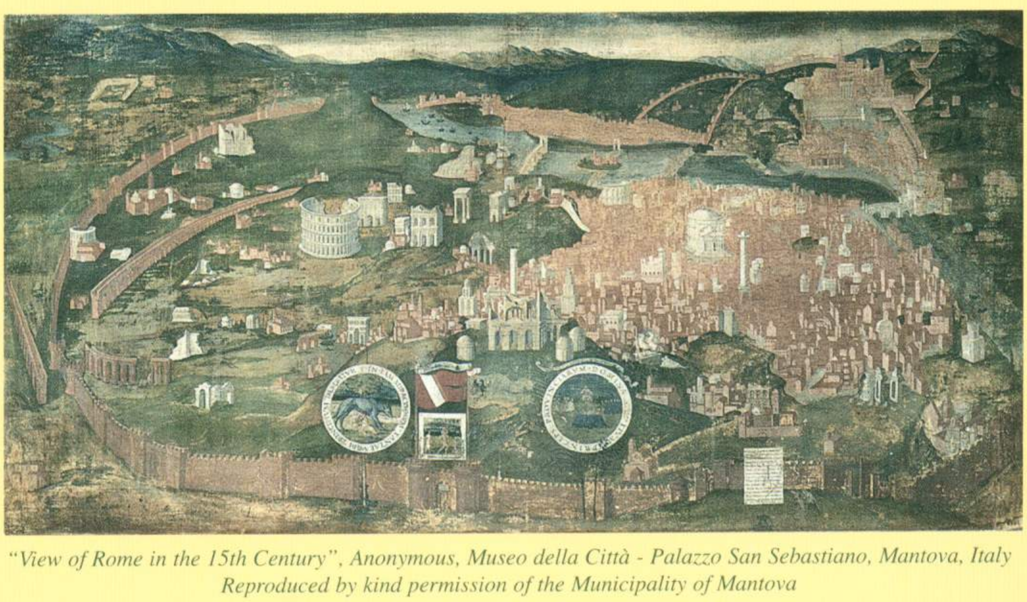

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ITER Related Materials Studies

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The properties of main structural materials of divertor and the first wall irradiated by high temperature plasma fluxes should be carefully studied as soon as possible, even before the start of the ITER experiments. As to the properties of the structural materials irradiated by powerful fluxes of 14 MeV neutrons, it is clear that the ITER is not able to generate the data required for the next step of fusion program because of low accumulated fluence.

Two mirror machines of the Budker Institute of Nuclear Physics are capable of providing extremely useful data for mentioned above fusion material studies. Multimirror trap GOL-3 can produce dense (of order of 10^{21} m^{-3}) plasma with temperatures T 2 keV and energy density of plasma stream within 0.5–50 MJ/m^2. A lot of experiments can be made on plasma-wall interaction (a study of evaporation, erosion and ionization of wall material, disruption and ELM simulations, etc). In particular, a threshold of volumetric destruction of carbon target has been discovered in the range of energy density flux of 10 MJ/m^2, the behavior of carbon particle in high temperature plasma and expansion of carbon plasma were studied. It was observed that this plasma expanded along the magnetic field at long distance (of order of 5 meters) with the velocity of $2 \cdot 10^4$m/s.

Using an injection of D and T atoms with energy of order of 100 keV into "warm" plasma confined in a magnetic system with high (R ~ 10) mirror ratio, one can obtain population of sloshing T ions, oscillating between two end mirrors. As a result, a powerful 14 MeV neutron flux can be obtained near the turning points. That is the main idea of the neutron source based on the concept of Gas Dynamic Trap (GDT NS). According to the theory, 2 MW/m^2 can be obtained in such a device at the area of order of 1 m^2. It should be noted that there is no one candidate to the role of a plasma-based neutron source with such low (about 150 gram/year) tritium consumption and with moderate consumption of electric power (60 MW).

The main physical properties of plasma confinement in the GDT device have already been studied. The longitudinal distribution of neutrons of D-D reaction obtained for the case of 4 MW injection of deuterons during 1 ms as well as intensity of neutron flux are found to be in reasonable agreement with the calculations. In this paper, the experimental results obtained on the GDT are described and the experiments on the next step (GDT-U) device with 10 MW injection of longer duration are discussed.

High-energy fuel ion diagnostics on ITER derived from neutron emission spectroscopy measurements on JET DT plasmas

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High-energy fuel ion (HEFI) populations are created in plasmas subjected to neutral beam (NB) injection and ion cyclotron resonance heating (ICRH). These heating schemes were tested at JET in the DTE1 and TTE campaigns and diagnosed with the help of neutron emission spectroscopy (NES). The JET experience can be transferred to burning plasma studies on ITER but for suitable rescaling including difference in plasma size and conditions, and machine operating parameters. The main differences are that ITER NB will use 1 MeV tangential D beams (compared with 140 keV at oblique angle in JET) leading to d deposition into circulating orbits with a pitch angle about 30°. ICRH will use different heating schemes including some resonating with T or D as tested on JET and shown to produce HEFI populations with pitch angle ≈90° and "tail" temperatures $T_{\perp} \geq 100$ keV depending on power density conditions. Another source of HEFI populations of both d and t of up to 3 MeV is α+d and α+t knock-on collisions, which give rise to a so-called alpha knock-on neutron (AKN) signature in the emission spectrum. With ITER temperatures in the 20-keV range, the AKN would make about 10^{-3} of the total emission compared to 10^{-5} for JET.

NB, ICRH and AKN induced HEFI components have all been the object of NES measurements on JET and models have been worked out for the analysis/interpretation of the data and projection to ITER; this includes a "bulk" (B) component mostly due to thermal fuel ions. Synergies between NB and ICRH have also been observed but are not considered here. The relative intensities of the HEFI components depend on plasma and heating conditions and were often found to dominate at JET for both NB and ICRH in high performance discharges. This is different from high performance ITER H-mode, which is estimated to be 99% thermal, or, Q_{th}/Q=0.99. Lower performance and transient conditions would give higher HEFI fractions and lower Q_{th}/Q ratio; not to forget, the experiments with lower Q_{th}/Q will have to pave the way to reach and optimize high performance conditions.

NES diagnostics benefit from optimised separation of the signatures in the neutron spectrum. This has been studied for the ITER conditions in new Monte Carlo calculations of the neutron emission spectrum for different heating scenarios. It is found that the AKN, NB and ICRH signatures can be distinguished under most conditions, especially because of the strong anisotropy of the NB and ICRH components. It is also found that a radial view provides the best conditions for diagnostics of the ICRH components; a counter-tangential view (i.e. counter to the NB direction) would be most sensitive to the NB induced component; and an oblique view in the co-tangential direction is ideal for diagnostics of the AKN induced component. The AKN can be diagnosed in most cases with limitations due to the NB component in the case of counter-tangential view and ICRH in the case of a radial view but only if the ICRH-driven tail temperature exceeds 200 keV. An interesting aspect in this context is the dual-sight line measurements now planned with the new JET instrumentation. A similar sight line arrangement can be considered for ITER and would provide a full separation of all HEFI components under most conditions.

*See the Appendix of J.Pamela et al., Fusion Energy 2004 (Proc. 20th Int. Conf. Vilamoura, 2004) IAEA, Vienna (2004)

Influence of radial electric field on high-beta plasma confinement in the gas dynamic trap

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One of the most important subjects of the GDT research program is MHD-stability of high pressure two-component plasma. In recent experiments the steady plasma confinement was realized by radial limiters biasing without any special MHD-stabilizers. The report presents the results of study of possible stabilization mechanisms. One of them is plasma line tying to limiters, second one is plasma differential rotation caused by the limiter biasing. Resistance of the Debye layer near the radial limiter is experimentally measured. It was shown, that the observed MHD-stable mode of operation cannot be completely provided by the plasma line tying to limiters.

Experimental studies of influence of the plasma scrape-off layer radial electric field on MHD-stability were carried out. By appropriate biasing of the radial sections of the limiters ~40 V jumps of potential near the plasma surface were produced which resulted in plasma differential rotation. Then it was observed that plasma lifetime considerably (1.5 times) increases. This experimental observation indicate that differential rotation considerably reduces the increment of MHD-instability.

At the moment, initial experiments to measure spatial and temporal variation of plasma parameters in this regime of confinement are carried out. A probe, which allows one to measure a transverse particle flux and plasma diffusion coefficient is developed. Additionally, an array plasma dumps, to which ion current can be independently measured, is installed at the end wall in the end tank. The purposes of these experiments are to estimate the influence of radial electric field on transversal transport and to find the radial potential, which is optimal for confinement. Relationship between plasma confinement time and radial potential profile is studied experimentally. Possible physical mechanisms of MHD-stabilization are discussed.

NTM Seed Island Formation by Error Field in Rotating Plasma

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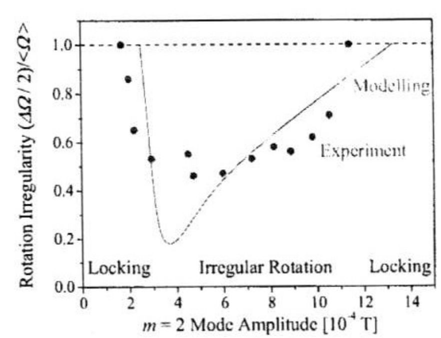
The dependence of the $m = 2$ mode rotation irregularity on the mode amplitude in the presence of an Error Field in T-10 tokamak is considered. The result is analysed from the point of view of NTM seed island formation by an externally applied helical magnetic field in rotating plasma. The T-10 experimental MHD signal processing procedure includes the calculation of the cosine, B_C, and the sine, B_S, space components of the $m = 2$ mode. The mode rotation irregularity is defined as $(\Delta\Omega/2)/\langle\Omega\rangle$ where $\Delta\Omega$ is the difference between maximum and minimum values of the mode oscillation angular velocity, Ω, over the oscillation period and $\langle\Omega\rangle$ is the average value of the angular velocity. This angular velocity is the time derivative of the mode space phase: $\Omega(t) = d[\mathrm{arctg}(B_S/B_C)]/dt$. Along with the mode amplitude variation, the rotation irregularity increases in both cases of sufficiently big and small amplitudes (see the Figure). The mode locking follows the increase of the rotation irregularity up to unity. In addition to the well known effect of large magnetic island locking which usually precede the tokamak discharge disruption, a locking of sufficiently small $m = 2$ magnetic islands is observed. The experimental data are simulated with the TEAR code utilizing a rotation model for the non-linear Rutherford tearing mode in the presence of an external helical magnetic field perturbation of the same helicity. In the case of large magnetic islands, the rotation irregularity and locking take place due to the variations of plasma rotation velocity under influence of the Error Field. In the case of small islands, similar effects on the mode rotation are attributed to the variations of the mode velocity with respect to plasma that arise as a characteristic of the externally driven non-linear tearing mode. According to the TEAR code simulations, the plasma rotation does not prevent the locked seed island generation by the Error Field.



Optimization of the relative calibration for a visible bremsstrahlung Z_{eff} diagnostic on TEXTOR via requirements of profile consistency

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On TEXTOR the profile of the average ionic charge Z_{eff} is determined from bremsstrahlung emissivity measurements in the visible. The recently upgraded bremsstrahlung diagnostic features a set of 24 fibre optic channels that guide the light to a CCD camera. In order to calibrate the system, an integrating sphere was entered into the TEXTOR vessel, providing a constant and uniform light source for illumination of individual channels. However, the so measured calibration factors do not lead to a fully physically acceptable line-integrated bremsstrahlung profile. Sources of error can enter the calibration in many different stadia, and the precise reason for this behavior is so far unclear.

In order to eliminate any sources of calibration error, a new criterium was established for the assessment of the relative calibration of the channels. The idea is based on the measurement of identical bremsstrahlung emissivity line-integrals on different channels. Here, in effect, the plasma is used as a calibration light source. In practice, the proposal was realized by measuring the emissivity line-integrals in two discharges with similar plasma parameters, but with a relative shift in the horizontal plasma position. A polynomial was fit to the line-integrated emissivity data from the first discharge, allowing the comparison with the emissivity line-integrals from the second discharge at the respective shifted positions. Since both discharges had similar bremsstrahlung emissivity profiles, the relative calibration factors could be estimated by minimizing the square differences between the emissivity line-integrals from both discharges, calculated along a single set of chords. Even a horizontal shift of only a few centimeters suffices to find a satisfying relative calibration, which allowed the first reconstruction of a physically plausible Z_{eff} profile using data from the upgraded diagnostic. To derive the absolute emissivity values, the emissivities measured by a set of centrally pointed channels can be taken as a reference.

The here outlined method is of general applicability, and provides a simple and self-consistent way for the calibration of the bremsstrahlung system, which can in principle be carried out at any time, without requiring access to the tokamak vessel itself or the establishment of a calibration set-up.

Prototype of dispersion interferometer for real time measurements of electron lineal density in fusion experiments

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Dispersion Interferometer based on a continues-wave CO_2 - laser source (λ=9.57 μm) with double plasma passage for the measurements of the line-integrated electron density in the TEXTOR tokamak and the GDT linear device has been developed and successfully tested in real experiments. It was demonstrate during the last measurement campaign on TEXTOR (November - December 2005) that Dispersion Interferometer allowed one to measure routinely the plasma linear density along the central chord of TEXTOR. Accuracy of measurement was $\langle n_e l\rangle_{min}=2.4\cdot 10^{13}cm^{-2}$, temporal resolution Δt=1 ms.

One important control task in tokamaks is the plasma position detection and feedback control. For this purpose, the calculated values of plasma linear density are analyzed and the feedback signal is directed to the system of magnetic correction coils. This application requires a real-time response from the diagnostic control system.

Prototype of the real time phase detection system for the Dispersion Interferometer was developed and tested in special simulation experiment on GDT. The phase detection system consists of PC operating under Real Time Linux, 12 bit 50 MHz Digitizer combined with Digital-to-Analog Converter (DAC). The phase reconstruction algorithm is realized in PC. The phase value is calculated and then transmitted to the Digital-to-Analog output. Simulations show that the full processing sequence can be completed within the time frame of ≈1 ms, fast enough to allow position feedback control.

A new probe-based method for measuring the diffusion coefficient in the tokamak edge region

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A new method for measuring the diffusion coefficient in the edge plasma of fusion devices is presented. The method is based on studying the decay of the plasma fluctuation spectrum inside a small ceramic tube having its mouth flush with a magnetic surface and its axis aligned along the radial direction. The plasma fluctuations are detected by an electrode, radially movable inside the tube.

In the experiment described herein, which was performed in the edge region of the CASTOR tokamak, the electrode measured the floating potential. The experimental arrangement is the same used for the direct plasma potential measurements according to the "Ball-pen probe" [1], which design is based on the Katsumata probe principle.

When the electrode protrudes from the tube, the measured signal shows the floating potential fluctuations of the plasma. Retracting the electrode into the tube, the signal power spectrum displays a decay. This decay is different for different frequencies, and is exponential. Assuming a mainly diffusive behaviour of the plasma inside the tube, the spectrum decay length can be used to derive a value of the diffusion coefficient.

The measurement was performed at different radial positions in the CASTOR edge region, so that a radial profile of the diffusion coefficient was obtained. Typical values of D are of 2-3 m^2/s, consistent with expectations from the global particle balance. The radial profile shows a tendency of the diffusion coefficient to increase going deeper into the plasma.

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Measurements of line radiation power in the CASTOR tokamak

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The spatially resolved VUV spectrometer based on original principle of imaging has been developed in IPP Prague in collaboration with the Budker Institute of Nuclear Physics, Novosibirsk, Russia. The Seya-Namioka spectrometer equipped with a spherical diffraction grating and a two-dimensional imaging system permits a radial profile monitoring of the chord-integrated intensity of selected lines in 50-200 nm wavelength range. Fast CCD camera allows to measure VUV radiation with spatial a resolution about 5 mm and temporal resolution of 1 ms. The spectrometer has been installed on the CASTOR tokamak and absolutely calibrated using the line branching ratio method. A pair of the hydrogen lines $H\alpha/L\beta$ was used for calibration. A photo multiplier tube with interference filter was applied for a visible line scanning.

Intensities of the hydrogen lines $H\alpha$ and $L\beta$ during the first milliseconds of the discharge, when bulk ionization occurs, are compared with well known ioniSation/eXcitation Branching ratio (S/XB). Such technique allows to estimate the ion density (6.10^{18} m^{-3}) and the flux of hydrogen into the plasma by value $(3\text{-}5)\cdot 10^{19}$ $m^{-2}s^{-1}$.

Dynamics of ionization of light impurities in plasma was measured and compared with STRAHL code calculations. Concentrations of impurities derived from line radiation power measurements are $(0.5\text{-}1.5)\cdot 10^{16}$ m^{-3} for oxygen and $(0.2\text{-}0.3)\cdot 10^{16}$ m^{-3} for carbon.

A comparison of the different spectral regions shows that power of soft-X radiation sufficiently exceeds power radiated in VUV and visible ranges. Concluding, the total radiation loses measured by fast AXUV bolometric arrays are determined namely by a hot plasma core and can be applied for reconstruction of the plasma shape and its behavior on the CASTOR tokamak.

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Detailed measurements of momentum balance during the periodic collapse of a transport barrier

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In this paper, we present results of edge plasma biasing experiments performed in the CASTOR tokamak (R=0.4 m, a = 85 mm, B_T= 1.3 T, $I_p \approx 10$ kA, $n_e \approx 10^{19} m^{-3}$). A biasing voltage of +200 V is applied to a graphite electrode immersed in the edge plasma of the tokamak. A poloidal array of 96 Langmuir probes, 16 magnetic coils, and 16 Hall sensors surrounding the full poloidal circumference monitors poloidal profiles of electric field, density, and magnetic field with high temporal resolution. A radial array of Langmuir probes measures the radial profiles of floating potential, poloidal electric field, and ion saturation current. A Gundestrup probe measures the parallel and perpendicular flows while a segmented tunnel probe measures the electron and ion temperatures. All data are acquired with up to 1 MHz sampling rate.

During biasing a clear and reproducible transition to improved confinement is routinely observed along with the formation of an edge transport barrier which is characterized by (i) a steepening of the time-averaged density gradient (ii) a reduction in recycling (iii) a substantial improvement of the global particle confinement. A strongly sheared radial electric field is created within the transport barrier followed by an abrupt collapse of the potential and density gradients. The observed radial propagation of dense structures and fast spikes of electron temperature immediately following the collapse indicate the ejection of hot dense plasma towards the wall. This process repeats with a frequency of about 10 kHz throughout the full biasing phase of the discharge.

Our sophisticated diagnostic set allows us to verify that radial momentum balance equation $E_r = \nabla_r p_i / n_i Z_i e - v_{\theta,i} B_\phi + v_{\phi,i} B_\theta$ is respected during the collapse of the transport barrier.

The synthesized hot ion plasmoid experiment at GDT

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An idea of the Synthesised Hot Ion Plasmoid (SHIP) experiment at the GDT device in the Budker Institute has been presented in [1]. In the next two years the required experimental equipment were constructed and plasma parameters in SHIP were calculated using the Integrated Transport Code System (ITCS). In December 2004 the experiments at the GDT-SHIP device has been started. The first results of study of SHIP plasmas with moderate parameters of injected neutral beams were presented in [2]. Later on, the new power supply of the SHIP-NB injection system was installed and the parameters of neutral beams were sufficiently increased with extension of the beam pulse duration from 1 to 5 ms.

The experiments are carried out in a small additional mirror cell that is installed at one side of the GDT central cell. The magnetic field on axis of the cell is in the range of 2.5 Tesla and the mirror ratio is set to ~ 2. The cell is filled with the plasma streaming out the GDT central cell. This plasma component with density of $1\text{-}3 \times 10^{19}$ m^{-3} is maxwellian and its electron temperature is about 100 eV. The two upgraded hydrogen/deuterium neutral beam injectors are used to provide a total equivalent current of about 60 amperes incident on a plasma in the mirror cell. Beam energy is set to 22 keV, pulse duration is 5 ms. The beam injection gives rise to high-energetic strongly anisotropic ion component build up, which maximum density exceeds that of the background warm plasma. The mean energy of the energetic beam-injected ions is about 10 keV. A set of special diagnostics was developed for this experiment.

This paper presents the recent results obtained in the experiments with SHIP. The results of numerical simulations are compared with the experimental results.

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Hydrogen prototype of the GDT-based neutron source: physical concepts and pre-calculation

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A project of 14 MeV neutron source based on a gas dynamic trap concept (acronym GDT-NS) [1] is being developed by the Budker Institute, Novosibirsk. The current status of the project is reviewed in [2]. The neutron source is intended to be used fusion materials testing and other application. The gas dynamic trap is an axisymmetric open system with a high mirror ratio for the confinement of a collisional plasma and high energy ions which are produced by an oblique injection of neutral beams at the center of the device.

The experimental GDT device is operated in the Budker Institute [2]. The next step in the GDT-NS project development is construction of Hydrogen Prototype (HPNS) of the source. The HPNS project goal is to generate a plasma physics database at plasma parameters as close as possible to those expected in the GDT-based neutron source and demonstrate steady confinement of the plasma.

The HPNS is completely axially symmetric device with the mirror ratio varied from 8 to 20 at 0.5-1 Tesla magnetic field at the midplane. The distance between mirrors is 10 m. The expander end cells provide MHD stability for the entire system and therefore should have a Min-B configuration. Plasma start-up in HPNS will be carried out by injecting plasma along the field line from the end. Then the injected cold target plasma is heated up and sustained by a combination of neutral beam injection and gas puff and/or injection of low energy (100-200 eV) neutrals from specially developed beam injectors. Eight hydrogen neutral beam injectors with a total power up to 10 MW will be used for initial experiments at HPNS. At this stage the pulse duration will be limited to 5 ms. This regime of operation was studied already at the GDT device for significantly smaller magnetic field (0.3T at mid-plane).

The paper presents the main parameters of the HPNS and layout of a first stage of HPNS device with 10 MW 5ms pulse neutral injection. The future operational scenarios of the experiment and results of numerical simulations by means of the integrated transport codes are also presented.

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Study of dynamics of anisotropic ion pressure profile in GDT by the spectral MSE diagnostic

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Confinement of fast ions with an anisotropic angular and energy distribution is the crucial objective of experiments in the gas dynamic trap mirror [1] in the Budker Institute. These ions are produced by trapping of 17 keV beams of hydrogen or deuterium injected in collisional "target" plasma. Having turning points in the magnetic field corresponding to the mirror ratio of $R=B^{turn}/B^{0}=2$, fast ions form sharp density peaks in the localized regions which naturally serve as testing cells in the projected 14 MeV neutron source [2] based on the GDT concept. Recent observations [3] have shown rapid radial pinch of anisotropic ions already at the initial stage of the neutral beam injection with the on-axis transverse β approaching 0.4, as measured by the single-chord MSE diagnostic [4]. The newly developed spectral diagnostic system comprising focused 40 keV H-beam and the eight chord observation optical system with a digital CCD detector, allows for magnetic field profile measurements in a single shot. Combined with equilibrium modelling, time-resolved |**B**| measurements (one 200 μs frame per shot) enabled us to study self-organisation of anisotropic ion pressure radial profile in GDT.

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Local Diagnostics of Hydrogen Neutral Atom Density Based on Laser Ionization in FT-2 Tokamak

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The report concerns with a local diagnostics for hydrogen neutral density measurements developed and tested in FT-2 tokamak. The diagnostic is based on quenching neutral hydrogen emission lines due to ionization of exited hydrogen atoms by a powerful laser beam in plasma.

The intensity of the laser beam, its width and laser pulse duration should be high enough to provide the diagnostic capabilities and measurement accuracy. That imposes severe requirements on lasers used for the diagnostics. A new proposed multipass intracavity system solves the problem. It consists of two spherical mirrors. The laser beam is directed into plasma through a hole in one mirror and after 22 passes returns back to the laser. So, the mirrors are a part of the laser cavity. The total beam path in the cavity is ~100 m. Such a system provides a high laser intensity in a wide plasma cross-section as well as a long laser pulse duration.

The achieved laser intensity is high enough to ionize nearly all excited atoms in the radiated plasma volume. Full ionization makes data elaboration more simple and reliable.

Low light losses in the laser cavity allow more efficient use of laser inversion and generation of several laser pulses during 3 ms pumping. The diagnostic utilizes each laser pulse to study fast dynamics of hydrogen atom density.

The diagnostics was applied in FT-2 tokamak. Both chord and local emission profiles for H_α and H_β lines were measured in Ohmic discharges. The local H_α and H_β line intensities were used to calculate densities of excited hydrogen atoms at 3-rd and 4-th levels. The ground state hydrogen atom densities found from the excited atom densities assuming radiative-collisional equilibrium model are presented as well.

Pellet Injection Experiments at GOL-3 Multimirror Trap for Plasma Fueling and Plasma-Surface Interaction Research

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A pellet injection technique is used at GOL-3 multimirror trap for the solution of several physical problems. Earlier use of small impurity pellets (CH_2, LiD) for the purposes of plasma diagnostics and for formation of dense plasma bunch inside the main plasma column was already discussed (see, e.g. [1]). In the report other two topics of the pellet injection activity will be presented.

The first topic is connected with continuing reactor-relevant studies of influence of a high-power pulsed stream of electron-hot plasma on solids (see, e.g., [2]). The new problem of expansion of dense target plasma along the magnetic field through a several-meters distance was investigated. A carbon pellet of 2-mm diameter was injected into the plasma for this purpose. The pellet was large enough that its surface up to some depth evaporated only. Specific energy load was ~50 MJ/m^2. Parameters of the carbon plasma during its expansion were studied. Similar behaviour of surface plasma can be in reactor-class tokamaks at fast dump of energy during ELM events.

Other physical problem for pellet injection is the increase in plasma density near the axis of GOL-3. Now achievable density is limited by decrease of conductivity of a preliminary (start) plasma and respective deterioration of compensation of a current of heating relativistic electron beam with a plasma return current that leads to disruption. It is checked up, that parameters of the preliminary discharge do not degrade because of a pellet by the moment of the beam injection. In the report the status of works on cryogenic pellet injector which is developed jointly by BINP and SPbSPU will be presented.

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References

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Effect of magnetic shear and resonant magnetic field on low-*m* mode in LHD

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An understanding of characteristics of ideal and resistive pressure driven instabilities in net current-free plasmas is one of major key issues for realization of high-beta plasma production. In standard configuration of Large Helical Device (LHD), the m/n = 1/1 mode where the resonance is located in periphery with magnetic hill and strong magnetic shear has been enhanced with increasing beta and pressure gradient. Also strong dependence of the mode on a magnetic Reynolds number has been found out, and it is close to that predicted by linear theory of resistive interchange mode. In this study, the following subjects have been considered in order to understand the configuration dependence of low-*m* pressure-driven mode, that is, (1) effect of the magnetic shear on the mode, and (2) interaction with m/n = 1/1 static magnetic island. The magnetic shear can be changed by increasing or decreasing a plasma aspect ratio. When the plasma aspect ratio increases from standard value (5.8) to 8.3, the central rotational transform increases, which leads to a reduction of the magnetic shear at $\iota/2\pi = 1$ surface. It means that the m/n = 1/1 mode moves from resistive *unstable* state to ideal *unstable* one. In the low-magnetic shear configuration, the strong m/n = 1/1 mode without rotation displaced the resistive mode observed in standard configuration, and it leads to a large degradation of a core plasma. The mode was also destabilized by the plasma current reducing magnetic shear, and the appearance is qualitatively consistent with ideal stability limit. This mode was easily stabilized by moderate m/n = 1/1 perturbation field with optimum spatial position. On the other hand, the perturbation field was also applied to resistive m/n = 1/1 mode in order to verify the stabilization effect and to investigate their interaction, which is important for understanding relationship between an excitation of the mode and magnetic structures ergodized by finite-β effects. The amplitude of the mode gradually decreased with increasing the perturbation field and the mode was completely suppressed when the field exceeds a certain value. The rotation of the mode slowed down before the complete suppression.

Characteristics of micro-turbulence in LHD from CO_2 laser interferometry and 2d phase contrast imaging

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Density fluctuations with low to medium k ($k_{perp}\ \rho_i \sim 0.1$-$1.5$) in both the core and edge are investigated on LHD, including the parametric dependencies of the fluctuation level and phase velocity, as well as the influence that fluctuations have on particle transport. Measurements were carried out using novel fluctuation diagnostics based on a 2D CO_2 laser interferometer, including 2d phase contrast imaging (PCI), and heterodyne imaging interferometer using high resolution phase counters. The 2d PCI system can measure the k spectrum of line-integrated density fluctuations along a chord passing close to the magnetic axis, sensitive to radial fluctuations in the core and poloidal fluctuations in the edge. It can provide moderate radial spatial resolution ($\Delta\rho \sim 0.1$), since the propagation direction in the 2d (6x8) image gives information about the radial location of the fluctuation (as fluctuations are known to be filament-like structures elongated along the magnetic field lines), and since there is a large variation of the direction of field lines perpendicular to the beam ($\sim$-40^0 to $+40^0$),. The system can be configured with different magnification factors to investigate different ranges of k, in "overview" mode from (0.2 – 0.6 mm^{-1}, characteristic of ITG/TEM scale turbulence), and "zoom" mode from (1-3mm^{-1}, characteristic of ETG scale turbulence). Because of Doppler shifting, high k fluctuations appear only at higher frequencies, where the signal intensity is weaker. The highest detected value of k, so far, is 2.5mm^{-1}, at around 1.5MHz ($k\ \rho_i = 1.5$).

Results from overview mode show different branches, including low k~0.2mm^{-1} core radial fluctuations and higher k (0.2-1.2mm^{-1}) poloidal fluctuations at mid-radius and towards the edge. The phase velocity of the poloidal fluctuations at mid radius is close to the measured ExB rotation velocity, while at the edge may propagate in the ion diamagnetic direction with respect to the rotating plasma. The transient particle diffusion coefficient and convection velocity was analysed experimentally from FIR and CO_2 interferometer data in gas-puff modulation experiments. Varying the heating power and magnetic configuration, a good correlation is found between the edge diffusion coefficient and particle flux, and the (lab and plasma frame) ion diamagnetic fluctuation amplitude. Based on measured profiles, calculations of the ITG growth rate using the GOBLIN (Gyro-kinetic ballooning linear) code were carried out. Discharges with higher ion diamagnetic fluctuation amplitude were found to have higher growth rate. This result is suggestive that ITG turbulence may have an important role on edge particle transport. An analysis of the driving terms for the ion diamagnetic fluctuation shows that, aside from density, the edge temperature gradient is related to the ion diamagnetic amplitude.

The fluctuations show burst-like intermittent phenomena in time. Analysing the radial phase velocity and density fluctuations (in the core from 2d PCI, and at the edge from interferometer data), the fluctuation-driven particle flux can be estimated. This can be compared with the total particle flux, determined from the change of density, during the rapid relaxation after pellet ablation.

Runaway electrons and the evolution of the plasma current in tokamak disruptions

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The evolution of the plasma current after the thermal quench of a tokamak disruption is governed by the equation for runaway electron production and the induction equation for the toroidal electric field. The electric field determines the runaway generation rate, and the runaway current produced modifies the electric field through the induction equation. A quantitative analysis of this coupled system of nonlinear equations [1] is presented, and the dependence of runaway density and electric field on plasma radius is determined. The calculations show that in JET about half the plasma current is converted into runaways, in agreement with observations, while in ITER the conversion ratio is predicted to be larger. The runaway electrons are produced both by the primary (Drecier) mechanism and a secondary avalanche caused by short-range collisions. The avalanche is the dominating production mechanism in large tokamaks, such as JET and ITER, but primary generation plays an important role in providing a "seed" for the avalanche. It is shown that when most runaways are produced by the secondary mechanism, the runaway current profile becomes more peaked than the pre-disruption current. In fact, the current density often increases on the magnetic axis although the total current decreases. This current peaking is due to electric field diffusion into the centre of the plasma, occuring on a time scale comparable to the runaway avalanche growth time. In addition, electric field diffusion can cause the runaway current to become radially filamented if the runaway seed profile has a small ripple. Finally, it is investigated how the pre-disruption plasma parameters affect the overall magnitude and shape of the final current profile through various mechanisms.

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Effect of Fast Heating of Ions in Multimirror Trap During Electron Beam Relaxation

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Experimental studies of plasma heating and confinement are carried out at GOL-3 facility. Deuterium plasma with density $n \sim 10^{15}$-10^{16} cm^{-3} is heated by powerful electron beam (1 MV, 8 μs, 120 kJ) and confined in multimirror magnetic field with Bmax/Bmin=4.8/3.2 T. Energy is transferred from the beam to plasma electrons due collective interaction, as a result electron temperature achieves ~1 keV just after beam injection.

After start of experiments in multimirror configuration an effect of fast collective heating of ions was discovered. The essence of this effect is that experimentally observed fast heating of ions during beam injection can't be explained by classical energy transfer from electrons via Coulomb collisions. The heating rate exceed classical one on three orders of magnitude such as ion temperature achieves 2 keV for plasma density $(0.5\text{-}1)\cdot 10^{15}$cm^{-3} at 20 microsecond after start of plasma heating.

A model of collective ion heating in cells of multimirror trap was proposed for explanation of this effect. This model predicts acceleration of plasma in the non-uniform magnetic field due to pressure gradients and excitation of density waves in mirror cells.

Special diagnostics were created for study effect of fast heating. Flashes of fusion neutron emission corresponding to plasma density oscillations are observed by local detectors placed along plasma column. Such oscillations predicted by theory were also directly measured by Thomson scattering system. In the report the review of model of fast ion heating, numerical calculations and comparison with experiments are presented.

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