1.1 - Project name

Tokamak ISTTOK

1.2 - Project team

Name	Degree	% participation
H. Fernandes	Doctorate researcher	90%
Igor Nedzelskiy	Dr.	95%
Rodrigo Mateus	Dr.	50 %
Rui Gomes	Dr.	95%
Humberto Figueiredo	Master	95%
Carlos Silva	Dr	60%
Ivo Carvalho	Master	60%
Paulo Duarte	Engineer	100%
Vladislav Plyusnin	Dr	20%
Pedro Carvalho	Dr	60%
André Sancho Duarte	Master degree researcher	45%
Tiago Valeriano Pereira		90%
Bernardo Carvalho	Doctorate researcher	15%
Bruno Santos	Master's degree researcher	10%

1.3 - Summary and highlights of research achievementes

In 2010 the main activities concerning the gallium jet studies had been finalized and reporte. A good explanations for the jet displacements were found with a impact on the proposed FTU experiment.

Correlation techniques allowed to prove that fluctuations measured by optical CII line intensity could be relevant when langmuir probes can not be used.

Dust retention studies by aerogel silicate have started in the current year in a colaboration with the Swedish Euratom association.

Major changes on the vaccum were made with the elimination of the heavy ion beam auxiliary pumping allowing a more flexible maintenance of the machine and the final migration to ATCA completed. In the following sections a detailed report of ISTTOK general activity is performed.

1.3.1 Introduction

This Project has included activities in the areas of:

- Study of fusion relevant materials;
- Real time control and data acquisition;
- Diagnostics;
- Plasma physics studies,

Which have been carried out in the frame of:

- The General Support of the Contract of Association;

- The following EFDA Tasks:

  - Demonstration of liquid plasma facing components (WP10-PWI-05);
  - Physics of rotation in plasmas (WP10-TRA-04);
  - Edge diagnostics (WP10-TRA-05)

1.3.2 Study of fusion relevant materials

The following tasks were performed in 2010:

- *Study of the power exausted by a gallium jet during its interaction with ISTTOK plasmas:* The determination of the temperature increase of a gallium jet during its interaction with the plasma has been performed using IR sensors. The absolute calibration of these sensors was performed "in situ" (gallium injection was performed, without plasma, and heating up the upper gallium tank to a known temperature) up to 120 ºC while higher temperature values have been assessed by extrapolation. Measurements of the gallium droplets surface temperature increase during their interaction with the plasma have been done using 2 sensors in a series of high reproducibility discharges. A 2.4 kW power extraction capability, corresponding to a 89 ºC droplet temperature increase, has been measured using the achieved results (Figure 1.3.2.1). This procedure as imposed by the displacement of droplets due to the plasma influence (see bellow) which implies moving the sensor Field Of View (FOV) in a step by step scanning until the maximum signal amplitude (droplet well within the FOV) is achieved.

(FN: Work made in EFDA task WP10-PWI-05).

- *Study of the plasma influence on a liquid gallium jet dynamic behavior:* An experimental campaign has been performed to study the perturbation of the plasma on the gallium droplets trajectory by varying toroidal field amplitude and direction, plasma current amplitude and direction, plasma position (vertical & horizontal) and gallium injector position.The main conclusion was that the observed jet deflection was due to Lorentz forces since a linear dependence of the shift amplitude on the toroidal field has been clearly observed. Furthermore the induced currents was understood to be produced by plasma potential asymmetries along the jet path within the chamber as could be deduced from the strong influence of the plasma position on the deflection behavior: maximum amplitudes are achieved when plasma is located at one end (upper or lower, depending on field direction) of the available vertical position. This last condition corresponds to the steeper gradient in plasma potential profile along the jet trajectory.

(FN: Work made in EFDA task WP10-PWI-05).

- *Study of the hydrogen retention on gallium samples for different exposure conditions to ISTTOK plasmas:* Two samples of gallium in liquid state have been exposed to the tokamak plasmas (100 discharges: ~3 s exposure) at different radial positions (r= 68mm and r=75 mm, different n_e, T_e and ion flux values). Analyses of these have been performed using ion beam (ERDA and RBS) techniques. Comparison of solid and reference samples with these last results was done showing that Hydrogen retention occurred near the surface in all the exposed targets and was higher for liquid samples. A retained fraction around 1 at.% was achieved for an average ion flux of 4×10^{22} ion/m^{2}s.Hydrogen retention in gallium was found to be substantially smaller than that in carbon without a noticeably large diffusion to the bulk. Furthermore experimental data seems to point towards the existence of saturation retention level at higher fluences. In this case, lower retained fractions could be achieved. XPS (X-ray photoelectron Spectroscopy for elemental analysis) profiles were obtained to determine samples surface composition and hydrogen retention depth profiles correction (**Figure retenção Hidrogénio**).

(FN: Work made in EFDA task WP10-PWI-05).

- *Study of W microstructural changes induced by the ISTTOK plasma:* Experiments carried out in other laboratories suggest that exposure of thick tungsten targets to plasma does not induce the formation of voids that tend to act as hydrogen trap and molecular recombination sites. This alleged behaviour has encouraged the use of tungsten in plasma facing components. However, plasma exposure of W wires to the ISTTOK plasma has revealed an extreme molecular retention in internal gas bubbles present in the microstructure of the irradiated materials. Additional tungsten targets are currently being irradiated at ISTTOK. Experimental results show that the microstructure of thick samples remains unchanged after irradiation. However, intergranular bubbles, abnormal grain grow and evidence of melting and/or evaporation are always observed at the tip of tungsten wires after long term plasma exposure. These opposite results suggest that bubble formation depends on the geometry of the target, namely on its specific surface area. Evidence of this geometric behaviour is commonly observed along the melted/eroded edges of irradiated tungsten tiles in large fusion devices. Further experiments are being performed at ISTTOK involving different geometries in order to demonstrate this dependence.

Figure Rodrigo. Cross-section cut image of the tip of an irradiated tungsten wire evidencing the presence of intergranular gas bubbles.

1.3.3 Real time control and data acquisition

The following tasks were carried out in 2010:

Power supply upgrades

Previously, the tomography diagnostic has been implemented on the MARTe control system running on an ATCA crate and used to determine the plasma position in real-time. The vertical field power supply has been redesigned in order to control the plasma position based on the tomography measurement, allowing an operation range of -350A to 350A at 60V with a new communication protocol with a baud-rate of 921600 bits/s.

In 2010, the horizontal field power supply was also upgraded and connected to the MARTe system (Figures 1.3.3.1 and 1.3.3.2). This power supply produces currents in the range of -130A to 130A at 12V.

Both power supplies are now controlled based on the plasma position calculated by the tomography diagnostic. Figure (../../../@api/deki/files/245/=28174_tomoposVSIvIh_(1).eps28174_tomoposVSIvIh (1).eps) shows the current supplied by both power supplies controlled by MARTe. During the first 13 ms of the shot, the current was pre-programmed and, during the remaining time, it was in feedback mode. During this time, the vertical plasma position was more centered than during the pre-programmed phase.

In order to integrate all the diagnostics and actuators in a Multiple Input Multiple Output (MIMO) controller on the MARTe framework, a new primary field power supply based on an IGBT H-bridge was designed and shall be constructed and tested in 2011 (Figure 1.3.3.3).

1.3.4 Diagnostics

The following tasks have been made:

Ion temperature fluctuation measurements:

A multi-collector Retarding Field Analyser (5 collectors 1.8 mm of diameter and 3 mm of distance between collectors) with distributed biasing of the collectors has been tested for fast ion temperature measurements. However, the large variation of the ISTTOK SOL plasma parameters within the collector's separation distance discarded this approach. Alternatively, a method based on the conventional RFA operational relations for shifted Maxwellian distribution of the analyzed ions, and two point measurements on the RFA current-to-voltage characteristic with two differently DC biased RFA electrodes has been proposed for the ion temperature fluctuations measurements. The method has been successfully tested in the ISTTOK SOL plasma and promising results obtained. The method was compared with conventional RFA measurements of the ion temperature and a good agreement found. The obtained results demonstrate that the ion temperature fluctuation level in the ISTTOK SOL plasma is quite high (~30%), taking into account the present temporal resolution of 50 kHz. Validation of the ion temperature fluctuations measurements including the effect of fluctuations in the shift potential and noise contamination proves the reliability of this result (see Figure ?).

(FN: Work made in EFDA task WP10-TRA-05).

Development of cherenkov type detectors:

A modified prototype of 4-channel detector for measurements of Cherenkov radiation was manufactured and tested in experiments on ISTTOK. Despite very low runaway electron densities the detector was capable to register the Cherenkov emission signals in all 4 channels sometimes at surprisingly high energy thresholds (95 keV, 120 keV, 181 keV and 260 keV, respectively). The fact that registered signals were almost of the same value and strong correlation between them was observed well corresponds to the model of mono-energetic electron beam generated due to Dreicer mechanism. The presence of fast electron population with energies of order or higher of 100 keV in plasma discharge inevitably should cause the appearance of X-rays emission (Figure ISTTOK_21770). Measurements of X-rays emission have been used for verification of the measuring capabilities of 4-channel Cherenkov-type detector. Comparison of the data on X-ray radiation to the data obtained from different channels of the Cherenkov-type detector has demonstrated close correlation between Cherenkov radiation and X-ray emission signals in different ISTTOK pulses (Figure Xrays_Cherenkov).

Upgrade of the heavy ion beam dignostic:

A new multi-cell array detector with 44 cells of 3 mm dimension have been developed and installed on ISTTOK that will allow an increase of the diagnostic spatial resolution. The distribution of the plasma loading signal has been investigated and the primary and secondary beam signals detected in different regimes of the HIBD operation.

Optimization of the optical system (photomultiplier, filter, optics) to measure the impurity influx from a plate: Focusing of the optical system on the probe head (graphite) has been achieved for several magnification factors (ratio image to object distance: m=4, 5 and 3). An optical fibre has been used to convey light to the photomultiplier head. Measurements have been performed showing an excellent detector response to fluctuation in the plasma local CII emission with a bandwidth around 100 kHz. Results have been compared to a photodiode response in the same conditions (splited fibre). (FN: Work made in EFDA task WP10-TRA-05).

1.3.5 Plasma physics studies

Plasma physics studies have been carried out related with:

Study the poloidal asymmetries in transport, edge flows and edge fluctuations: Asymmetries on a flux surface have been directly investigated with a probe system that simultaneously samples the plasma at fixed minor radius on four poloidal angles (see figure [ISTTOK cross-section]). Data from ISTTOK clearly show poloidal asymmetries in both equilibrium and fluctuating parameters in the edge plasma. Asymmetries favoring the LFS are observed for both B_T and I_p directions in density, turbulent particle flux, diffusion coefficient and fluctuation levels, suggesting a 'ballooning' transport (see figure ?). The inboard/outboard asymmetry is not observed to depend significantly on the I_P and B_T directions, contrary to the observed with the up/down asymmetry that favors the ion ÑB drift direction.

The larger cross-field particle transport at the LFS for both B_T and I_p directions, is consistent with the fluctuations characteristics. Fluctuations at the outboard are more intermittent as demonstrated by the high fluctuation level and skewness at this location. The frequency resolved turbulent particle flux also shows differences between the inboard and outboard midplane. The contribution of the low frequency range ($f < 50$ kHz) dominates the turbulent flux at the HFS, contrary to the observed at the LFS where a significant transport is observed for frequencies up to 150 kHz. ISTTOK results clearly demonstrate that the turbulence drive is ballooning-like leading to a poloidally asymmetric transport.

Finally, significant poloidal differences are also measured in the parallel flow, which has opposite direction at the LFS and HFS. Furthermore, the parallel flow is observed to not depend strongly on the B_T direction and to reverse with the I_p reversal. Clear evidence is presented that Pfirsch-Schluter flows are responsible for the majority of the observed parallel flow at the inboard and outboard midplane.

Systematic investigations of the statistical properties of the impurities influx measured with photomultipliers tubes: Study of the dynamical link between intermittent events and impurity influx: A diagnostic system has been installed in the ISTTOK tokamak that for simultaneous measurement of the density fluctuations and the impurities influx in the same region with a high temporal resolution, allowing the study of the coupling between turbulence transport and impurity influx. It is observed that both the time evolution and the spectra are very similar in the two techniques and therefore we can conclude that the CII signal fluctuations reflect the fluctuation in the local plasma parameters. Fluctuations measured by the two techniques not only have similar properties but also are correlated as they are measured approximately in the same sampling volume. As the correlation between one of the probes and the CII emission is high (~0.6) and with no time delay we can conclude that both diagnostics are sampling the same plasma region and that the optical diagnostic is really measuring the local plasma fluctuations. Results demonstrate therefore this diagnostic tool is adequate to characterize the intermittent events in the plasma boundary and study of their role on edge particle sources (FN: Work made in EFDA task WP10-TRA-05).

Study of naturally occurring edge flows: The ISTTOK boundary plasma mean velocity near the outer midplane was measured on the parallel and perpendicular directions, using a Gundestrup probe, in four different configurations by reversing independently the toroidal magnetic field and the plasma current directions. The parallel flow was found to not depend significantly on both the toroidal magnetic field and plasma current directions and assumes low Mach numbers in the confined region. In the scrape-off layer the parallel flow is significantly larger and always directed towards the nearest limiter regardless the direction of both magnetic field and plasma current. Results on perpendicular plasma flow velocity are remarkably symmetric with respect to a reversal in the magnetic field direction. The reversal occurs just inside the limiter position, near the shear layer region. This behavior is clearly related to the Er x B drift (fig. Humberto.2).

Further measurements were performed aiming at investigating the dynamical relation between parallel flow and turbulence induced particle flux, taking advantage of the time resolution of the data acquisition system (0.5 us) The existence of this link was investigated by computing the coupling between the probability density functions of those quantities. It was found that a clear link exists at about 1 cm inside the limiter, where the particle transport reaches its maximum average value (fig. Humberto.3).

Study of the Reynolds stress radial profiles: Radial profiles of the turbulent Reynolds stress were obtained for ISTTOK discharges. External edge biasing was applied during a small period (2 ms) of the discharges in order to trigger relevant modifications on the plasma poloidal flow velocity, to which the radial gradient of the Reynolds stress could be compared.

It was found that this Reynolds stress gradient is very large on the shear layer region. This result is consistent with the hypothesis of the Reynolds stress being a regulation mechanism of the perpendicular flow.