Description of the stellarator TJ-II

(provided by KJ McCarthy, Ciemat)

The TJ-II is a low magnetic shear stellarator of the heliac type with a major radius of 1.5 m and an average minor radius, *r*, of ≤0.22 m. Its magnetic field at the plasma centre, B(0) ≤1 T, is generated by a system of poloidal, toroidal and vertical field coils. The resultant plasma cross-section is bean shaped and the plasma volume is ~1 m^3. TJ-II was designed to have a high degree of magnetic configuration flexibility. During experimental campaigns, plasmas, created using hydrogen, deuterium or helium as the working gas, are heated using one or two gyrotrons operated at 53.2 GHz, *i.e.*, the 2^{nd} harmonic of the electron cyclotron resonance frequency (P_{ECRH} ≤500 kW, t_{ECRH}≤ 300 ms). Plasma discharges up to 300 ms long can be produced once every 8 minutes. In this way, central electron densities, $n_e(0)$, and temperatures, $T_e(0)$, up to 1.7×10^{19} m^{-3} and 1.5 keV, respectively, can be achieved. Additional heating by the injection of accelerated neutral hydrogen atoms (E_{NBI} ≤32 keV, P_{NBI} ≤1 MW, t_{NBI} ≤ 120 ms) from two tangential Neutral Beam Injectors (NBI) results in plasmas with $n_e(0) \leq 5\times10^{19}$ m^{-3} and $T_e(0)$ ≤400 eV when a lithium coating is applied to the vacuum vessel wall. Note: plasma control is achieved by occasionally coating the vacuum vessel walls with boron and lithium and by daily performing a ~30 minute GDC with helium. Finally, the majority ion temperature, $T_i(0)$, is ≤120 eV for both heating schemes.

The TJ-II vacuum vessel has a total internal volume of 6 m^3 and a total inner surface area of about 75 m^2. One of the peculiar characteristics of TJ-II plasmas is their strong interaction with the region of the chamber surrounding the hard core. In fact, this part of the vessel represents the main limiter for most magnetic configurations. The T-II is also equipped with a mobile liquid lithium limiter. Finally, the TJ-II possesses a complicated vacuum-vessel geometry, a bean-shaped plasma cross-section and a fully 3-dimensional plasma structure. Nonetheless, it has excellent diagnostic access (96 portholes) and is equipped with a large set of diagnostics.

Diagnostic systems employed on TJ-II can generally be grouped into two types termed passive and active. In the first instance, passive systems are used to collect electromagnetic radiation or escaping particles, without causing a perturbation to the

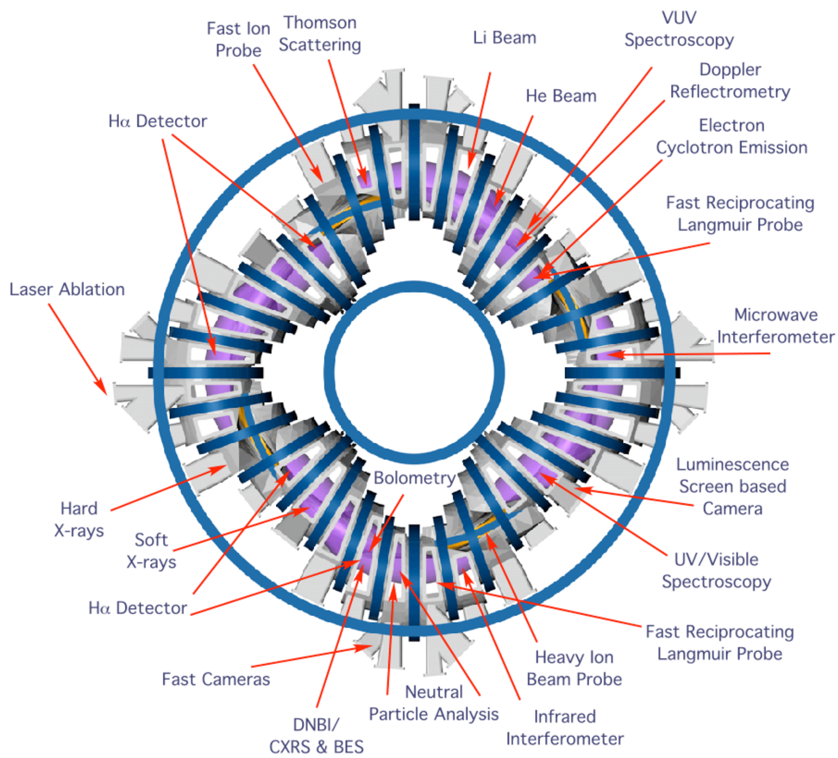

Figure 1. Schematic overhead view of TJ-II showing the locations of its main diagnostics. The plasma (purple), the vacuum vessel (grey) and the magnetic fields coils (blue & yellow) are shown.

plasma, and convert and amplify detected signals to voltage traces that can be analysed at a later time. Passive systems provide important data for TJ-II *e.g.* Hα monitors to study plasma edge physics, visible and VUV spectroscopy to identify and follow the evolution of impurities, Electron Cyclotron Emission radiometry to obtain continuous T_e values at a set of plasma radii, X-ray monitors to measure core T_e and to detect suprathermal electron populations, neutral particle analysers to obtain ion temperature profiles, and magnetic diagnostics such as Rogowski coils, Diamagnetic loops and Mirnov coils to measure plasma current, plasma kinetic energy and magnetic field fluctuations, respectively. In parallel, active systems, that require an external stimulation, provide more specific information about the TJ-II plasmas. For instance, these involve laser light (to obtain central n_e and T_e profiles by Thomson Scattering (one profile per discharge), impurity injection by laser blow-off (to determine viscosity and diffusivity coefficients plus particle confinement times and impurity accumulation), Gas Puff (to study edge turbulence with a $H\alpha$ filter and a triple bundle fast frame camera), a narrow beam of accelerated neutral hydrogen (to obtain impurity ion temperature, Ti, and velocity profiles as well as electric fields by Charge Exchange Recombination Spectroscopy or magnetic field magnitudes and pitch across the plasma radius by the Motional Stark Effect), narrow beams of accelerated heavy charged particles (to obtain plasma potential profiles using two Heavy Ion Beam Probes having Cs+ ions accelerated to 150 keV), a pulsed helium beam (to obtain n_e and T_e at the plasma edge by the Line Ratio method), and microwaves (to study plasma fluctuations and radial electric fields by Doppler Reflectometry and to obtain density profiles by AM Reflectometry). In addition, probe based diagnostics (Langmuir or Mach) are employed on TJ-II to study the plasma edge. In all cases it is a requisite that perturbations are minimal in order to avoid altering the parameter(s) of interest to be measured. Also, not all systems are operated continuously, rather they need to be requested by users.

In TJ-II, fuelling is normally accomplished using a piezoelectric valve driven by a pre-programmed voltage signal. The signal profile, defined by the desired density profile, provides both pre-fill and active fuelling before and along a discharge, respectively. The average hydrogen flow rate is $\leq 3.5\times 10^{19}$ particles s^{-1}. A pellet injector is also operated on TJ-II. It is a 4-pellet per discharge system equipped with a cryogenic refrigerator for *in-situ* hydrogen pellet formation, fast propellant valves for pellet acceleration (800 to 1200 m/s), in-line diagnostics for determining pellet velocity and mass, plus straight delivery lines. Small pellets with 0.42 mm and 0.66 mm diameters (containing ≤4×10^{18} and ≤1.2×10^{19} hydrogen atoms, respectively) are required for experiments in which the electron density must not rise above the gyrotron cut-off limit (~1.7×10^{19} m^{-3}). Larger pellets with diameters of 0.76 mm and 1 mm, containing ≤1.8×10^{19} and ≤4.1×10^{19} hydrogen atoms, respectively, can be injected into higher density NBI-heated plasmas.

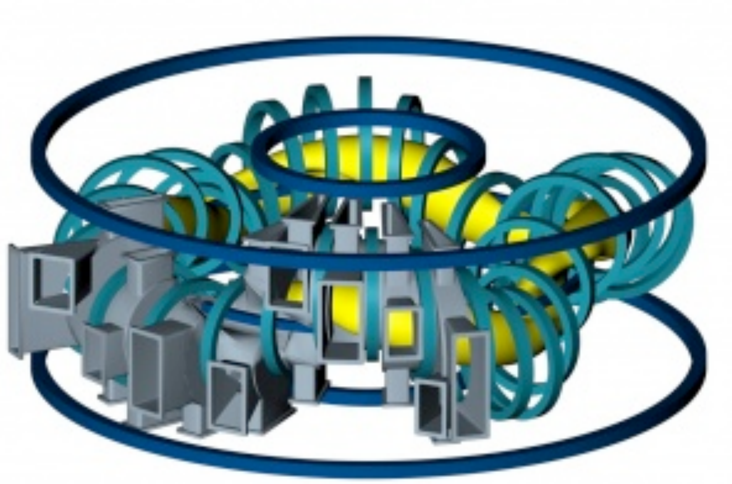

Figure 2. An artistic perspective of the TJ-II device showing the plasma (yellow), part of the vacuum vessel (grey) and the magnetic field coils (shades of blue).

The TJ-II is operated 2 or 3 days per week depending on needs, persons available etc. The experimental hall is closed at 9 am and remains closed until 5:30 pm when operation finished. Requests can be made to enter the hall between discharges but these are short and limited. First discharges are made at about 10 am once all engineering checks have been completed. Discharges are made once every 8 minutes so typically, 40 to 50 discharges can be made per day if no problems occur during the day. All data are stored on a central database - requests for specific data can be made after operation (shot number and data types). During operation the discharge data can be viewed in the TJ-II control room via a special data acquisition system as time traces. Some diagnostics such as fast frame cameras have separate data storage and viewing systems. Several time traces can be viewed simultaneously on local screens. TJ-II operation is controlled by one engineer and two physicists. Requests concerning discharges should be made to one of the physicists. Changes to gas puff, signal triggers, heating regime etc. can be made between discharges but major requirements should be requested prior to the operation days, e.g. magnetic configuations, NBI heaters.

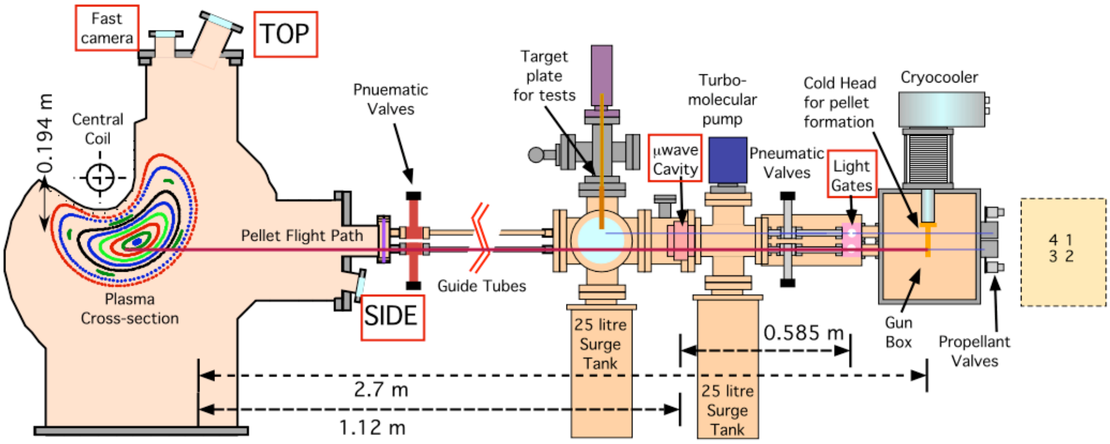

Figure 3. Sketch of the cross-section of the TJ-II and the pellet injector. The kidney-shaped closed magnetic field surfaces are seen on the left. Some TJ-II diagnostic posts are also shown.

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