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The Scientific Program of the Ignitor Experiment

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Introduction

Demonstration of ignition, the study of the physics of the ignition process, and the heating and control methods for a magnetically confined burning plasma are the most pressing issues in present day research on nuclear fusion and they are specifically addressed by the Ignitor experiment [1]. The machine is the first that has been proposed and designed to achieve fusion ignition conditions in well confined deuterium-tritium plasmas. Thanks to its unique features (high magnetic field, high plasma current density, high plasma density) Ignitor will explore plasma regimes that are not accessible to other existing or planned machines, providing needed information on some of the most critical extrapolations involved in designing burning plasma experiments. The operating life of the Ignitor device will follow three stages, characterized mainly by different ion mixtures: a preliminary phase in H or ^{4}He, where most engineering systems will become operational; a "physics intensive" D phase where the burning plasma experiments will be simulated; and a D-T phase where meaningful burning plasma conditions will be explored. Examples of the experiments and studies that can be carried out in each of these phases are presented.

Hydrogen/Helium phase

The first objective of the preliminary phase is to commission and bring to full power all systems and subsystems, with the exception of the tritium handling and diagnostics systems that rely strictly on fusion reactions (X-ray spectroscopy can provide T_i measurements, rather than neutron diagnostics). The full engineering capabilities of the machine will be tested, together with the fast multiple pellet injector. At this time as many diagnostics systems as possible will be installed. The advantage of working in aneutronic conditions can be exploited by conventional systems such as visible and UV spectroscopy that may have to be removed for the subsequent stage. Good practice with the remote handling of in-vessel components can be acquired at this time.

Deuterium phase

Preliminary operation in D will be devoted to an intensive physics program including investigation of particle and heat transport, validation of the scaling laws in a new range of plasma parameters, density profile control by gas puffing and pellet injection, test of current ramp scenarios. It will allow the investigation of the high density regimes that characterize Ignitor, the experimental scaling of Z_{eff} with increasing density, and the dependence on β_{pol} of the sawtooth characteristics. The full range of currents and toroidal fields will be utilized and the available ICRH system will be tested at relatively high power levels, following the verification of the effectiveness of the proposed heating schemes (deposition and absorption studies, rotation studies). Finally, the injection of ICRH comparable to the expected alpha power in D-T sub-ignited plasmas can be used to investigate transport, plasma–wall interactions, production of high energy tails for the study of fast particles driven instabilities, so called “advanced tokamak” scenarios, and long pulse operation. As an example, the evolution of a D-D discharge with I_p up to 7MA, B_t up to 9T and 15MW of absorbed power is compared with that of a D-T discharge with 10MW (see Fig.1). All relevant simulations are carried out using the JETTO equilibrium-transport code [2] and assuming a Bohm-gyroBohm transport model for both electrons and ions. Sawtooth oscillations are triggered by a critical peaking factor of the plasma pressure ($p_{kc}=p_0/<p>=3$), chosen on an empirical basis, as the pressure profile is a paramount parameter for burning plasmas. The performances are similar: in both cases peak temperatures above 6keV are reached, with volume-averaged densities around $3.4x10^{20}$ m^{-3} and confinement times close to the ITER97L global scaling. The alpha power of the D-T discharge is compensated by the higher ICRH power of the D-D case.

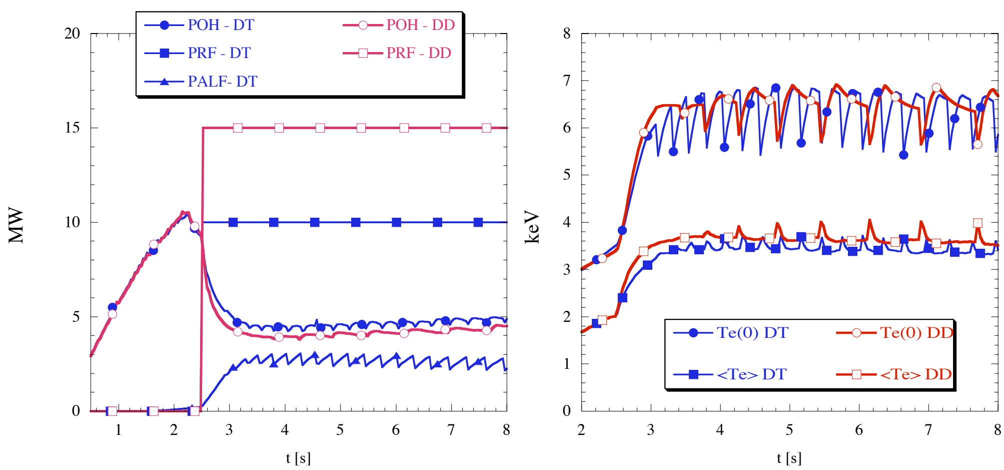

Fig. 1-Time evolution of powers (left panel) and temperatures (right panel) for a D-D and a D-T shot

Deuterium-Tritium phase

In the most ambitious phase of the scientific program a D-T mixture is employed, and maximum values of magnetic field (13T) and plasma current (11MA) will be important objectives. D-T experiments allow the investigation of important issues, such as Ohmic ignition, steady state at high Q, reversed shear scenarios, α−particle confinement, ash accumulation and removal, dynamics of L-H transition. In this phase, where burning plasma conditions are envisaged, the control of the plasma evolution is the most important issue and the transition from ignited to sub-ignited discharges should be pursued. In fact, this problem was investigated by appropriate numerical simulations: these include tuning injected heating power, the effect of the expected sawtooth oscillations driven by the plasma pressure gradient, and careful control of the D and T concentrations. Steady state, sub-ignited conditions were looked for by balancing the fuel composition and the amount of additional heating power, in the presence of sawtooth oscillations [2]. In particular the RF power can be injected repeatedly. The two runs that are compared in Fig.2 are obtained with Bohm-gyroBohm thermal diffusivity for electrons. The ion diffusivity is neoclassical in one case, following some FTU results at high density [3], and of Bohm-gyroBohm type in the other one, as shown in the left panel of Fig.2. Notice that comparable electron and ion thermal diffusion coefficients improve current penetration (right panel in Fig.2).

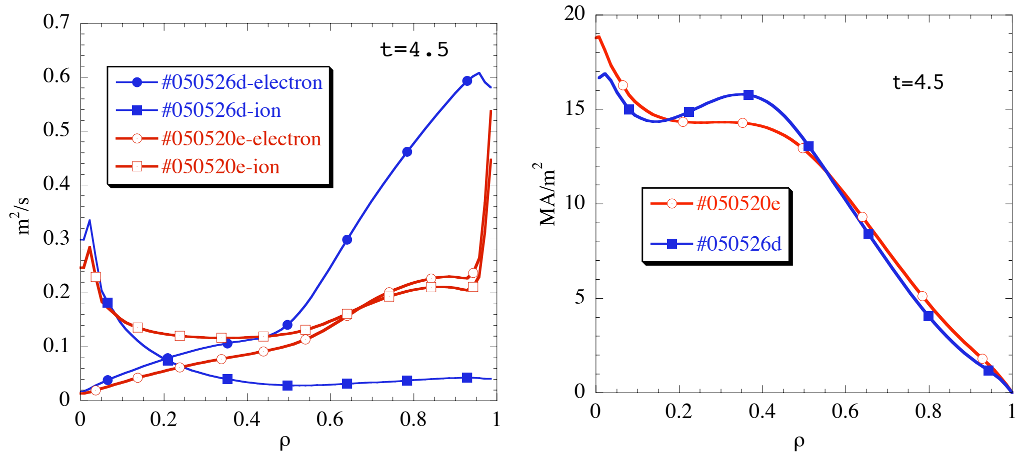

Fig.2 –Electron and ion thermal diffusivity profiles at 4.5s in the two shots (left panel). Current density profiles at the same time (right panel).

In both cases Tritium is fed 2s after the discharge start-up, when the ohmic power has already reached a significant value, the working density during the flattop time is ~$5.5 \times 10^{20} m^{-3}$ and the impurity content corresponds to an effective charge Z_{eff}~1.4. A RF pulse (~3.2MW) with a rather wide deposition profile is injected at different times. The results point out that, by properly adjusting the RF injection, similar performances are obtained, considering the ignition factor $I_M = P_\alpha / P_{loss}$ (Fig.3, right panel). The confinement time, relative to the ITER97L scaling law, is about 1.5 along the steady state phase (see Fig.4, right panel), in line with the results obtained in the FTU machine in the presence of ECRH, a heating process like the one expected to be produced by the α-particles.

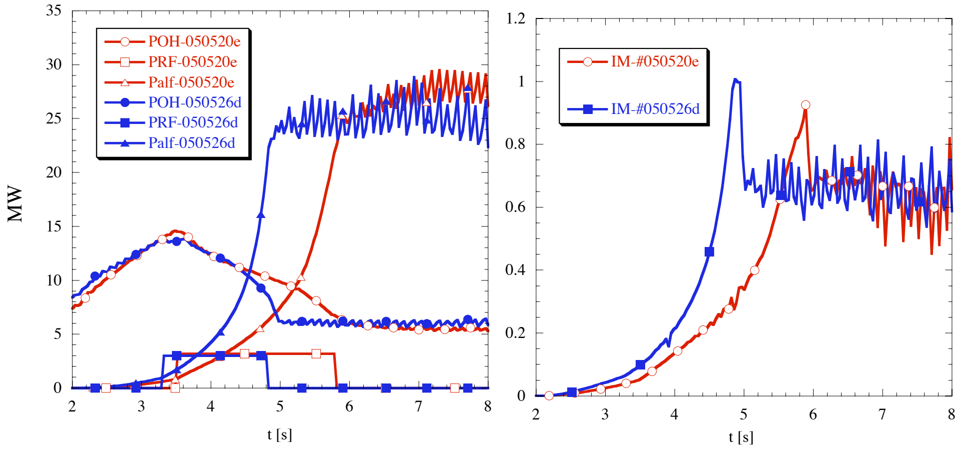

Fig.3-Time evolution of ohmic, RF and alpha power in the two shots (left panel). The ignition margin is in the right panel

The physics of transport and stability of fusion plasmas is not yet fully understood. Ignitor is expected to require short times to become productive and its regimes of operation at reduced parameters can overlap with those envisioned in large-scale devices in terms of the relevant dimensionless parameters. So its construction would be highly beneficial also to give useful information for large-scale experiments such as ITER. Notice that Q>10 ($Q=P_{fus}/P_{input}$) can easily be obtained.

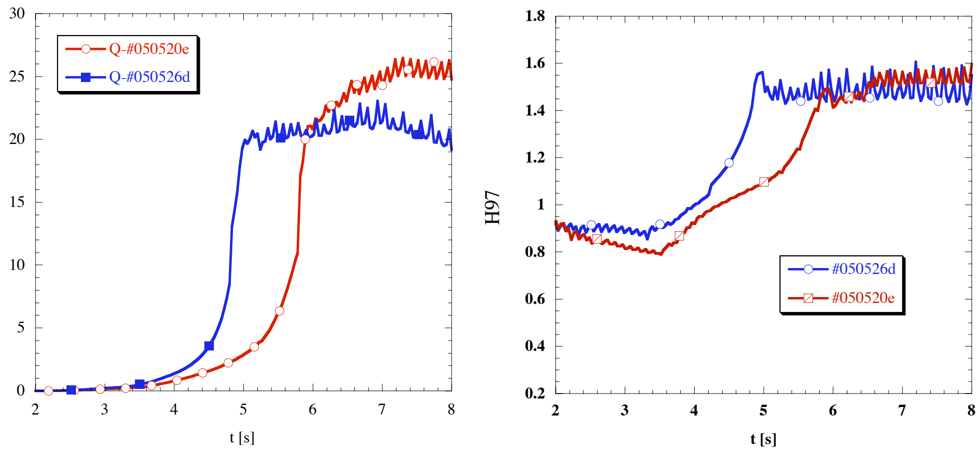

Fig.4-Time evolution of Q(left panel) and confinement times relative to ITER97L(right panel)

References

1-B. Coppi, A. Airoldi, F. Bombarda et al., *Nucl. Fusion* **41(9)**, 1253 (2001)
2-A. Airoldi and G. Cenacchi,"Ignited and subignited plasmas in Ignitor", IFP Report FP **04/4** (2004)
3-F. Alladio et al.,18th IAEA Fusion Energy Conference, Sorrento, 2000,(Vienna:IAEA) CD-ROM file **OV/2**