Recent European developments in fusion research towards ITER and DEMO

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The achievement of high confinement at high triangularity and at high density is a necessary condition for reaching the QD-T = 10 ITER target (H98 = 1, βN = 1.8, ne/nGW = 0.85).
Past experiments in JET with the ITER like Wall (ILW) in 2012-2014 showed that the high puff rates needed to keep the W core radiation within acceptable limits in the baseline scenario at high-δ(δav ~ 0.4, Ip = 2.5 MA) resulted in a confinement deterioration larger (10 – 30%) than that observed with the C-wall. A systematic interpretative heat transport analysis has been carried out where 10 pairs of ‘similar’ discharges for the two wall configurations have been analyzed. No significant change in effective heat conductivities have been found between similar pairs of discharges confirming that the core confinement is not degraded due to the change from C to (Be,W) for the first wall in JET. The degradation of the JET-ILW confinement with β at high ν\* is due to the reduction of the pedestal confinement since the core transport remains constant.

Experiments in JET in 2015–2016 have been conducted using a new high-δ configuration at high δav = 0.39 with a divertor geometry optimized for pumping (both strike points in the divertor corners). Under these conditions, high confinement plasmas are obtained up to 2 MA confirming that divertor pumping is a key element to access to good confinement in ILW scenarios. These new results represent a significant improvement with respect to earlier JET- ILW results.

A novel ICRH absorption scheme has been tested in JET which necessitates the presence of three different ion species in the plasma. These so-called three-ion ICRH scenarios show strong absorption of RF power at very low concentrations of the minority ions by choosing a proper main plasma mixture such that the L cut-off layer is located close to the third ion species cyclotron resonance. Thanks to the enhanced left- hand RF field component, RF power is efficiently absorbed even if the third ion species is present in trace quantities (~0.1%–1%). Proof of principle experiments have been carried out at JET and Alcator C-Mod. Three-ion minority heating of 3He ions in H-D plasma mixtures, D-(3He)-H scenario, has been successfully explored on JET with 3He concentrations as low as ~0.2% where 4.5 MW of ICRF power is coupled to H-D plasmas (3.2 T / 2 MA). RF generation of energetic 3He ions has been confirmed by several independent measurements. The new three-ion scenarios bring new applications and opportunities for ICRF operation, including a dedicated tool for fast-ion physics studies and new heating scenarios for JET and ITER, e.g. taking advantage of the presence of intrinsic 9Be impurities at low levels in JET-ILW as well as on ITER with the Be first wall.

Up to 2020, the focus of the JET campaigns is the preparation of the D-D, T-T and D-T campaigns and the investigation of the hydrogen isotope effects on fusion performance with the ITER first wall material mix. After the 2016–2017 shutdown, the major challenge for the 2018–2019 campaigns consists of integrating high confinement operation with the W-divertor constraints at full applied heating power. With the installation of upgraded actively cooled components, the NBI system will be capable of providing 34 MW in either deuterium or tritium to further extend the performance of the ILW.

The main construction phase of W7-X was completed in 2014. First plasma operation started in December 2015 and lasted until March 2016 with altogether 10 weeks of plasma operation. During this first operational phase (OP 1.1) the plasma was limited to an effective minor radius of a = 0.49 m by five inboard limiters. Although the main focus of the first operational campaign of W7-X was on the integral commissioning of the basic device together with first plasma operation, the largely trouble-free operation made it possible to spend a significant fraction of the campaign on physics studies.

Plasma breakdown was easily achieved with the available ECRH power. Continual plasma vessel conditioning with ECRH and GDC resulted in discharge lengths up to the limit defined by the maximum energy which in the OP 1.1 configuration could be injected into a single discharge (initially 2 MJ, eventually raised to 4 MJ). OP 1.1 discharges were typically characterized by low plasma densities (line averaged densities significantly below 1020 m–3), electron temperatures in the core region up to 10 keV exceeding the ion temperature by a factor of ~5, and the tendency for plasma termination by an uncontrolled increase of plasma radiation. The study of impurity generation and transport is ongoing.

After the installation of a test divertor unit, first experience with the magnetic island divertor will be gained in the operational phase 1.2 (OP 1.2). During this phase the uncooled divertor targets can take energies up to 80 MJ, allowing 10 sec plasma pulses at 8 MW of heating power. OP 1.2 will be followed by the installation of a steady-state capable high-heat-flux divertor and the completion of active water cooling of all in-vessel components in preparation of high power (10 MW) steady-state plasma operation up to pulse lengths of 30 minutes (OP 2).

The realization of a fusion relevant neutron source is a necessary step for the successful development of fusion and the definition of DEMO. The progress achieved in the EVEDA phase of the IFMIF project (running under the Broader Approach between EU and Japan) is ruling out technical concerns and potential showstoppers raised in the past. The Linear IFMIF Prototype Accelerator (LIPAc) presently under installation and commissioning in the Rokkasho Fusion Institute in Japan, will validate the concept of IFMIF accelerators with a D+ beam of 125 mA at 9 MeV. The final phase of the commissioning of the H+/D+ beams at 100 keV has taken place during 2016; the commissioning of the 5 MeV beam is foreseen for 2017. The 9 MeV D+ beam will be achieved within this decade.

Thus fusion research is now in the position where soon steps towards constructing a Li(d,xn) fusion relevant neutron source could be taken.