Progress on fusion research in Europe

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In the first JET campaigns with the ITER-like Wall (ILW) the priority of the experiments was on fuel retention and material migration studies. In recent campaigns, JET experiments have focused on the development of integrated scenarios in plasmas with plasma currents up to 4 MA, magnetic field up to 3.7T and auxiliary power up to PNBI ~ 27MW, PICRH ~ 7MW, PLHCD ~ 3MW. The aim was (i) to achieve low heat loads to the plasma-facing components and (ii) to avoid tungsten accumulation in view of realising high performance plasmas. The importance of the magnetic geometry, strike point location and divertor pumping were investigated in view of achieving good H-mode confinement, combined with an adequate control of tungsten accumulation by central heating using Ion Cyclotron Resonant Heating (ICRH) and sufficient gas fuelling. Significant efforts were devoted the realization of scenarios with large edge radiation which are essential for ITER.

H-mode and hybrid plasmas were obtained with energy confinement enhancement factors (Η98) in the range of 0.9-1.2 compared to the IPB98(y,2) scaling law. Previously stationary H-modes could be established with the ILW by avoiding W-accumulation through the production of frequent ELMs regimes by gas puffing. This had a detrimental effect on confinement, most likely because of pedestal cooling by gas injection. During the last two years stationary H-modes with confinement as projected for ITER (H98=1) have been produced by carefully placing the divertor strike points to maximise pumping. In this way stationary, long pulse (~9s) H-modes have been produced at low values for Zeff.

On the request of ITER, a dedicated experiment has been carried out in JET to verify predictions on the effects of transient tungsten melting in ITER due to ELMs. The horizontal tile of the JET divertor is made by solid tungsten arranged in four stacks of lamellae in order to minimize the electromagnetic loads during disruptions. Repetitive ELMs in JET can reach energies that are large enough (~ 300 kJ per ELM) to melt tungsten. Deliberate shallow tungsten melting has been produced by operating with the outer strike point on one protruding lamella, intentionally modified and installed in one divertor module on the innermost stack. A series of seven identical 3MA discharges with 23MW of heating power were produced. JET results are consistent with simulations of tungsten melting and propagation. The results have also given confidence that flash melting of the tungsten divertor elements by ELMs is relatively benign compared to bulk melting.

The Wendelstein 7-X (W7-X) stellarator (average minor and major radius a = 0.55 m and R0 = 5.5 m, plasma volume of about 30 m3) is now in its commissioning phase, that started in May 2014. The magnetic field (B=2.5 T) with five-fold symmetry, is created by 50 superconducting modular coils and 20 superconducting planar coils that will allow to vary the magnetic configuration substantially. Additional coils are installed (e.g. trim coils) to directly affect the SOL plasma. The divertor will make use of magnetic islands at the 5/4, 5/5 and 5/6 resonances of the rotational transform. Heating systems planned for W7-X are ECRH, NBI and ICRH and will be upgraded as the programme progresses. ECRH is planned to be the stationary high-power heating source (~ 10MW at 140GHz; X2, O2 heating). First plasmas are foreseen for late 2015.

To demonstrate reactor potential, W7-X needs to operate stationary at high-power and high-density. The first operational phase of W7-X will start with carbon limiter discharges, later replaced by divertor plasmas using an inertially cooled test divertor. In this first phase, the discharge lengths will be limited to 5–10 s depending on the heating power, defined by the maximum energy that can be deposited to the inertially cooled divertor (2MJ). In the second operational phase, with the actively cooled divertor installed, stationary discharges are planned with pulse lengths up to 30 min. Different fuelling schemes will be tested to avoid central density depletion due to thermo-diffusion. Furthermore, the behavior of impurities as well as the potential occurrence of edge-localized modes will be investigated.

One of the main aims of W7-X is to demonstrate good fast ion confinement at fusion-relevant  values of about 4%. To mimic the behaviour of alpha particles in a future stellarator reactor, a source of sufficiently energetic ions with energies in the range of 50 – 100 keV is needed in W7-X. Installation of an ion cyclotron resonance heating (ICRH) system is foreseen to ensure the creation of such populations. A novel heating scenario based on a three ion species plasma is planned to very efficiently generate high energy fast particles even at the highest densities forecasted for W7-X (> 2 1020 m-3).