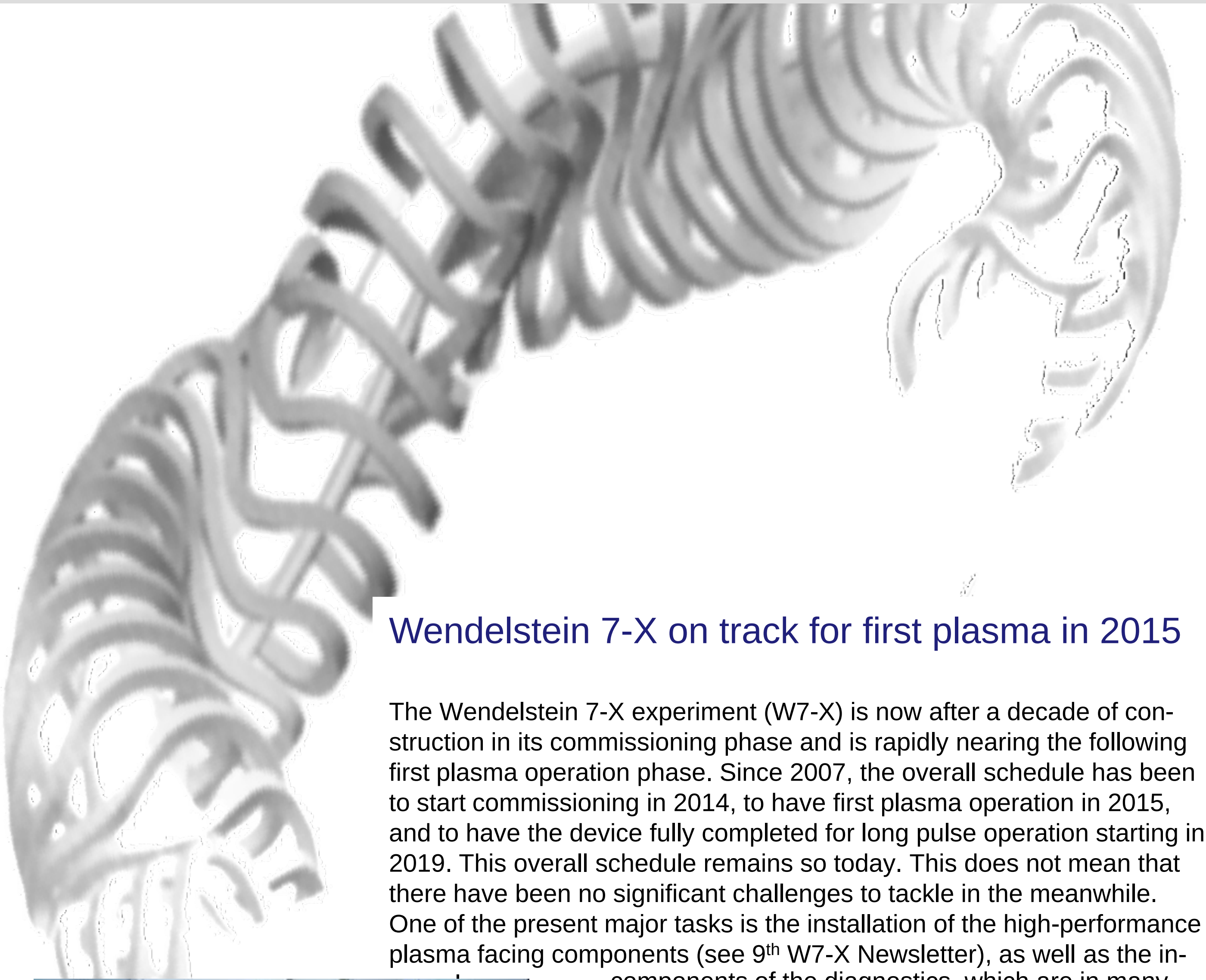
Wendelstein 7-X

NEWSLETTER

No. 10/ August 2014



Wendelstein 7-X on track for first plasma in 2015

The Wendelstein 7-X experiment (W7-X) is now after a decade of construction in its commissioning phase and is rapidly nearing the following first plasma operation phase. Since 2007, the overall schedule has been to start commissioning in 2014, to have first plasma operation in 2015, and to have the device fully completed for long pulse operation starting in 2019. This overall schedule remains so today. This does not mean that there have been no significant challenges to tackle in the meanwhile. One of the present major tasks is the installation of the high-performance plasma facing components (see 9th W7-X Newsletter), as well as the in- components of the diagnostics, which are in many cases integrated with the plasma facing components. These installation tasks are taking somewhat longer than anticipated.

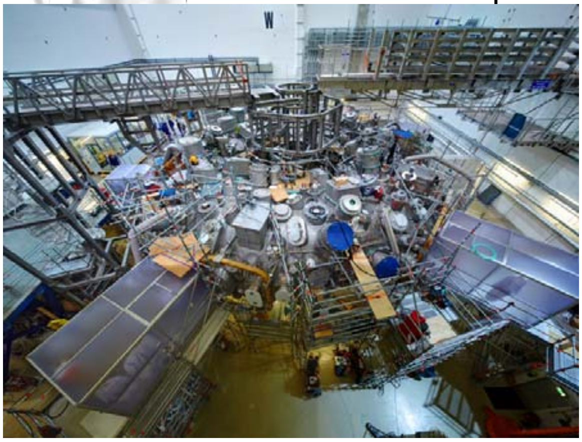


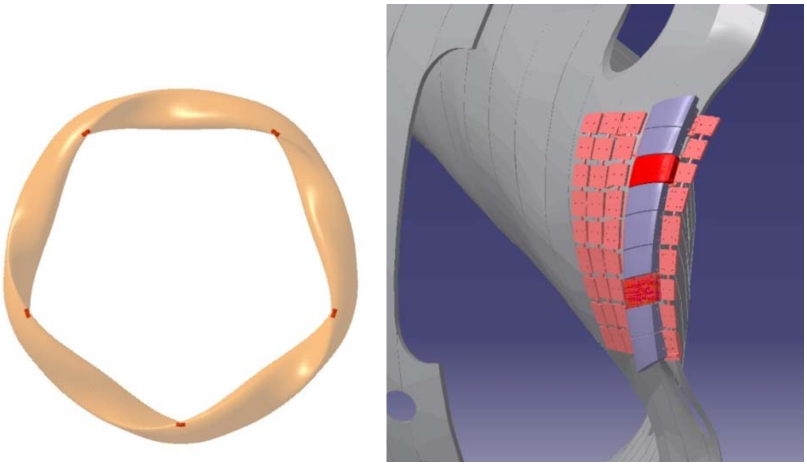
photo: IPP, Bernhard Ludewig

Figure 1. A recent view into the Wendelstein 7-X torus hall shows the nearly completed machine and the increasing amount of external components

In order to stay within the schedule, the plans for first plasma have been revised as follows:

1. The first plasma operation phase, referred to as OP1.1, will begin and end in 2015, lasting about three months. Instead of the earlier plan to have first plasmas with the ten test divertor units (the TDU), the first plasmas will be created with five graphite limiter stripes (the limiter).
2. The de-installation of the limiter, the installation of the TDU, and the completion of the installation of other plasma facing components will occur immediately thereafter. This will take about one year.
3. The plasma operation phase with the TDU, referred to as OP1.2, will begin in 2016.

The installation of the fully cooled plasma facing components for steady-state operation will take approximately two years, and the second major plasma operation campaign, OP2, with plasma pulses as long as 30 minutes, will begin in 2019.
The introduction of inboard limiters saves significant time on the path to first plasma, and thereby allows an early integral commissioning of the main systems needed for plasma operation: Cryostat, cryogenic cooling plant, the superconducting magnet system, the vacuum systems, electron cyclotron resonance heating (ECRH) system, and the essential diagnostics.



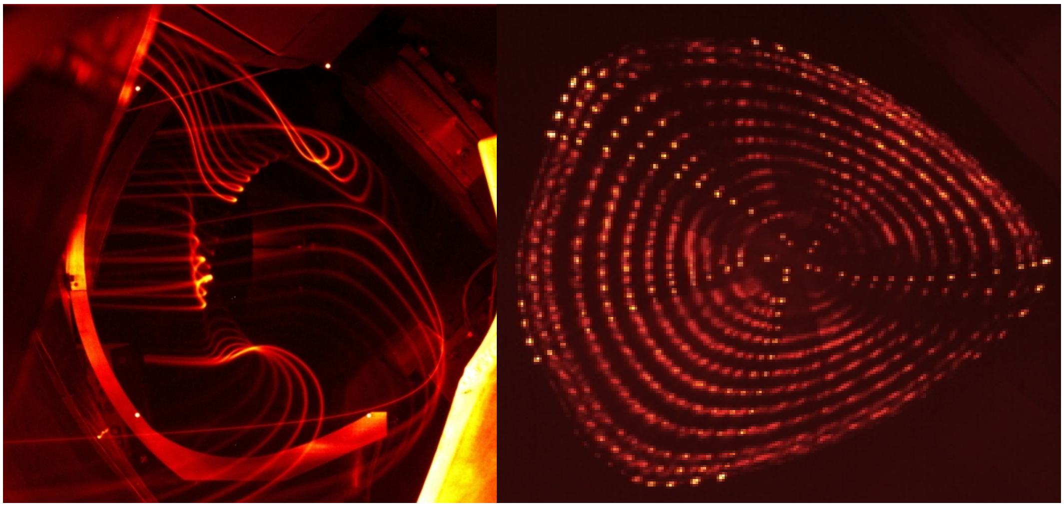
IPP, Dirk Hartmann

Figure 2. Left: The symmetric locations of the five limiter stripes are shown in a top-down view. Right: a CAD drawing of one of the five limiters as installed on wall protection elements. The tiles in red may be equipped with special probes to measure the plasma edge parameters

The limiters are designed so that they should be able to allow plasma operation with up to 2 MJ of injected energy per plasma pulse. That means, for example, that one should be able to make plasmas with a 1 second lifetime heated with 2 MW of ECRH. Such pulses are long enough to allow for an exciting first plasma operation program, where many important questions can be answered. In OP1.2, the TDU will allow pulse lengths of 10 seconds at 8 MW of ECRH, and in OP2, the fully water-cooled plasmas will last up to 30 minutes, ensuring that truly steady state operation can be studied.

The limiter will consist of five identical rows, placed symmetrically around the five-fold symmetric torus. Each row consists of nine high-temperature resistant graphite tiles that will intersect the intense plasma heat flux. A careful 3-D machining of the limiter surface will ensure that the intense heat flux is spread over the limiter face as uniformly as possible. A basic and yet nontrivial goal of OP1.1 is to be able to repeatedly create plasmas with electron temperatures well above 10 million degrees Celsius (approximately 1 keV). However, much more can be achieved if no major problems occur on the way to these first plasmas.

In the following we will give some examples of physics questions that can already be addressed in OP1.1, and why they are of interest



Photos: IPP, Matthias Otte

Figure 3. Field line mapping results from the predecessor to W7-X, W7-AS. To the left, individual field lines are visualized with an electron beam using background gas. To the right, the nested magnetic flux surfaces are measured using the electron beam and a phosphorescent rod (not visible).

The magnetic field quality of W7-X , in particular the existence of nested magnetic surfaces, is of utmost importance for reaching good confinement of the plasmas. This can be accurately measured and therefore verified even before making a first plasma. An electron beam injected along the magnetic field will follow the magnetic field lines almost exactly, and will therefore trace out the shape of the magnetic surfaces in detail.

Small error fields that may be detected during the electron beam flux surface mapping can be corrected using the set of five trim coils that was added for this exact purpose through a collaboration with the United States (also mentioned in the 9th Newsletter).

Once the desired magnetic topology has been verified and the operational magnetic field strength of 2.5 Tesla and a high quality vacuum have been reached, plasma operation can begin. The plasmas will be created by injection of microwaves at 140 GHz, which strike a resonance with the electrons in the magnetic field, and efficiently heat them up enough that they cause subsequent ionization of neutral atoms, eventually breaking down the neutral gas into a plasma.

The first W7-X plasmas will be helium plasmas. Such plasmas are relatively easy to create and control, and should serve rather efficiently to condition the walls of the machine. The ability for the ECRH generated plasmas to help condition and clean the plasma vessel will also be studied. Since the plasmas in the later operational phase OP1.2 will be made from hydrogen, some hydrogen plasma operation will also be performed towards the end of OP1.1.
The first plasmas will be relatively low density (1 to $5{*}10^{19}$ m^{-3}), with a relatively short pulse duration, initially 0.1 seconds, extending to several seconds, as experience is gained. The combination of low density and electron heating will lead to a situation where the electron temperature (~ 35 million K) is significantly higher than the ion temperature (~10 million K).

The much hotter electrons are predicted to be lost at a higher rate than the ions, initially. As a consequence, the plasma becomes slightly positively charged. This will enhance the electron confinement and decrease the ion confinement to the point where the two species are lost at the same rate, and a steady state for the charge content is established. This steady state will have an outward pointing electric field, which should improve the overall performance. The electric field also changes the orbits of the particles and can lead to an overall increase in plasma confinement in addition to impurity screening. As longer discharges with higher densities are achieved, the ion temperature will get closer to the electron temperature, and this beneficial feature may disappear again during a discharge. These phenomena can be studied in quite some detail in this first phase.

Summary

Wendelstein 7-X is rapidly approaching first plasma operation. The first plasmas will be created with a reduced set of in-vessel components, most importantly with a limiter instead of a divertor. A first analysis shows that despite the reduced number of in-vessel components, an exciting and relevant physics program can be achieved in this phase.

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