J. Plasma Fusion Res. SERIES, Vol.1 (1998) 53–56

The WENDELSTEIN 7-X Project

GRIEGER Guenter and the W7-X Team
Max-Planck-Institut für Plasmaphysik,
EURATOM Ass., Greifswald and Garching, P.O.B. 1533, 85740 Garching, Germany

(Received: 30 September 1997/Accepted: 22 October 1997)

Abstract

Before freezing all essential parameters for the construction of W7-X, their compatibility has been re-checked with the evolution of knowledge on HELIAS-type stellarators. It was found that no modification of earlier conclusions became necessary. Thus, W7-X is being realized according to the original plan except for somewhat more space which could be provided for the divertor arrangement. The Greifswald branch of IPP is under construction. The buildings will be ready for occupancy around the year 2000, when also the first parts will be delivered for the construction of the experimental facility.

Keywords:
Wendelstein 7-X, HELIAS, stellarator, IPP Greifswald

1. Introduction

As an essential milestone in the course of realization of WENDELSTEIN 7-X (W7-X)[1], the corner stone was layed for the new Greifswald branch of the Max-Planck-Institut für Plasmaphysik on 19 June 1997. W7-X is appearing on the scene when the world fusion programme has embarked on ITER to demonstrate burning plasma operation. Since for the time being the data base and thus the predictive capacity is largest for tokamaks, ITER has to be a tokamak. But since a fusion power station to become attractive has to prove economic competitiveness and general public acceptance, it is generally agreed that concept improvements are still necessary. W7-X is right in time to aim at demonstrating the particular ability of HELIAS-type stellarators [2] to provide these needed concept improvements. W7-X will be ready for operation several years after LHD [3,4] which aims at the same goal. But these few years of delay with respect to each other have allowed the introduction of several new results of stellarator theory in the concept of W7-X, and in this respect the two devices are designed using different criteria, and in this sense they are complementary. Once both are operating, it will be interesting to compare their performance.

During this conference, there are several overview papers on W7-X: on the W7-AS experiment by F. Wagner, on stellarator theory by J. Nührenberg, on the W7-X divertor concept by H.Renner, on the W7-X device construction by M. Wanner, on HELIAS-type power stations by H. Wobig, and on special details by some others, too. Apart from a short description of the new institute to house W7-X and its infrastructure, this paper will recapitulate the general philosophy underlying the concept of W7-X. This is justified because at the transition from the W7-X design to the construction phase it is useful to re-iterate the main points of the basic philosophy, and it is the last chance for re-checking their continued validity before everything is frozen.

2. Stellarators for Concept Improvement

HELIAS-type stellarators were designed by starting from reactor needs. The strong net toroidal currents inherent to the tokamak concept and responsible for their potential disruption could be avoided in HELIAS-

Corresponding author's e-mail: guenter.grieger@ipp.mpg.de

©1998 by The Japan Society of Plasma Science and Nuclear Fusion Research

type stellarators. This allowed full exploitation of the possibilities offered by the HELIAS concept and optimization of the magnetic configuration practically independent of the plasma pressure β for $<\beta>$-values of up to 5%, or even higher. This is fully sufficient for the operation of a fusion power station. These systems show the following desired properties:

- inherent capability of stationary operation
- absence of current disruptions
- sufficiently small loss cone for particles
- sufficient energy confinement
- negligible bootstrap current
- no need for current drive
- no need for feed-back position control
- no density limit except for a soft one arising from impurity radiation.

Thus, compared to the tokamak concepts of today, operation of power stations based on the HELIAS concept are expected to be much more benign and circulating power saving.

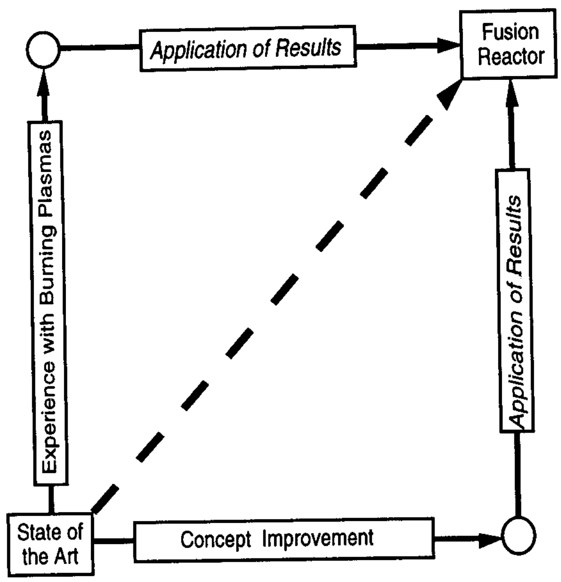

Fig. 1 Strategy for reactor development.

3. Strategy

Within the limits of present-day devices (W7-AS), the HELIAS concept has been successfully checked. But before relying on the reactor properties, an integral concept test is necessary with parameters close enough to the reactor ones. This is the task of W7-X. For satisfying these aims, W7-X has

- to possess the final reactor configuration, and
- to be large enough to yield conclusive predictions on DT plasmas so that extrapolations to reactor conditions are in an acceptable range.

The use of DT plasmas is not necessary in W7-X. As indicated in Fig. 1, it is rather possible to exploit the experience on DT plasmas gained with ITER, and to combine it with the results of W7-X. But this is only possible if both experiments, on burning plasmas with ITER, and on concept improvement with W7-X, are done in parallel.

4. Dispense with DT Operation

If W7-X had to be operated with DT to yield conclusive results, cost and complications had to be expected close to those envisaged for the construction and operation of ITER. It has to be considered, however, that the physics of the fusion process itself is well known, and that, practically, it is only the interaction of fusion-generated particles with the bulk plasma which is not covered by the exclusive use of non-DT plasmas. But information on this point will be available from ITER DT operation which can be checked on W7-X by injecting high energy neutral particles into H plasmas, and by performing some experiments with DD plasmas. This way of procedure reduces the cost of construction and operation by order of magnitude and allows much faster experimentation. The radioactive burden remains small and under all circumstances access to the experiment remains possible after one or two days at the latest. In addition, no problem will arise with the later decommissioning of the device.

5. Demonstration of Stationary Operation

Due to the absence of the need for strong toroidally flowing plasma currents, stellarators have the inherent property of stationary operation. This property was considered so important by the European Commission's Ad Hoc Group examining the proposal for W7-X that it requested W7-X to be made capable of yielding its demonstration above any doubt. This means that W7-X itself must be made capable of truly stationary operation which leads to the following requirements:

- The magnet system must be superconducting to arrive at manageable power consumption.
- A 140 GHz, 10 MW, cw heating source must be available. This can be achieved by using gyrotrons of 1 MW unit power.
- Continuous handling of 10 MW plasma throughput power must be possible. This is a design task.
- The divertor system must be capable of handling this throughput power and particle flux in stationary

fashion, and of limiting the impurity fraction to tolerable levels. This is a development task for W7-X but promising concepts exist.

Additional heating schemes are necessary for flexible experimentation but pulse durations of 10 s or so are sufficient. 30–110 MHz, 4 MW ICRH, and 55 keV, 3 MW NI(H), or 65 keV, 4.5 MW NI (D) will be available. During stage 2 of the experiment, the heating power will be increased to 20 MW for exploring the β-limit but also for this purpose pulses of 10 s are sufficient.

6. Characteristic Data of W7-X

Evolution of knowledge in physics and related technology have not yielded any request for changes of the basic machine parameters of W7-X. Only the shape of the inner coil surface and the corresponding shape of the vacuum vessel could be somewhat modified to provide more space for the divertor equipment and thus to make the divertor situation a bit more comfortable. All the performance relevant parameters were confirmed by the ongoing studies. The final characteristic data of W7-X are collected in the following table:

- Average major radius .... 5.5 m
- Average plasma radius .... 0.53 m
- Twist, on axis/boundary 0.84/0.99
- Pfirsch-Schlüter/diamagnetic currents 0.7
- Magnetic well depth .... 1.0 %
- MHD stability limit $<\beta>$ 4.3%
- Equivalent ripple 1.5%
- Reduction factor of bootstrap current ...... ≤0.1
- Magnetic field on axis/at coils .... 3.0/6.1 T
- Total magnetic energy .... 600 MJ

The basic configuration of W7-X is displayed in the following Fig. 2:

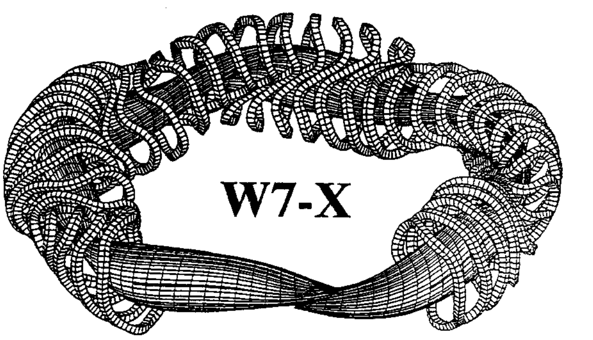

Fig. 2 W7-X, basic configuration.

Within the following limits, a coil system superimposed to the basic coil configuration shown in Fig.1 allows ample flexibility in the variation of the configuration :

- Twist on axis 0.75–1.01
- Twist on boundary 0.83–1,25
- Shear 0.10–0.20
- Mirror field on axis 0.00–0.10
- Magnetic well depth 0.004–0.015

This flexibility inherent to the machine can be utilized to search for the optimum parameters to be expected for the three essential cases: long mean free path, high β, and high performance. These are listed in the following table:

	long mean freepath	high β	high performance
B [T]	2.5	1.25	3.0
P [MW]	10	20	24
n(0)[10^{20} m^{-3}]	0.5	1.5	**3.0**
$T_e(0)$ [keV]	**6.0–9.4**	1.4–2.5	2.2–3.5
$T_i(0)$ [keV]	2.6–4.0	1.4–2.3	**2.2–3.4**
β(0) [%]	2.7–4.3	**11–19**	6.0–9.3
<β> [%]	0.7–1.3	**3.6–6.9**	2.0–3.5
τ_e [ms]	84–160	57–109	**158–291**

7. Extrapolation to Reactor Conditions

With respect to the extrapolation to reactor conditions and the predictive power of the expected W7-X results, the following statements can be made:

- The configurations are identical, only $|B|$ is doubled.
- The same normalized mean free path, $\Lambda^*=\lambda\iota/\pi R=100$, can be reached by ECRH for $n=0.6\times10^{20}$ m^{-3}, $T=3$ keV.
- The same ratio between plasma to ion gyroradius will occur for $Q_\rho=a/\rho\iota=350$ for $T_i=1$ keV (at $\Lambda^*=13$ for $n=0.5\times10^{20}$ m^{-3} for ECRH).
- The same relative plasma pressure $<\beta>=5\%$ will be produced for full heating power at half B.
- The ignition parameter, $n_i \times T_i \times \tau \simeq 30$ [10^{20} m^{-3} keV s] $\sim \beta \times Q_\rho^3 \times B$ can be approximated only within one order of magnitude because in W7-X not all the dimensionless parameters can be made equal to reactor values at the same time.
- α particle physics can be simulated by the injection of high-energy particles.
- The extrapolation is largest in magnetic energy (×100) but this is acceptable since no change in technology is required.

8. Operation Scenarios

W7-X will be capable of truly stationary operation and the power consumption for operating the confinement device with its superconducting magnet will be tolerable. But the power for providing 10 MW of stationary ECR heating may require up to 50 MW to be drawn from the grid which will yield an electricity bill of about 100.000 DM per operating day of 8 hours duration. It will thus be more economic to consider quasi-stationary operation for a few minutes with verification of the results by longer operation from time to time. For the exploration of the β-limit, 10 s pulses will be sufficient in any case.

9. The Greifswald Branch of IPP

For housing the W7-X activities, a new branch of IPP has been founded at Greifswald which is located at the north-east corner of Germany. Construction of the institute and all the infrastructure needed for the operation of W7-X has begun. It is expected that the buildings will be ready for occupancy in the year 2000 or 2001. Up to this time, the team of engineers responsible for the construction of the W7-X facility as well as the team operating W7-AS will continue to reside at Garching. Only Nührenberg's group on Stellarator Theory has already moved to Greifswald and shares rented space with the team of engineers responsible for the construction of the institute buildings and the infrastructure.

10. Summary

By also exploiting the results coming from DT using devices like ITER, W7-X is expected to answer conclusively all questions about the reactor properties of advanced HELIAS-type stellarators. The institute buildings and the infrastructure are under construction at the new site at Greifswald.

References

[1] G. Grieger *et al.*, Fusion Technology **21**, 1767 (1992).

[2] G. Grieger *et al.*, Physics Fluids B **4**, 2081 (1992).

[3] A. Iiyoshi, M. Fujiwara, O. Motojima, N. Ohyabu and K. Yamazaki, Fusion Technology **17**, 169 (1990).

[4] M.Fujiwara *et al.*, J. of Fusion Energy **15**, 7 (1996).