

Wendelstein 7-X going ahead

A comprehensive proposal for the W7-X project has been put forward to EURATOM for Phase I approval. As is usual in such cases, EURATOM has formed an Ad Hoc Group for the assessment of the proposal. The Wendelstein 7-X Ad Hoc Group (WAHG) consisted of 16 leading scientists from European laboratories, JET and NET, with A. Gibson as chairman. In its examination of the proposal the WAHG formed five subgroups on special topics, all of which had intense interactions with the proponents during the first half of this year. The WAHG unanimously recommended the project for EURATOM Phase I approval on scientific and technical grounds. This recommendation has led the Programme Committee (PC) and the Consultative Committee for Fusion Programme (CCFP) to propose that EURATOM authorize the start of engineering design and release the funds for associated R & D work.

The final report of the WAHG was issued in August 1991. It considers W7-X as the appropriate European next-step stellarator, with adequate size and parameters, and emphasizes the improvements of the W7-X concept:

- ➡ the drastic reduction of the particle drift excursions from the magnetic field surfaces,
- ➡ the near elimination of the bootstrap current,
- ➡ the minimization of Pfirsch-Schlüter currents, with the minimization of Shafranov shift, and
- ➡ the modular coil realization.

The W7-X project as laid out in the proposal will be designed as follows:

The magnetic field is produced by 50 poloidally closed nonplanar coils distributed in five identical modules, i.e., five field periods. In order to give operational flexibility to the device 20 additional noncircular planar coils are mounted over the modular coil system. In the Standard configuration, all currents are identical in the nonplanar coils and zero in the planar ones.

Modifications of this configuration are obtained either by energizing the planar coils (e.g., to produce low or high rotational transform, inward or outward shift of magnetic axis) or by energizing each of the five groups of identical nonplanar coils with slightly different (by a few percent) currents (e.g. to produce low or high mirror ratio, low or high shear).

Conventional NbTi superconductor technology has been chosen to allow a stationary magnetic field with long-pulse (30-s) plasma operation.

The main dimensions and parameters are:

major radius	5.5 m
Average plasma radius	0.5 m
Rotational transform on axis	0.84
at the edge	0.99
Magnetic well depth	1%
Average field on axis	3.0 T
Average coil radius	1.14 m
Average coil current density	48 MA/m ²
Maximum field at coil	6.1 T
Magnetic energy	600 MJ
Minimum plasma-wall distance	0.11 m

In the standard configuration, the intended plasma parameters are:

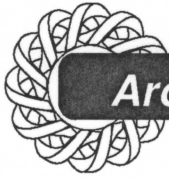
central ion and electron temperatures of 2– 5 keV
central density up to $2 \times 10^{20} \text{ m}^{-3}$

A preparatory R&D programme has been started with the goal of constructing a full-size modular prototype coil.

J. Junker and F. Rau for the Wendelstein 7-X Team
Max Planck Institut für Plasmaphysik
Garching, Germany

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Around the Labs

The Effects of Edge-Electrode Biasing in IMS

A positively biased electrode is placed in the edge region of the IMS plasma to induce a radial electric field and poloidal rotation in a fashion similar to the experiment performed on the TEXTOR device by R. R. Weynants et al.,¹ where significant improvements in particle confinement were observed. Initial observations using Langmuir and emissive probes show that the plasma potential and density profiles and the rotation characteristics are significantly different from those observed in unbiased plasmas.

Large changes are seen in the plasma potential profile with electrode biasing, as shown in Fig. 1. The lower trace is for a nominal discharge with a nonbiased electrode and is seen to be almost flat across the cross-section of the plasma. The upper trace shows the potential structure when the electrode is biased to +80 V and reveals strong gradients toward the edge regions. The separatrix is located at major radius values

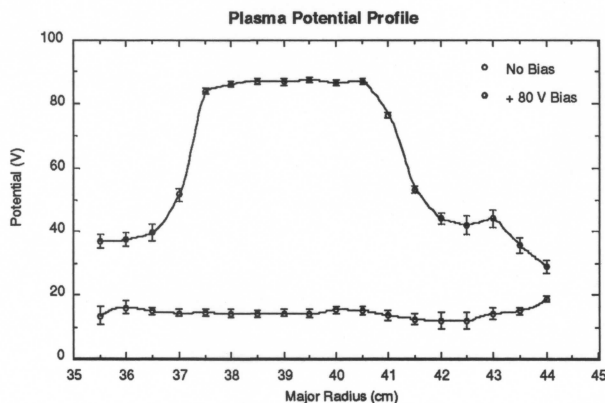


Fig. 1. IMS plasma potential profile measured with emissive probes.

of 35.5 cm and 42.5 cm for this scan, and the electrode is located at 41.5 cm. The profiles presented were obtained approximately 1/3 of the way around the machine toroidally from the biasing location. The effect on the density profile is seen in Fig. 2, where the nominal hollow profile becomes nearly flat across the magnetic surfaces that lie within the location of the biased electrode.

The radial electric field derived from the potential profile of Fig. 1 suggests that there should be a significant poloidally directed $E \times B$ drift to the plasma in the vicinity of the electrode. The density fluctuation spectra of two closely spaced, poloidally separated Langmuir probes were measured to obtain the time delay between the two signals and, equivalently, the local poloidal flow velocity. These measurements revealed a strong plasma rotation in the region of the electrode with a peak value of approximately 15 km/s, in close agreement with that predicted from the potential gradient in Fig. 1. Independent measurements of the poloidally directed ion currents are also consistent with a poloidal rotation with a peak value of 10 km/s.

The effect of biasing on the radial fluctuation-induced particle transport was also investigated. Fig. 3 shows these results and indicates a significant reduction in the magnitude of the radial transport near the edge regions of the plasma with biasing. This result is consistent with observations in the naturally occurring velocity shear

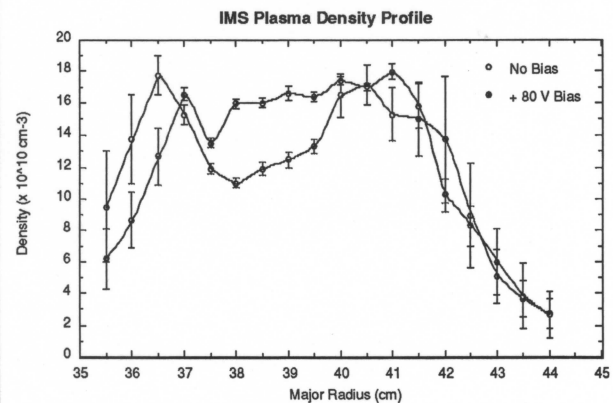


Fig. 2. IMS plasma density profile with and without applied electrode bias.

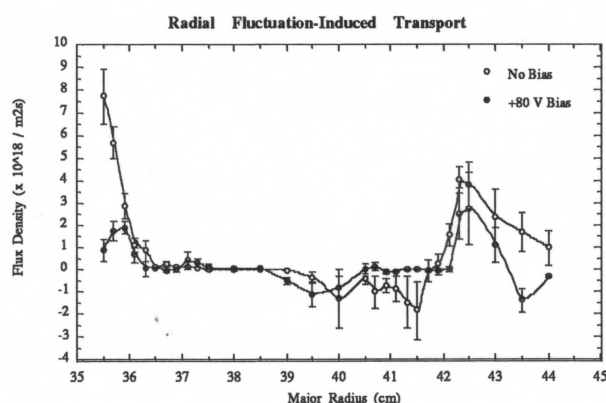


Fig. 3. Fluctuation particle transport profile showing the effect of the bias.

layer in the edge of the TEXT tokamak.² The present results from IMS also suggest that the velocity shear produced by the electrode biasing results in a reduction of the fluctuation-induced particle transport. Efforts are in progress to obtain more complete information on the effect of the electrode biasing on the IMS plasma transport processes.

Simon Anderson
University of Wisconsin
Torsatron-Stellarator Laboratory
1510 Johnson Drive
Madison, WI

1. R. R. Weynants et al., in *Proceedings of the 17th EPS Conference on Controlled Fusion and Plasma Heating*, Amsterdam, 1990, p. 287.

2. Ch. P. Ritz et al., *Phys. Rev. Lett.* **65**, 2543 (1990).

Heat Wave Studies in W7-AS with 140-GHz ECRH

Heat wave experiments have been conducted in W7-AS using a modulated 140-GHz gyrotron developed at the Kernforschungszentrum in Karlsruhe, Germany. This method allows one to generate a small periodic temperature modulation whose propagation is monitored by means of the multichannel heterodyne ECE radiometer. The aim of the experiments is to derive the electron thermal conductivity in a fast and direct way. Generally it can be determined in two ways, dynamic and static. The static method measures the temperature gradient for a given heat flux and calculates the heat conductivity as the ratio of flux and gradient, and the dynamic method determines the conductivity from the time-dependent reaction to a small, usually periodic temperature perturbation (modulation) applied to a stationary plasma state. The local amplitude and phase of the generated heat wave and their harmonics are the physical quantities used to determine the transport coefficient of interest.

In the W7-AS experiment with a 2.5-T resonant magnetic field on axis, the 70-GHz ECRH system is used for plasma buildup and heating. In earlier heat wave experiments one of the 70-GHz gyrotrons, operated in the first harmonic O-mode, was power modulated to generate the small time-dependent perturbation in the plasma center. The most important experimental condition for the method is the realization of well-localized power deposition in a zone sufficiently narrow to get clear separation of the source and the wave propagation region. Using the first harmonic O-mode, this condition is fulfilled for electron temperatures above about 2 keV and electron densities above $2 \times 10^{19} \text{ m}^{-3}$. Otherwise, the single-pass absorption through the central resonance zone is incomplete, giving rise to uncontrolled power deposition.

The situation is clearly improved when the second harmonic X-mode at 140 GHz is used as the modulated ECRH heating source. Due to the much higher optical depth of the plasma for this mode, absorption of the wave is complete within a few centimeters around the resonance layer for temperatures of the order of 100 eV at densities near $1 \times 10^{19} \text{ m}^{-3}$.

The experiments have been carried out using a plasma heated with ECRH alone (0.4 MW at 70 GHz) with a central electron temperature of about 2 keV and a central electron density of $2.5 \times 10^{19} \text{ m}^{-3}$. The ion temperature is around 300 eV, and radiation is insignificant in

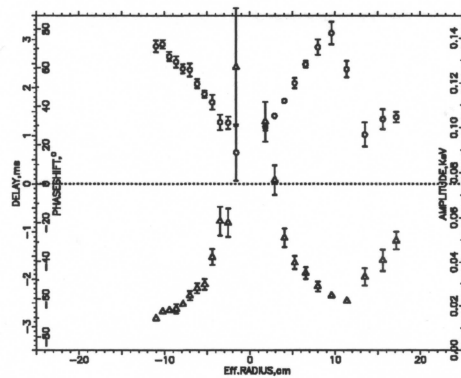


Fig. 1. Time delay (upper curve, circles) and amplitude of the heat wave (triangles) as a function of radius for central deposition of the modulated 140-GHz microwave power. The discharge is heated by two 70-GHz gyrotrons. Outside +10 cm the EC emission is inferred from suprathermal emission from the plasma center.

the plasma core region. So electron thermal conductivity is the main loss channel. The modulated 140-GHz beam delivers about 60 kW to the plasma, resulting in a maximum modulation amplitude of a few tens of eV. The modulation frequency is varied between 40 and 400 Hz.

Figure 1 gives an example of the time delay and the amplitude decay from which the electron thermal conductivity can be derived. The result of a simple slab-model analysis is given in Fig. 2. For comparison with the heat conductivity from the stationary power balance, a code has been installed predicting both amplitude and phase and using as input quantities the thermal conductivity from the stationary power balance, the stationary profiles, and the power deposition profile.

Predictions and measurements are in agreement within a factor of two. In a linearized model, both the local electron heat diffusivity and the convection velocity are

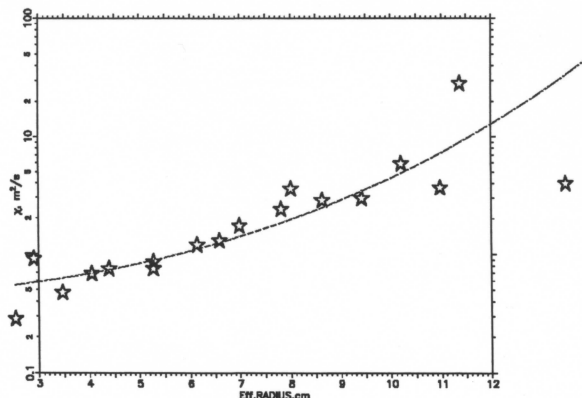


Fig. 2. Electron thermal conductivity as derived from the data of Fig. 1 using a simple slab model.

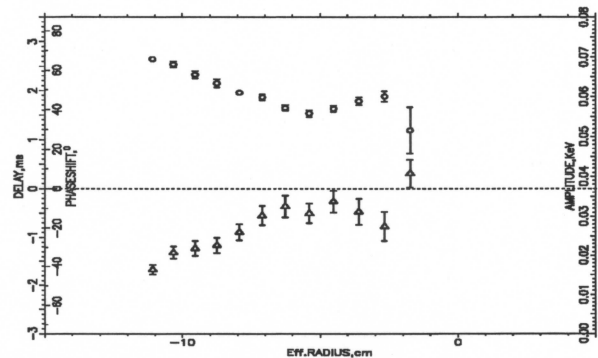


Fig. 3. Time delay (upper curve) and amplitude of the heat wave for off-axis deposition of the modulated 140 GHz power. Deposition is around -5 cm. The heat wave propagates both inward and outward.

estimated by means of a least-squares fit to the experimental profiles of modulation amplitude and time delay.

The high single-pass absorption of the incident microwave beam, even outside the plasma center, allows off-axis deposition experiments. The absorption of the 140-GHz radiation is virtually complete; therefore, the ECE spectrum between 130 and 150 GHz can be measured without any protection (notch filter) in front of the radiometer. Off-axis deposition is realized by optically steering the modulated microwave beam along a vertical line towards the plasma edge.

Examples of the phase delay as a function of radius are given in Figs. 3 and 4, demonstrating that heat waves propagating both inward and outward can be generated in this way. Theoretical analysis of these cases is under way.

H.-J. Hartfuss for the Wendelstein VII-AS Team
Max Planck Institut für Plasmaphysik
Garching, Germany

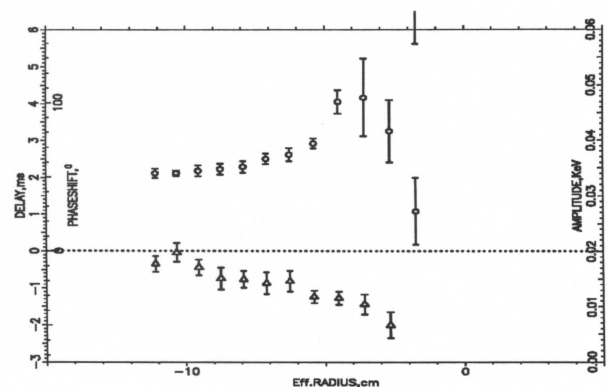


Fig. 4. Same as Fig. 3 with deposition around -10 cm. The heat wave is propagating only inward.

News from CHS

CHS ended its ICRF heating experiment in August. Two half-turn antennas have been taken off for upcoming ECH and NBI experiments. The next ICRF experiment is scheduled in 1992 with higher power. CHS will run till a short break for the second NBI installation in December. The major purpose of machine operation at present is to supplement diagnostics data for various kinds of experiments that have continued to operate since last year. Among them, we have obtained preliminary ECH results after improvement in the focusing system. The system, which was installed last year, consists of a stair-cut launcher, reflecting mirror, reflecting polarizer, and focusing mirror. By improving the reflecting and focusing mirrors, we can obtain a total conversion efficiency, for TE₀₂ mode to a Gaussian beam, of about 50 – 60% compared with about 30% for the previous system.

Electron temperature and density profiles for both on-axis and off-axis heating have been compared, and the effect of improved focusing has been confirmed by comparison with the deposited power profiles estimated from the pressure decay after the ECH turn-off. A substantial increase in the central electron temperature is observed for on-axis heating. Density clamping has been studied with the focused beam and is thought to be related to the trapped electrons. The focused irradiation on inboard and outboard sides on the same magnetic surface, but at a different confining magnetic field strength for each resonance, has been compared to see the effect of the helical ripple depth on the trapped electron production. The decrease in the density is enhanced for the outboard irradiation, which can be explained qualitatively. More detailed results will be reported in the next issue.

Keisuke Matsuoka for the CHS group
National Institute for Fusion Science
Nagoya 464-01, Japan

The relative calibration of a vacuum ultraviolet spectrometer

Vacuum ultraviolet spectroscopy is a powerful method for investigating impurity behavior in magnetic confined plasmas. However, it is a difficult task to calibrate the whole measuring system without a synchrotron radiation source. Recently the series of charge-exchange recombination lines from oxygen and carbon were used, but these lines are distributed sparsely, so a more detailed calibration method is required.

In this article we report on a relative sensitivity calibration measurement using titanium lines, which were observed in the Heliotron-E plasma. The titanium spectra were analyzed in discharges when titanium was accidentally dropped into the plasma. The fraction of these shots was about 2% of the shots sampled. Figure 1 shows a typical titanium spectrum for Ti XIV, Ti XV, and Ti XVI. The average central electron density and central temperature were $6 \times 10^{13} \text{ cm}^{-3}$ and 500 eV, respectively. The prominent lines are listed in Table 1.

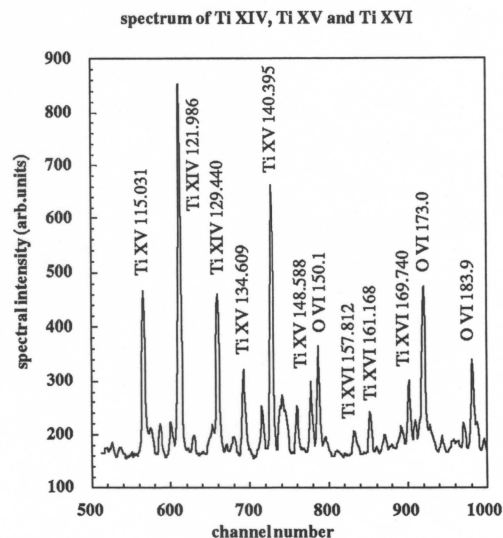


Fig. 1. Titanium spectrum observed when titanium was accidentally dropped into the plasma.

Table 1. Classification of titanium spectra

ion species	wavelength(Å)	configurations	terms	A-values (10^8 s^{-1})
Ti XIV	121.986	$2s^2 2p^5 - 2s^2 p^6$	$2P^0 - 2S$	627
	129.440	$2s^2 2p^5 - 2s^2 p^6$	$2P^0 - 2S$	259
Ti XV	115.031	$2s^2 2p^4 - 2s^2 p^5$	$1D - 1P^0$	1150
	134.609	$2s^2 2p^4 - 2s^2 p^5$	$3P - 3P^0$	191
	140.395	$2s^2 2p^4 - 2s^2 p^5$	$3P - 3P^0$	280
	148.588	$2s^2 2p^4 - 2s^2 p^5$	$3P - 3P^0$	82
Ti XIV	157.812	$2s^2 2p^3 - 2s^2 p^4$	$4S^0 - 4P$	132
	161.168	$2s^2 2p^3 - 2s^2 p^4$	$4S^0 - 4P$	120
	169.740	$2s^2 2p^3 - 2s^2 p^4$	$4S^0 - 4P$	100

The lines Ti XIV and Ti XV (140.395 Å, 148.588 Å) originate from the same upper levels, as shown in Figs. 2 and 3. The intensity ratios of these lines are given strictly. The estimated variation of the relative sensitivity at these wavelengths is less than 10%. The upper levels for the observed Ti XVI are not same as those shown in Fig. 4. The intensity ratios of these lines are reasonable ones, if the population densities of these levels are proportional to the statistical weights. Application of the laser blowoff technique with other materials could provide more detailed calibration results.

K. Kondo
Plasma Physics Laboratory
Kyoto University
Uji, Kyoto, Japan

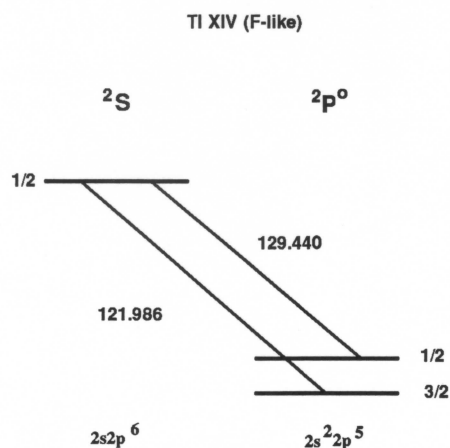


Fig. 2. The simplified Grotrian diagram for Ti XIV.

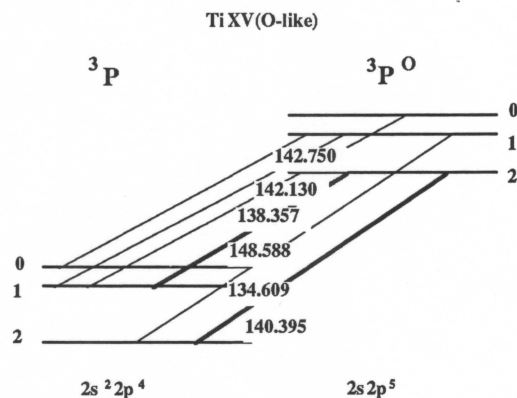


Fig. 3. The simplified Grotrian diagram for Ti XV.

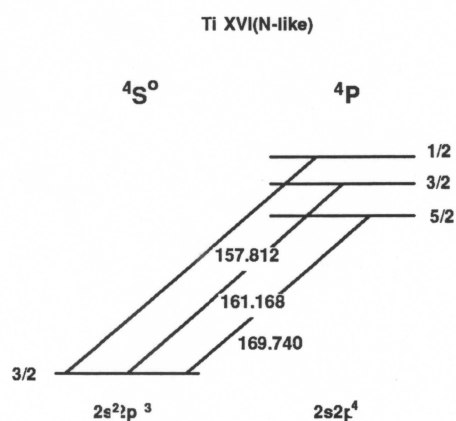


Fig. 4. The simplified Grotrian diagram for Ti XVI.