



stellarator news

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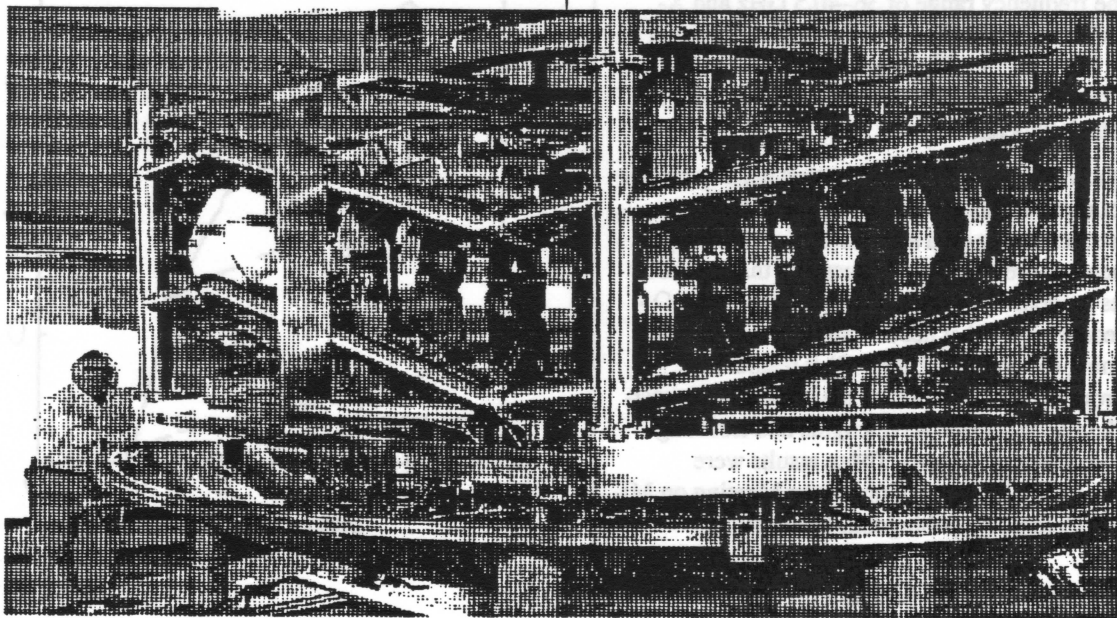
First Plasma in the H-1 Helic

A demonstration plasma was produced in the H-1 Helic in Canberra, Australia, for the first time at 3:48 p.m. EST on December 2, 1992. The initial operation, limited to low fields ($B < 800$ G) by a temporary power supply, has successfully used both ICRF (≈ 1 kW at 14 MHz into an uncooled 'helicon' antenna) and ECRF (2 kW mean power at 2.45 GHz from a domestic magnetron) to produce mean densities up to $1 \times 10^{11} \text{ cm}^{-3}$ (measured by an 8-mm interferometer). The density increases with B . Visual indications show that the plasma column is defined by the helical flux surfaces as computed. Once the base pressure is low enough and a larger motor-generator supply is connected, an extensive program of e-beam field mapping (using several techniques) will start.

The H-1 heliac is a versatile 3-field-period, high-transform device intended for basic plasma studies in a wide range of toroidal configurations and plasma conditions. Its main parameters are $R_0 = 1$ m, $a \approx 0.2$ m, $B < 1$ T (pulsed), 0.2 T (dc), and 0.25 MW of ICRF power.



The H-1 plasma.



The H-1 heliac and its "fearless leader" a few days before the tank went into place.

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Around the Labs

Electron density profile reconstruction for the Uragan-3M torsatron via upper X-mode reflectometry

O-mode microwave reflectometry is widely used for electron density profile reconstruction in tokamaks and stellarators. Use of the X-mode is less common because the refraction index of this wave depends on an additional parameter—the magnetic field. In tokamaks the total magnetic field is strongly influenced by a plasma current; this is not the case for stellarators, in which plasma influence on the total magnetic field distribution is weak (of the order of beta). Therefore, it is possible to reconstruct the electron density profile from measurements of the upper X-mode cut-off position vs probing frequency using data from vacuum magnetic field calculation along the wave trajectory.

This approach was used to reconstruct the electron density profile for an rf heated plasma in the Uragan-3M torsatron. A homodyne reflectometer with the BWO tuned in the frequency range of 36–40.5 GHz and X-mode launch was used in a regime with $B = 1.2$ T and $n_{\text{emax}}(0) = 5.0 \times 10^{12} \text{ cm}^{-3}$. Figure 1 shows the time behavior of the central electron density obtained from a 1.2-mm interferometer.

Figure 2 shows the results of the electron density profile reconstruction at 17 ms and the X-mode frequency curve. Laser scattering data are also shown. The upper X-mode needs larger probing frequencies than O-mode but it gives evident advantages in comparison with O-mode reflectometry: (1) it needs a smaller range of frequency tuning (of order of $2a/R$); (2) it results in smaller errors in determination of the cut-off layer position, Fig. 2 (due to shorter wavelengths and less magnetic field gradient influence). These results were presented at IAEA Technical Committee Meeting on Microwave Reflectometry (Abingdon, England, 3–5 March 1992).

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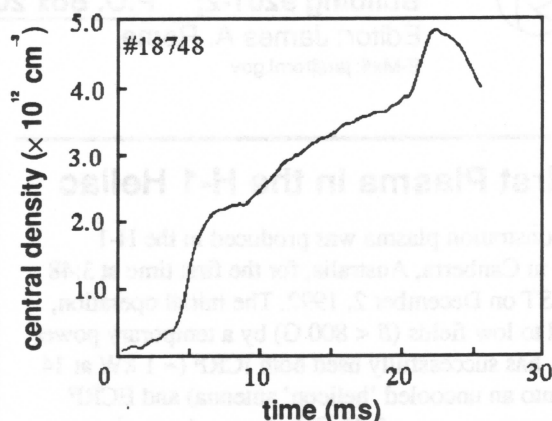


Fig. 1. Temporal behavior of central density for rf plasma in U-3M for both O- and X-modes.

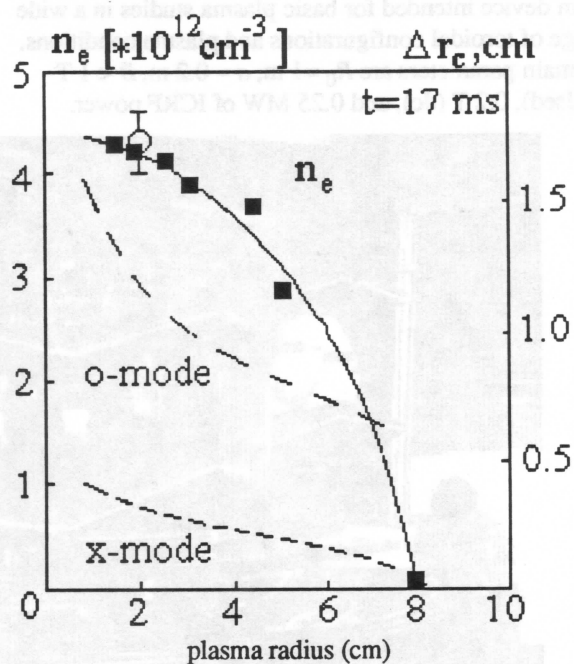


Fig. 2. Reconstructed electron density profile from X-mode reflectometry data (squares) and using Thomson scattering (circles). Dotted lines show the uncertainties of cut-off layer position determination.

A new antenna for icrf heating in the W7-AS stellarator

The first experimental campaign of ICRF heating in the W7-AS stellarator [1] fell short of its goal to heat the plasma at power levels comparable to those of ECRF or NBI heating. The rf power which could be coupled to the plasma was limited by arcing in the transmission line. No relevant changes in the plasma parameters could be observed at pure second-harmonic heating of a hydrogen plasma, while for minority heating of hydrogen initial heating was quickly masked by radiation collapse due to impurities. ICRF heating was, on the other hand, successfully used to produce a nonresonant target plasma for NBI heating.

For the next campaign two different strategies to increase the coupling efficiency of the antenna were considered. The first is to use conventional antennas (as in the first campaign) and shape them as closely as possible to the last magnetic surface. The second is to design a new antenna capable of coupling a narrow $k_{\parallel}$ spectrum around low values of $k_{\parallel}$, i.e., of cutting that part of the spectrum which either cannot propagate at all or decays too rapidly in the evanescence zone between the antenna and the cut-off layer. Obvious disadvantages of the first solution are, for example, that good matching of the antenna can be ensured only for a given value of the magnetic configuration; even more important, however, is the fact that such a method fails to demonstrate the feasibility of ICRF heating in future devices, where no external structure can be tolerated too close to the plasma. The main difficulty with the second solution is that the antenna must be quite broad since, in order to couple a $k_{\parallel}$ spectrum centered around wavelengths of 1 m or more, the antenna must necessarily be 1 m or more broad in the toroidal direction and the rf current must be smoothly distributed on it, which is clearly not possible with a conventional design.

The second strategy was selected and a broad antenna has been constructed and is ready to be operated in the W7-AS stellarator, see Figs. 1 and 2.

The toroidal breadth of the antenna is approximately 1 m, much larger than the 20-cm feedthrough port diameter. The antenna is situated on the high-field side, is short circuited at both ends, and can be fed independently at the four positions A, B, C, D (Fig. 2). It is therefore possible to change both the polarization of the electric field and the $k_{\parallel}$ spectrum coupled by the antenna (it can be centered either around $k_{\parallel} = 0$ or around $k_{\parallel} = 6 \text{ m}^{-1}$).

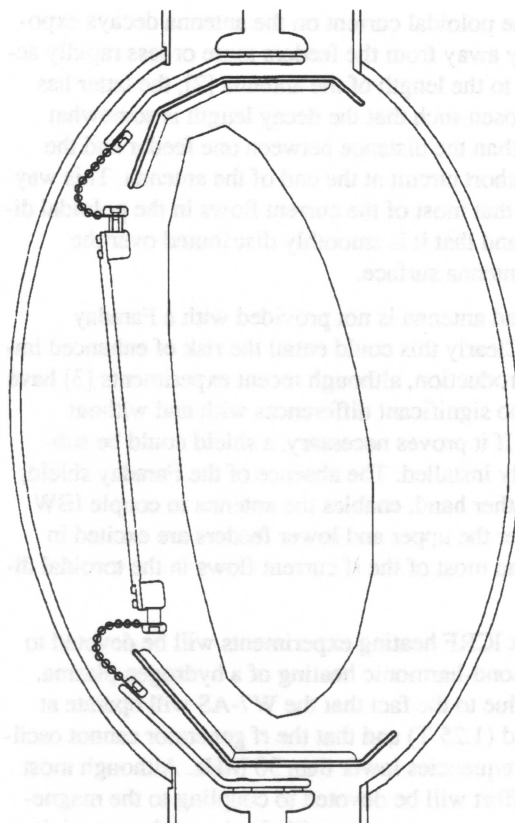


Fig. 1. Poloidal cut through the antenna at the location of one of the two feeder pairs.

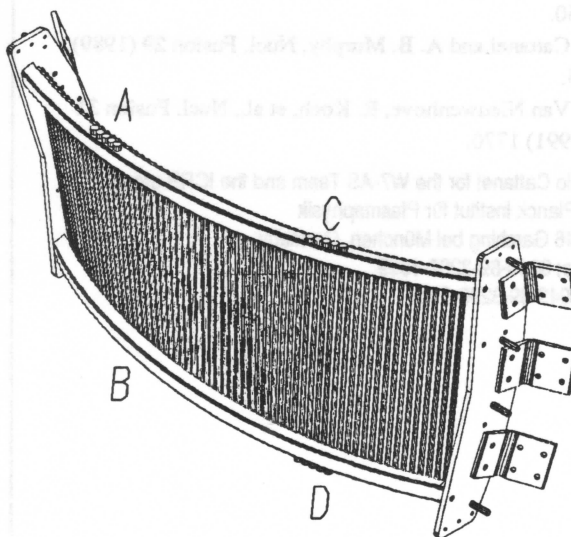


Fig. 2. Drawing of the antenna.

Since the poloidal current on the antenna decays exponentially away from the feeders more or less rapidly according to the length of the antenna [2], the latter has been chosen such that the decay length is somewhat shorter than the distance between one feeder and the nearest short circuit at the end of the antenna. This way ensures that most of the current flows in the poloidal direction and that it is smoothly distributed over the whole antenna surface.

The broad antenna is not provided with a Faraday shield. Clearly this could entail the risk of enhanced impurity production, although recent experiments [3] have shown no significant differences with and without shields. If it proves necessary, a shield could be subsequently installed. The absence of the Faraday shield, on the other hand, enables the antenna to couple IBW whenever the upper and lower feeders are excited in phase and most of the rf current flows in the toroidal direction.

The first ICRF heating experiments will be devoted to pure second-harmonic heating of a hydrogen plasma. This is due to the fact that the W7-AS will operate at half-field (1.25 T) and that the rf generator cannot oscillate at frequencies lower than 30 MHz. Although most of the effort will be devoted to coupling to the magnetosonic wave, an attempt will also be made to exploit the favorable high-field side location of the antenna for IBW coupling.

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Plasma edge transport study on W7-AS

Topology

W7-AS exhibits a flexible boundary topology which can be controlled by the external rotational transform and the positions of the two rail limiters. Poloidal and toroidal inhomogeneities arising from both limiter action and intrinsic magnetic perturbations in the vicinity of "natural" resonances $t = 5/m$ have been confirmed by 2-D resolved data from a Langmuir probe array [1].

For t values up to $1/2$ and small limiter aperture, the scrape-off layer (SOL) topology is characterized by large flux bundles of homogeneous connection lengths [2]. In the standard low-iota case ($t \approx 1/3$), L_c values of one, two, and three toroidal turns are dominant. The $L_c = 3$ flux bundles derive from the mapping of each limiter onto itself after three toroidal turns, whereas the $L_c = 1$ and 2 bundles reflect the mapping of the limiters onto each other. The ion saturation currents from the Langmuir probe array show respective poloidal maxima and minima.

Transport analysis

Within these coherent regions of the SOL, poloidal transport is small and a 1-D radial treatment of the plasma transport is appropriate, if the density is not too large (ECRH discharges). Accordingly, the particle and energy losses to the limiters can be parameterized by parallel residence times with transmission coefficients for the energies at the sheath [3]. Restricting ourselves to this case, we applied a 1-D (radial) fluid transport model to the flux bundles intersected by a fast reciprocating Langmuir probe [1].

For the particle and electron energy fluxes, standard diagonal diffusivities were assumed, including heat transport by particle diffusion. Owing to the strong toroidal asymmetry of the configuration, the transport equations had to be averaged along the flux tubes. T_e was assumed to be constant in the parallel direction, with the density dropping by a factor of 2 from the stagnation points to the limiters. $T_i = T_e$ was used throughout the SOL for lack of reliable experimental data. This assumption has little impact on the results owing to the weak dependence of the ion saturation current, I_s , on T_i and to the negligible ion-electron collisional coupling for the small densities in the SOL.

Particle ionization sources and energy losses were obtained from H_α calibrated DEGAS code calculations [4,5], for which the same flux tube geometry was used as for the plasma transport code. This allowed a direct

coupling of the source terms to the transport equations for the plasma.

Impurity radiation losses in the SOL were estimated from a nonequilibrium model, which takes into account the dependence of the radiation power on the parallel residence time [6]. An average impurity level of 5% carbon was assumed throughout the SOL.

The analysis has been applied to three limiter-dominated, $\tau \approx 1/3$ ECRH discharges at different density levels $n_e(0) = 2.2, 1.4, \text{ and } 0.5 \times 10^{19} \text{ m}^{-3}$ [7]. The central T_e varied from 1 to 1.6 keV (Fig. 1). The ECRH power was adjusted to give, for the three discharges, nearly the same electron temperature at the last closed magnetic surface (LCMS). Radial profiles of I_s and T_e in the SOL were obtained from Langmuir probe data and were typically nonexponential (Fig. 2, solid lines are the model fits).

Local transport coefficients D and χ_e were determined by least-squares fitting the calculated profiles of ion saturation current and electron temperature to the Langmuir probe data. The corresponding D and χ_e in the core were obtained from conventional particle and energy balance.

D in the SOL was found to increase with radius, matching the core profiles very well (Fig. 3). A radial increase

was indicated for χ_e as well, but a smooth transition at the LCMS was only possible by doubling the total energy losses. This clear underestimation of the energy losses in the model may be due to the effects of poorly known quantities that play a crucial role in the SOL, e.g., secondary electron emission at the limiters, impurity concentration, and Z_{eff} .

By relating D to the local n_e for the analyzed discharges, a uniform scaling with the inverse of the density seems to extend from the periphery of the confinement region ($r_{\text{eff}} = 8 \text{ cm}$) deep into the SOL over more than two orders of magnitude for D (Fig. 4). This scaling results from a regression analysis with a density and temperature power law ansatz for D , for which the temperature was found to be a nonrelevant parameter. A similar scaling was found earlier for the SOL-averaged D as function of the LCMS density for several ECRH and NBI discharges [1]. Furthermore, impurity diffusion coefficients, as estimated from the decay time of central aluminum lines for Al ablation into 280- to 350-kW ECRH discharges at $B = 2.5 \text{ T}$, see [8], provide a good extrapolation of the D scaling to higher density values. A D -value as deduced from fluctuation analysis also agrees quite well. It is planned to extend the database onto a larger range of densities and ECRH powers in order to validate the given scaling.

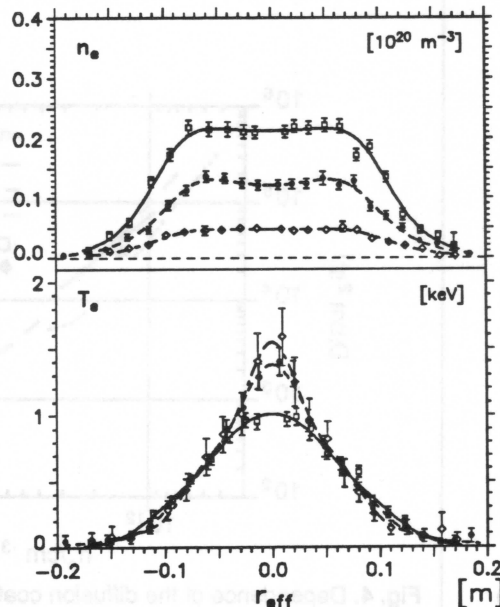


Fig. 1. Radial temperature and density profiles of the three analyzed discharges ($B = 1.25 \text{ T}$, $\tau = 0.35$, limiter position $r_{\text{eff}} = 12.3 \text{ cm}$). The ECRH power was chosen to give similar temperatures at the LCMS.

W7-AS profile database

shots:

19520–19545 ———
19469–19500 ---
19589–19617 ---

shots	B_0 [T]	τ_e	W_e [kW]	P_e [kW]
19520	1.26	0.347	1.18	274
19469	1.26	0.349	0.62	199
19589	1.26	0.350	0.21	192

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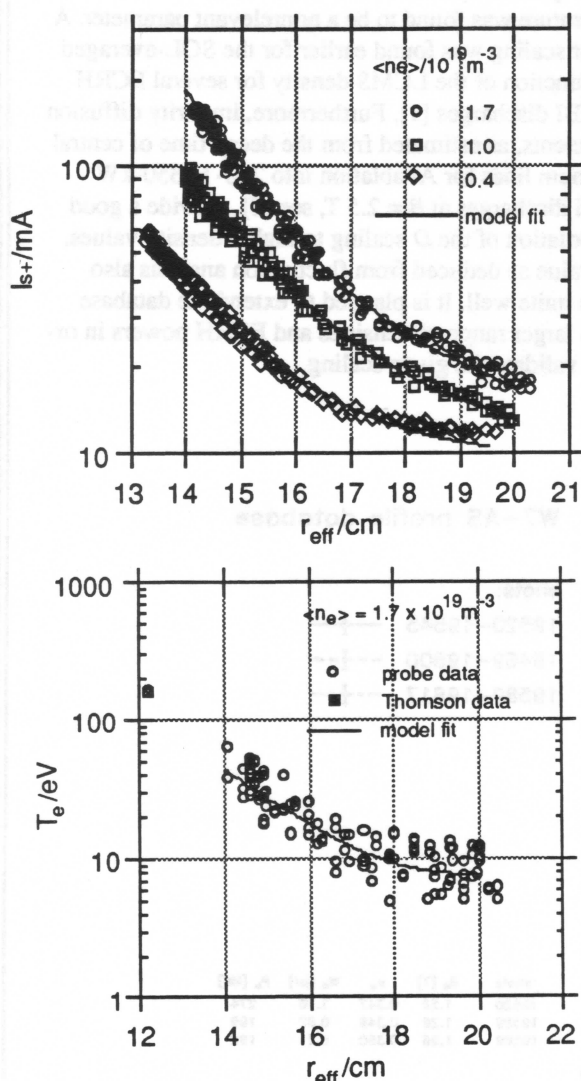


Fig. 2. Radial profiles of ion saturation currents for the analyzed discharges (top) and a typical profile of electron temperatures in the SOL from Langmuir probes (bottom). Model fits shown as solid lines.

ECRH, $B = 1.25 \text{ T}$, $\nu = 0.35$, $r_{lim} = 12.3 \text{ cm}$

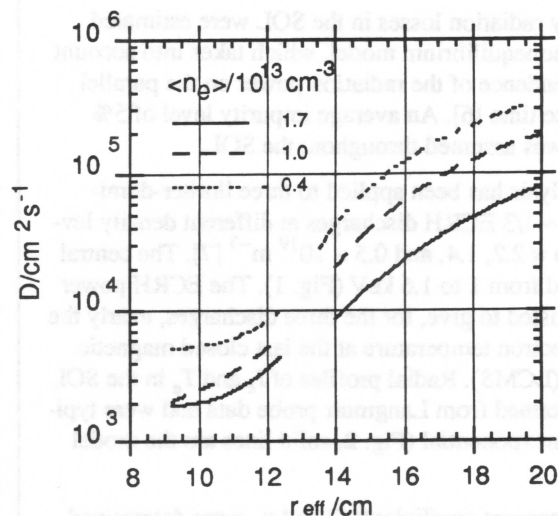


Fig. 3. Radial profiles of particle diffusion coefficients. Values inside the LCMS are derived from DEGAS code calculations combined with H_α data, values in the limiter shadow from SOL model, and Langmuir probe data. Error bars from statistics less than a factor of 2.5.

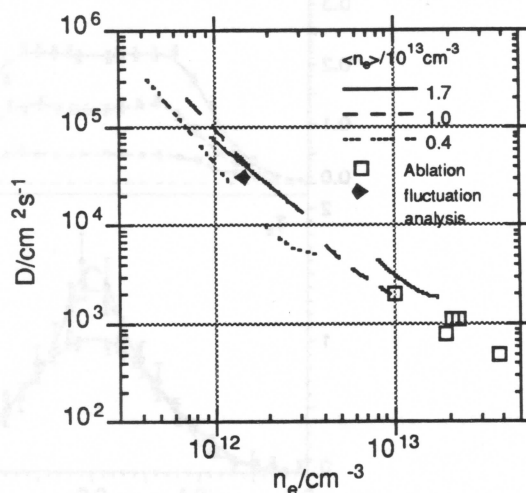


Fig. 4. Dependence of the diffusion coefficients shown in Fig. 3 on the local plasma density. Values of D from fluctuation analysis and aluminum ablation experiments are shown for comparison.

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