Some features of RF discharge development in the Uragan-3M torsatron

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INTRODUCTION

In the ℓ =3/*m*=9 U-3M torsatron with an open helical divertor a hydrogen plasma is RF produced and heated ($\omega \lesssim \omega_{ci}$). The RF power is introduced into the plasma with using an unshielded frame-like antenna with a broad spectrum of parallel wavelengths.

O.M. Shvets., I.A. Dikij, S.S. Kalinichenko *et al. Nucl. Fusion* 1986 26 23.
M.D. Carter, A.I. Lysoivan, V.E. Moiseenko *et al*. *Nucl. Fusion* 1990 30 723
Yu.G. Zalessky, P.I.Kurilko, N.I. Nazarov *et al. Fizika plazmy* 1989 15 1424 (in Russian).

Continuation of works:

V. V. Chechkin, L. I. Grigor'eva, Ye. L. Sorokovoy *et al.* 2009 *Plasma Phys. Reps.* 35 852.
I. M. Pankratov, A. A. Beletskii, V. L. Berezhnyj *et al.* 2010 *Contrib. Plasma Phys.* 50 520.

Time evolution is studied of:

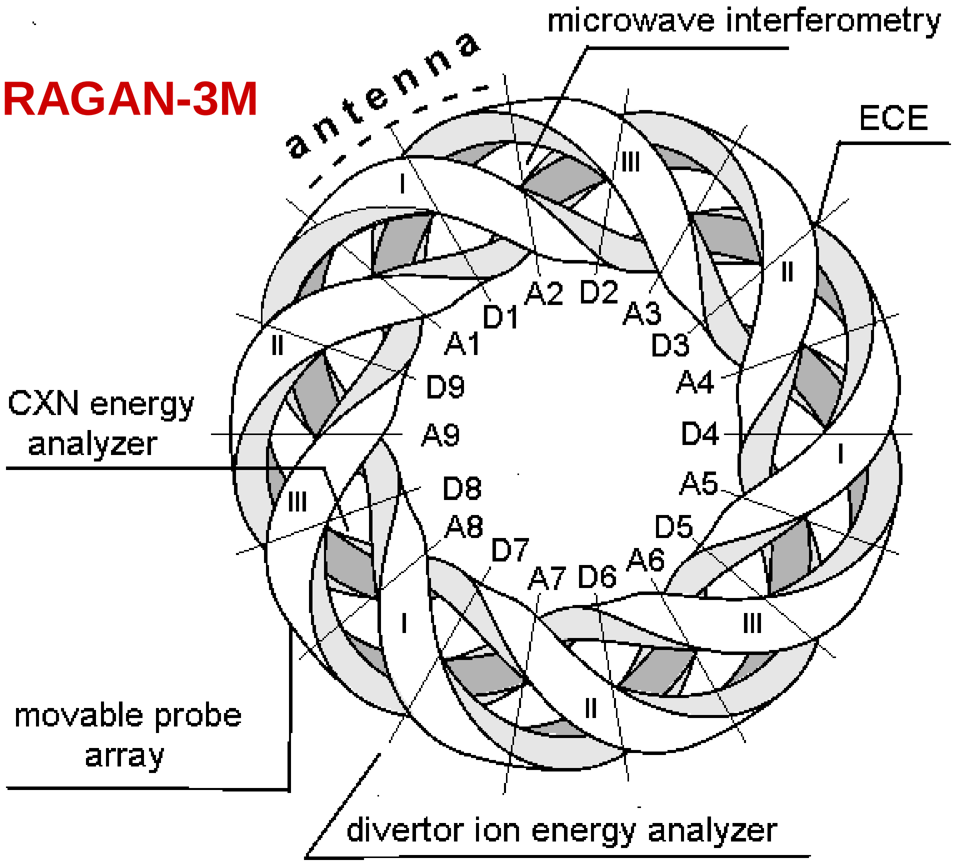
- Density $\bar{n}_e$ and electron cyclotron emission (ECE) from the central plasma at different values of RF power *P* fed to the antenna;
- Edge radial electric field E_r and edge turbulent transport;
- Fast ion (FI, $\gtrsim$500 eV) generation and loss.

The results are of interest to:

- Target plasma formation for subsequent production and heating of a denser plasma using another, shorter-wave antenna;
- Studying processes which are determinative in formation of the H-like mode states in U-3M and need a more detailed investigation.

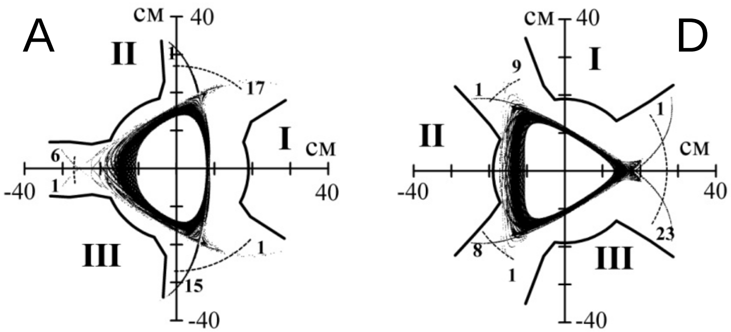
EXPERIMENTAL CONDITIONS

URAGAN-3M



I, II, III, helical coils

A1, D1, A2, D2,…, A9, D9, symmetric poloidal cross-sections in the periods 1, 2,…, 9



RF antenna is mounted under coils I and III with the leads in D1

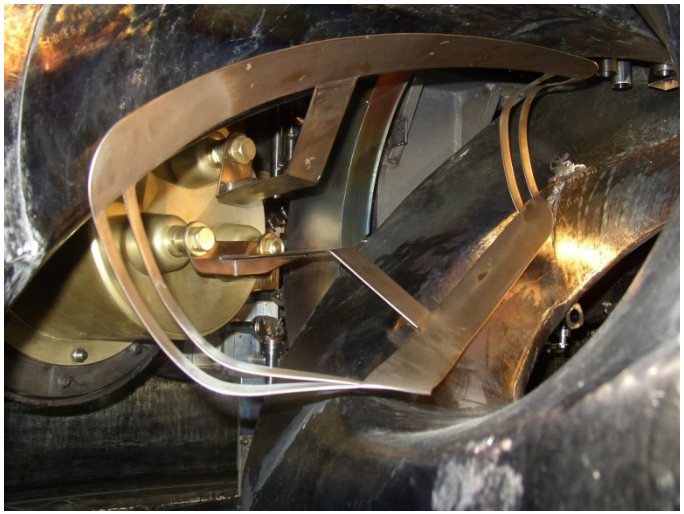
$\ell = 3$ / $m = 9$ torsatron, R_o=100 см, $\bar{a}\approx$12 cm, $\iota(a)/2\pi\approx0.3$.

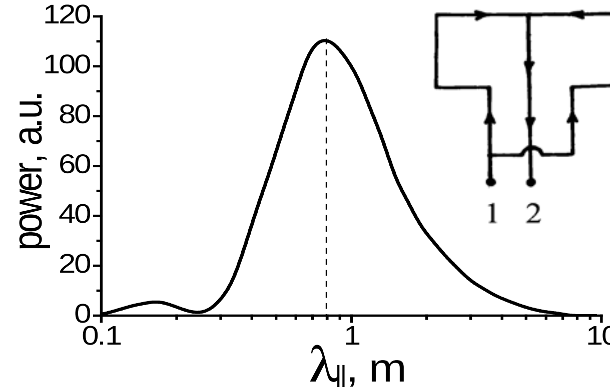
Helical coils only, $B_\phi \lesssim 1$ T, with the whole magnetic system enclosed into a large (70 m^3) vacuum chamber – an open helical divertor.

Continuous fuelling gas (hydrogen) admission, p~10^{-5} Torr.

RF plasma production and heating, $\boldsymbol{\omega \lesssim \omega_{ci}}$ under local Alfven resonance (LAR) conditions: $N_{||}^2 = \varepsilon_1$ ($N_{||} = k_{||}c/\omega$, $\varepsilon_1 \approx \omega_{pi}^2/(\omega_{ci}^2-\omega^2)$).

Twisted frame-like antenna.





$\lambda_{||}$~40-400 cm; $n_i \approx (7\text{-}0.07)\times 10^{12}$ cm^{-3};
$\lambda_{||maxP} \approx$ 80 cm; $n_{imaxP} \approx 1.8\times 10^{12}$ cm^{-3}.

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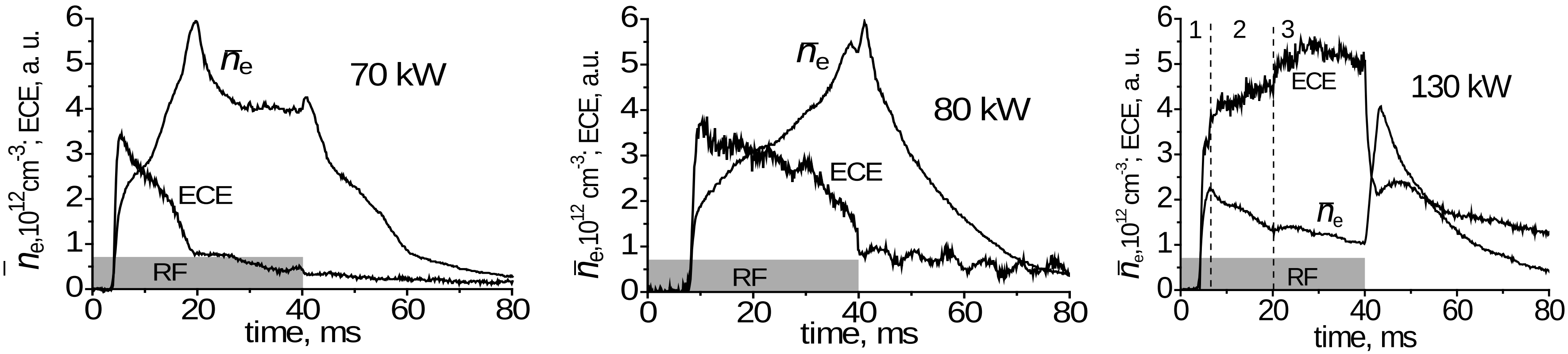
***Fizika plazmy* 1989 15 1424 (in Russian).**

B_ϕ= 0.72 T; $\omega/2\pi$= 8.8 MHz ($\omega = 0.8\omega_{ci}(0)$)
RF power fed to the antenna P $\lesssim$ 150 kW

$\bar{n}_e$~ units$\times 10^{12}$ cm^{-3}
Two groups of ions: T_{i1} ~ tens eV (optical spectroscopy); T_{i2} ~ 300-600 eV (CXN)
$T_e(0)$ ~ 500-700 eV (ECE).

TIME EVOLUTION OF ELECTRON DENSITY AND RADIATION TEMPERATURE AT DIFFERENT LEVELS OF RF POWER

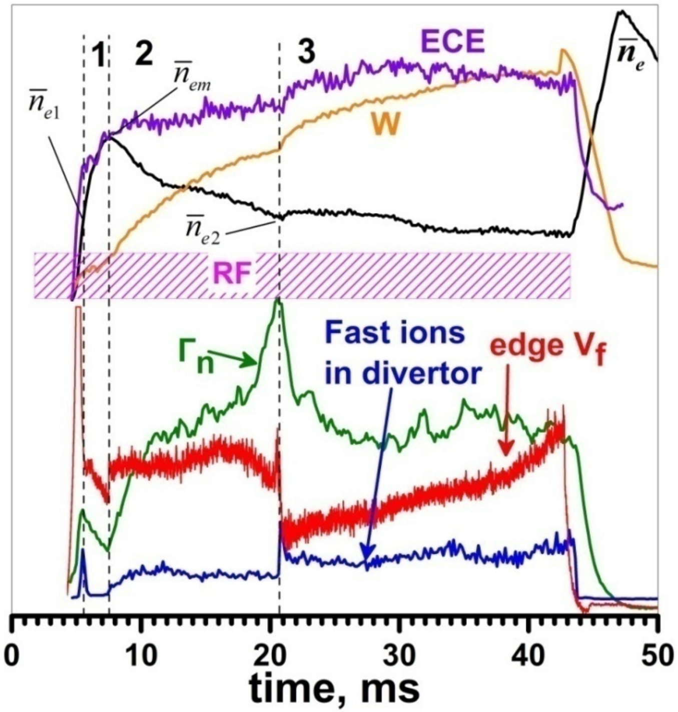


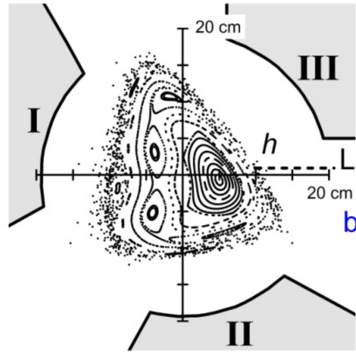
***P*~ 60 → 80 kW:** $\bar{n}_e$ attains ~2×10^{12} cm^{-3} (in ~2.5 ms at P=60 kW), then the density rise is slowed down ($\bar{n}_e(t)$ bend), with maximum $\bar{n}_e \approx 6\times10^{12}$ cm^{-3} attained the later the higher P is.
The central ECE attains its maximum at $\bar{n}_e \approx 2\times10^{12}$ см$^{-3}$, then multiply drops, presumably indicating a LAR zone shift to the periphery.
***P*>80 kW:** $\bar{n}_e$ does not attain $\approx 6\times10^{12}$ cm^{-3}, starting to decay before RF off, and the faster the higher P is, this being a manifestation of confinement degradation with power. At $P \gtrsim 100$ кВт the maximum density becomes $\bar{n}_{em} \approx 2\times10^{12}$ cm^{-3} ($\bar{n}_e(t)$ bend), while the high level of ECE persists over all the RF pulse, indicating optimum RF heating conditions.
***P*>110 kW,** as soon as the slowly decaying density approaches $\bar{n}_{e2} \approx 1.2\times10^{12}$ cm^{-3}, some commonly observed indications of the H-like mode transition occur:

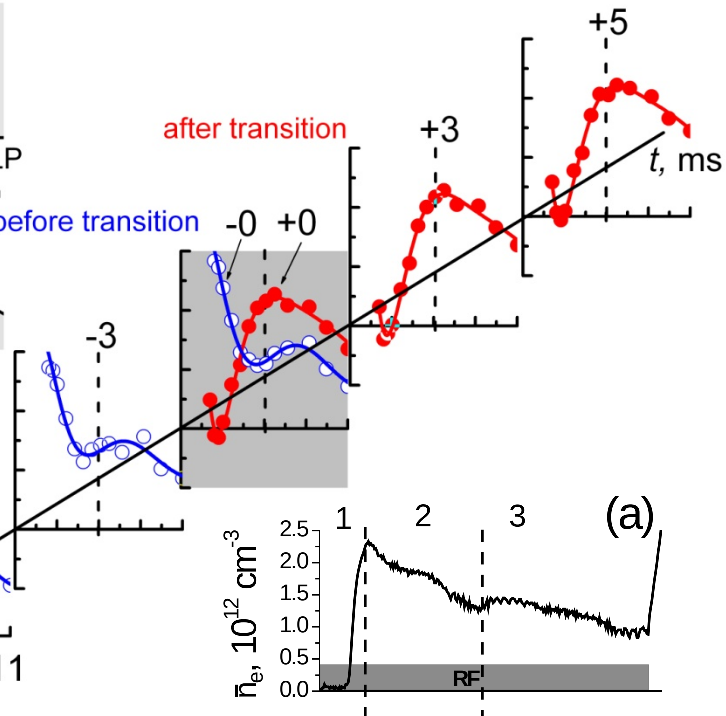
The $\bar{n}_e$ rise after RF off is due to the transport reduction with plasma cooling at a continuous influx of the fuelling gas (confirmed by numerical modeling).

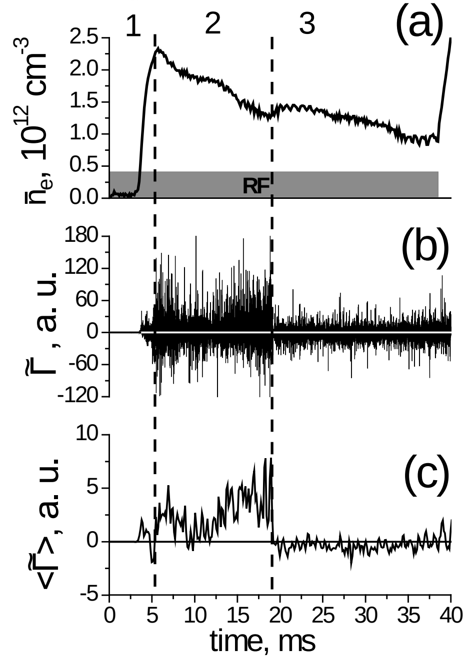
N.T. Besedin *et al.* 1993 *Stellarators and Other Helical Confinement Systems. Collection of Papers Presented at the IAEA TCM (Garching, Germany, 1993)* (Vienna: IAEA) p. 277

P = 130 kW









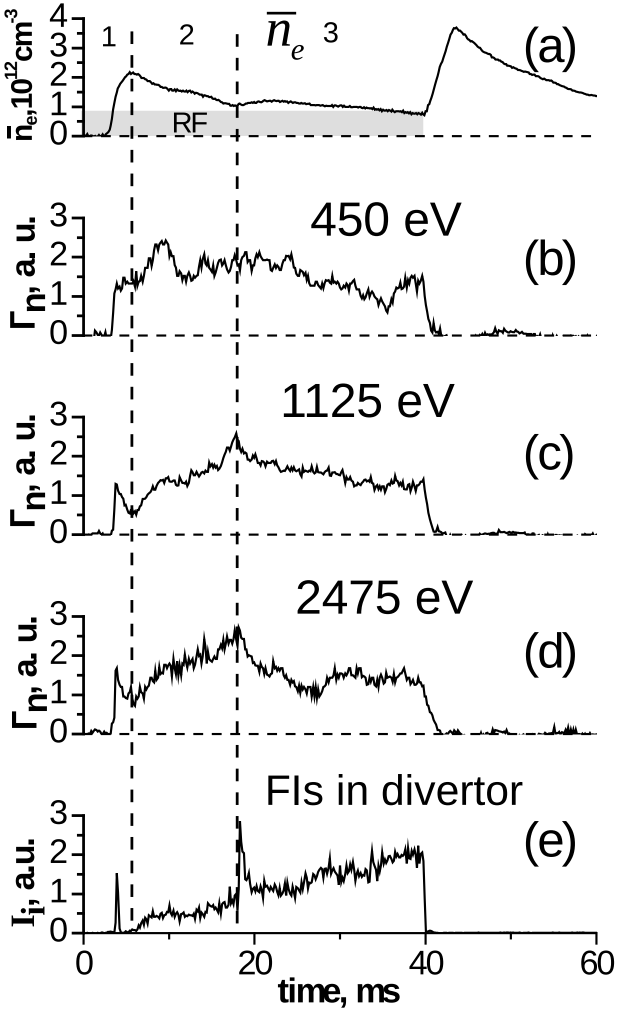
Indications of H-like mode transition:

- Temporal suspension of $\bar{n}_e$ decay and even some $\bar{n}_e$ rise;
- $W_{dia}(t)$ and ECE(t) bendings toward speeding-up of their rise;
- Step-like change in the edge potential V_f caused by an edge $|E_r|$ (and E_r shear) rise;
- Edge turbulence suppression

A distinct time correlation between the level of edge turbulent flux $\tilde{\Gamma}$ and the rate of average density decay

TIME BEHAVIOR OF FAST IONS (T_{i2} GROUP, ≳500 eV) AND THEIR LOSS.

The link between FI loss and H-mode transition



(b): $W_\perp$ < 500 eV: no correlation with $\bar{n}_e$(t)

(c, d): $W_\perp$ > 500 eV: Γ_n (t) changes in antiphase with $\bar{n}_e$; resonance-like dependence of Γ_n on $\bar{n}_e$

(e): a short-time (< 0.5 ms) single burst of FI outflow to the divertor ("burst of FI loss") just before H-like transition – an indication of transition to be triggered by the FI loss.

SUMMARY

1. Using the frame-like antenna with a broad spectrum of parallel wavelengths $\lambda_{||}$, a cold plasma with $\bar{n}_e$~(4-7)×10^{12} cm^{-3} (*P*~60-80 kW) and a plasma with high $T_e(0)$ and $\bar{n}_e$~2×10^{12} cm^{-3} (P > 100 kW) can be produced in U-3M. At present both regimes are being investigated as possible sources of a target plasma for production and heating of denser (up to ~ 10^{13} cm^{-3}) plasmas using another, shorter-wave antenna with azimutal currents.

Kasilov S.V., Lysojvan A.I., Moiseenko V.E., Plyusnin V.V. *Stellarators and Other Helical Confinement Systems* (Vienna: IAEA, 1993, p. 447).

2. Processes occurring during the RF pulse can be divided into slower and faster ones by their characteristic time scale.

Slower processes (tens/units ms): $\bar{n}_e$ decay and energy content W_{dia} rise (both ~10 ms); FI concentration rise (units ms). As a result, a peculiar “coupling resonance” sets in where optimum conditions for FI generation at $\bar{n}_e \approx 1.2\times10^{12}$ cm^{-3} are realized.

Faster processes (hundreds/tens μs) responsible for the H-like mode transition in itself: the burst of FI loss (hundreds μs) → the edge E_r bifurcation toward a more negative value with the higher E_r shear (tens μs) → suppression of the edge turbulence and the turbulence-induced transport (tens μs) with improvement of plasma confinement as a final result.

τ_E is shown to increase from 2.7 ms to 5.1 ms

V.K. Pashnev, *et al*. *Problems At. Sci. Tech.* 2010 No. 6 Series: Plasma Phys. (16) p. 17

3. Similar to other devices, in U-3M a specific radial profile of the edge electrostatic potential with the “well” near the LCFS and a lower E_r shear are formed in the L-like state and can be attributed, by analogy, to the non-ambipolar ion orbit loss. The previously formed E_r shear considerably increases with transition, with the potential “well” shifting inside the LCFS.

4. Triggered by a short-time enhanced FI loss, the state of discharge with the modified edge E_r profile where the turbulent transport is suppressed persists for a comparatively long period without recovering the pre-transitional high level of the edge turbulence.

In more detail see
PAST (Problems of Atomic Science and Technology). Series “Plasma Physics”. 2012. No. 6 (82), p. 3

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