Russian Research Centre “KURCHATOV INSTITUTE”
Institute of Nuclear Fusion

STATUS OF PLASMA NEUTRALIZER DEVELOPMENT

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Fourth IAEA Technical Meeting on Negative Ion Based Neutral Beam Injectors, Padova, ITALY, 9 – 11 May, 2005

PLASMA NEUTRALIZER DEVELOPMENT

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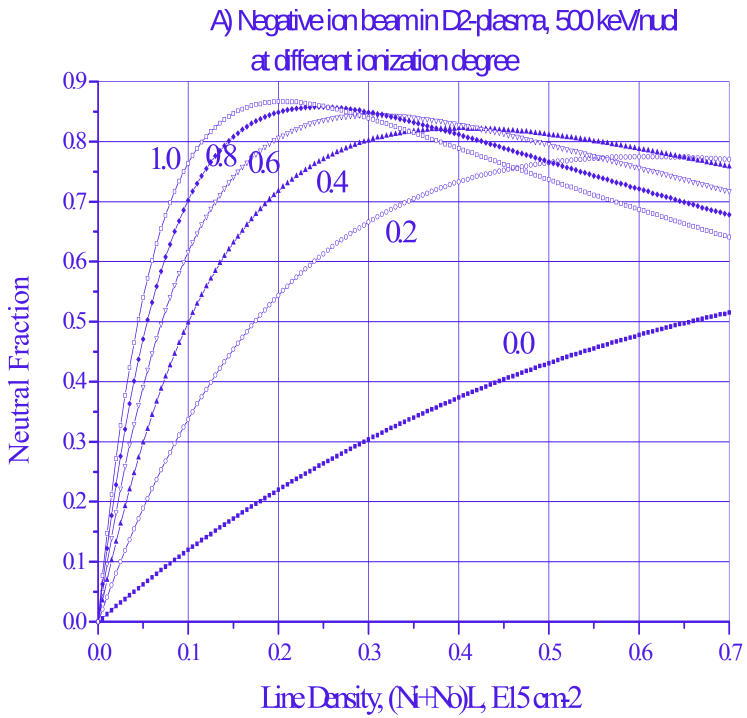
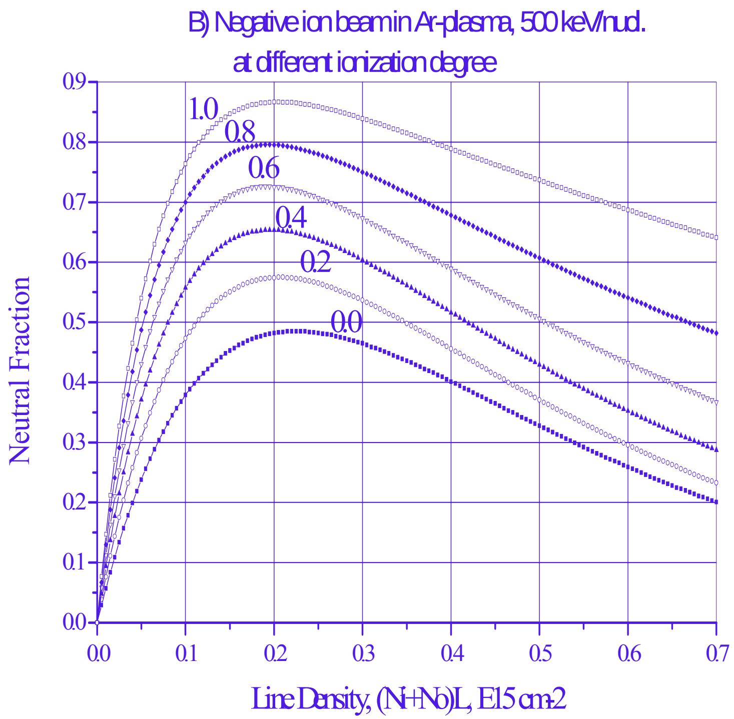
Abstract

The plasma neutralizer (PN) could be an attractive upgrade for Neutral Beam Injection Systems based on Negative Ion Beam acceleration with further electron stripping (NNBI). While gas neutralization can provide the stripping efficiency ~ 60% the plasma one gives significant improvement up to ~80%.

A multicusp magnetic trap with peripheral microwave discharge for plasma generation was proposed and investigated as a scheme for PN. Acceptable properties were demonstrated.

Negative ion stripping efficiency depend upon the target thickness and ionization degree for different targets: A) D_2 - target; B) Ar – target.



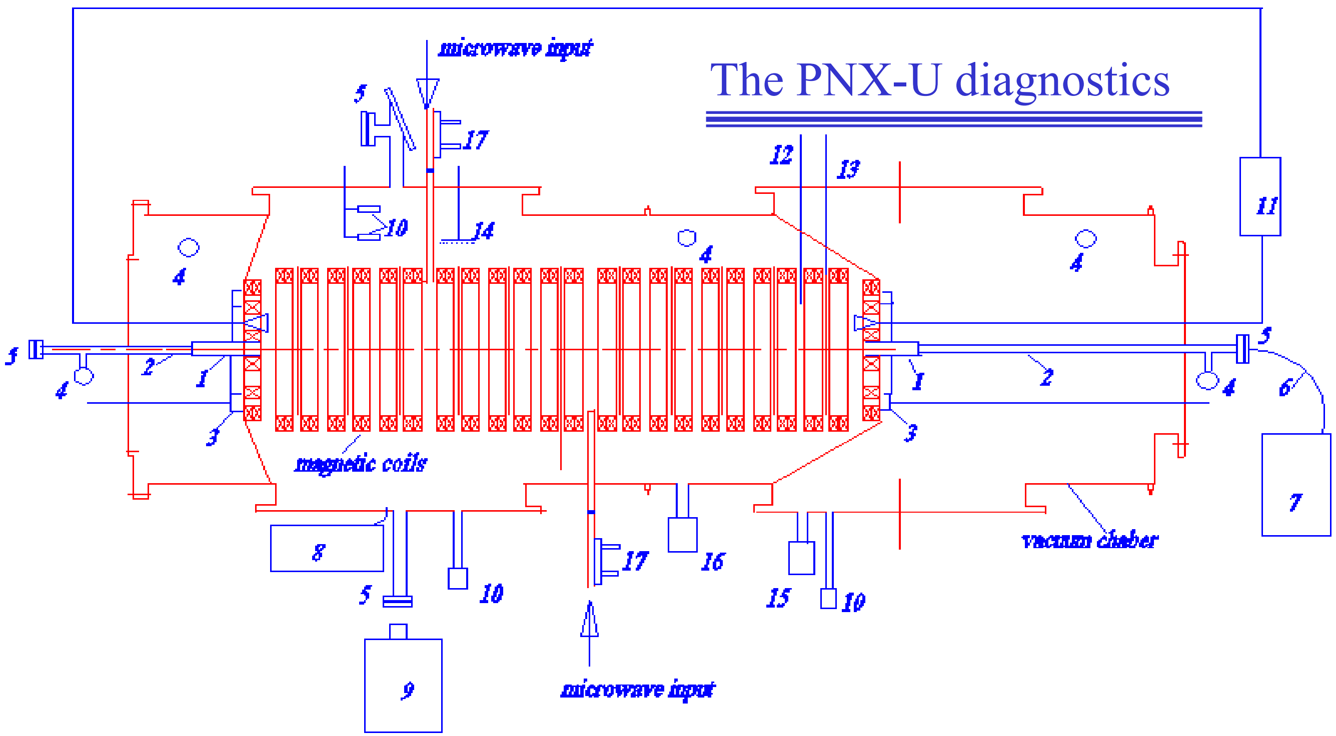


Gas and plasma neutralizers properties; relative advantages / disadvantages can be easy seen.

	Gas	Plasma
Neutralization efficiency	49 - 62%	up to 86%
Gas flow to duct	1	0.3 – 0.03
Power consumption	~ 0	~100 kW/m^3
Feasibility	Easy	Realistic

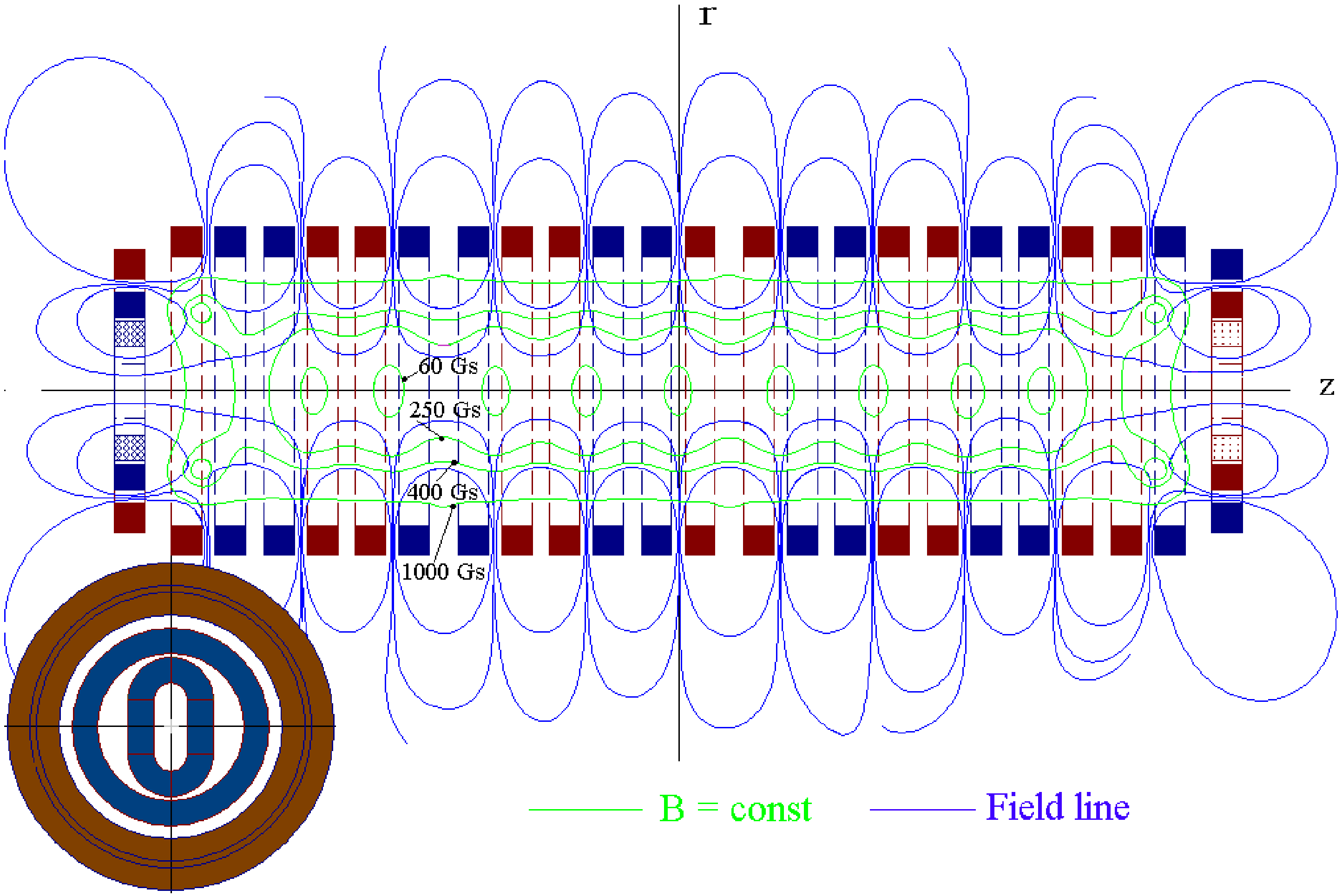
The main items to check:

- Energy confinement time scaling;
- Specific power cost of steady state operation, power balance;
- Plasma ionisation degree;
- Mechanism of PN volume plasma infilling, plasma uniformity;
- Electron and ion densities and temperatures, its special distribution;
- Multi-charged ion generation (for Argon);
- Choice of working gas, gas recycling, gas boxes influence;
- Plasma density limitation at ECR plasma generation;
- Cross magnetic field plasma losses.

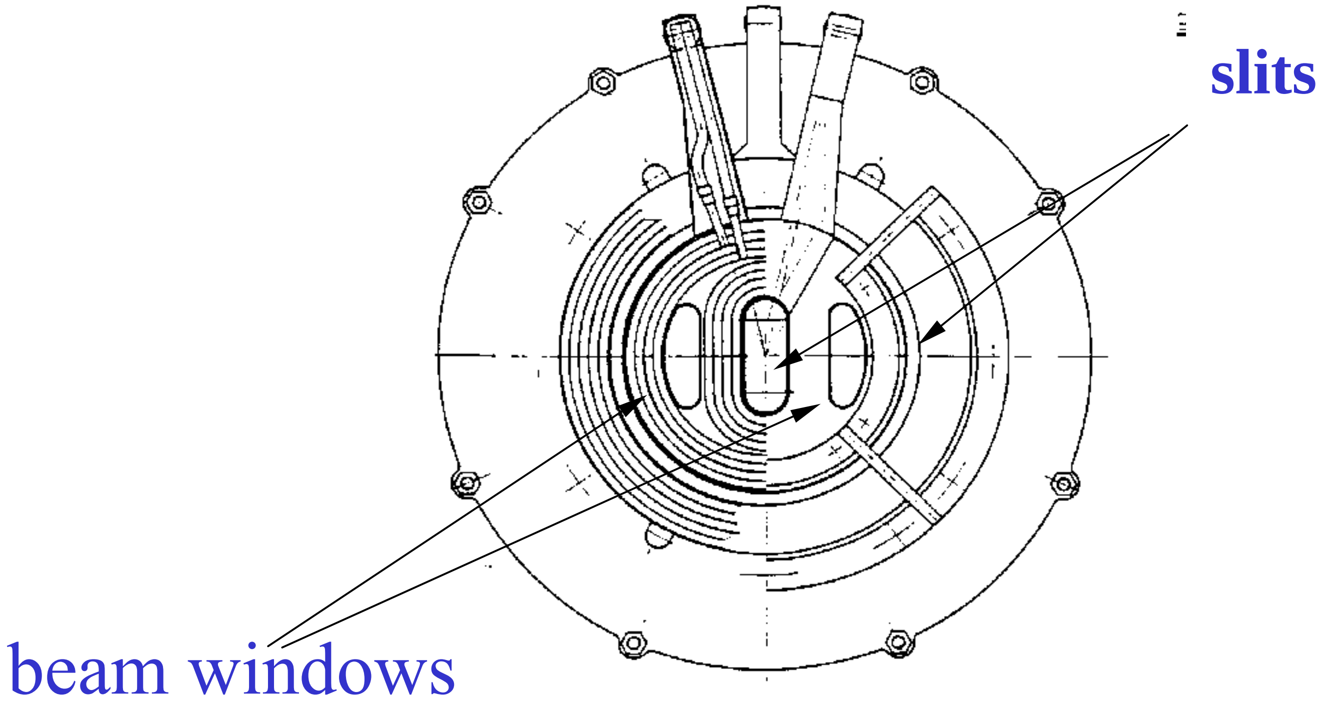


1-axial plasma collector, 2- tube, 3- end slit plasma collector, 4-gauge, 5-optical window, 6- optical conductor, 7- optical plasma radiation monochromator, 8- laser fluorescense monochromator, 9- excimer laser, 10- multygrid plasma flow analyser, 11- 4-mm interferometer, 12- movable Langmuir probe in gap, 13- movable Langmuir probe in slit, 14- Langmuir probe system placed outside coils, 15- photomultiplier, 16- gas mass spectrometer, 17- microwave directional coupler.

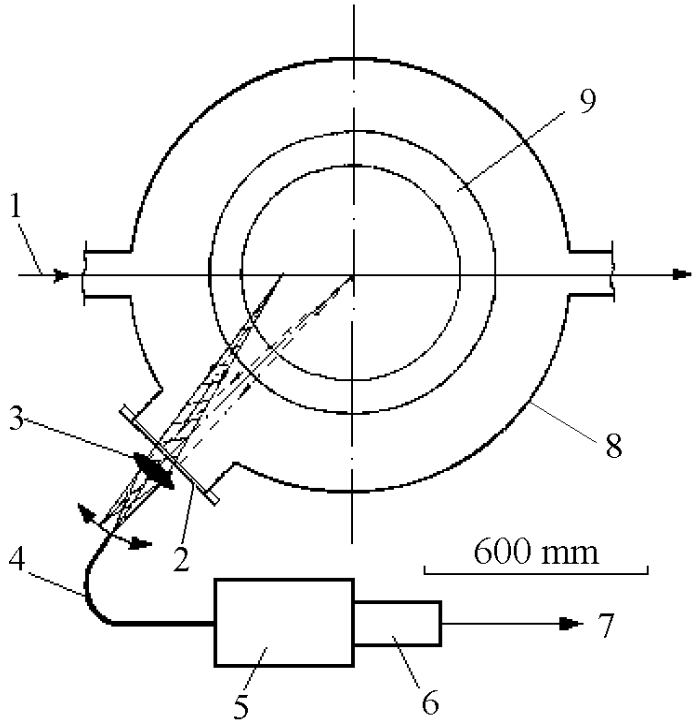
PNX-U magnetic system



Edge coils configuration.



The spectroscopy apparatuses displacement in PNX-U cross section



1 –laser ray; 2 –quartz window; 3 –scanning system lens; 4 –light guide;

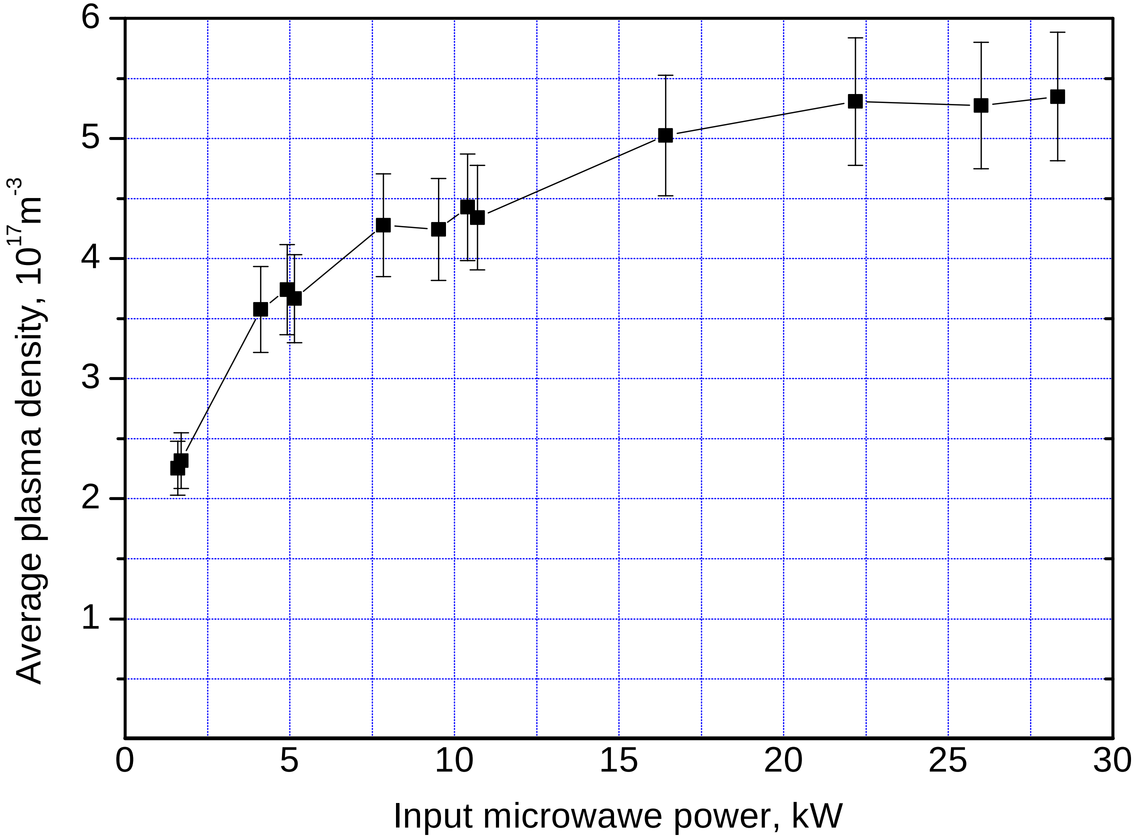
5 –monochromator; 6 –photo multiplier; 7 –to filing system;8 –vacuum chamber;

9 –magnetic coil

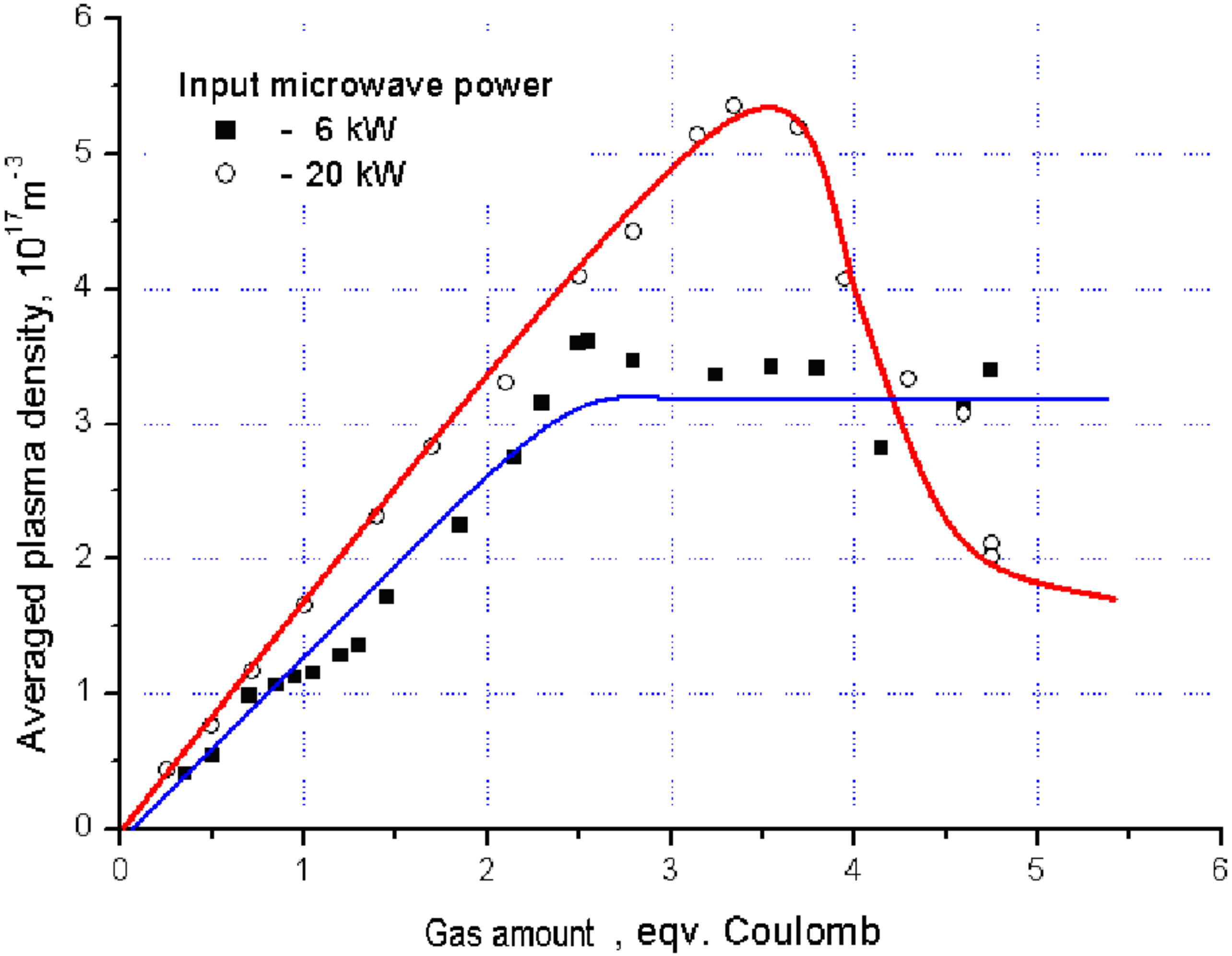
PNX-U Specification and Plasma Parameters

Parameter	Experiment
Magnetic system size: length/diameter	2.2m / 0.6m
Magnetic slits number	15
Total slits length	~50m
Plasma volume	$0.5 m^3$
Magnetic field in slits	0.36T
Magnetic field operation mode	steady state
Microwave generator	klystron
Microwave frequency	7GHz
Microwave power per one klystron	50kW
Klystron number	2
Klystron operation mode: duration/period	0.5s / 5s
Target thickness, *nl*	$0.2 \cdot 10^{19} m^{-2}$
Plasma density	$10^{18} m^{-3}$
Electron temperature: center/periphery	~10eV / ~20eV
Ion temperature	~10eV
Plasma potential	~+30V
Average degree of ionization	>0.9
Power density	$0.1 MW/m^3$
Working gas	Ar
Gas pressure	$10^{-5} \div 10^{-4}$ torr

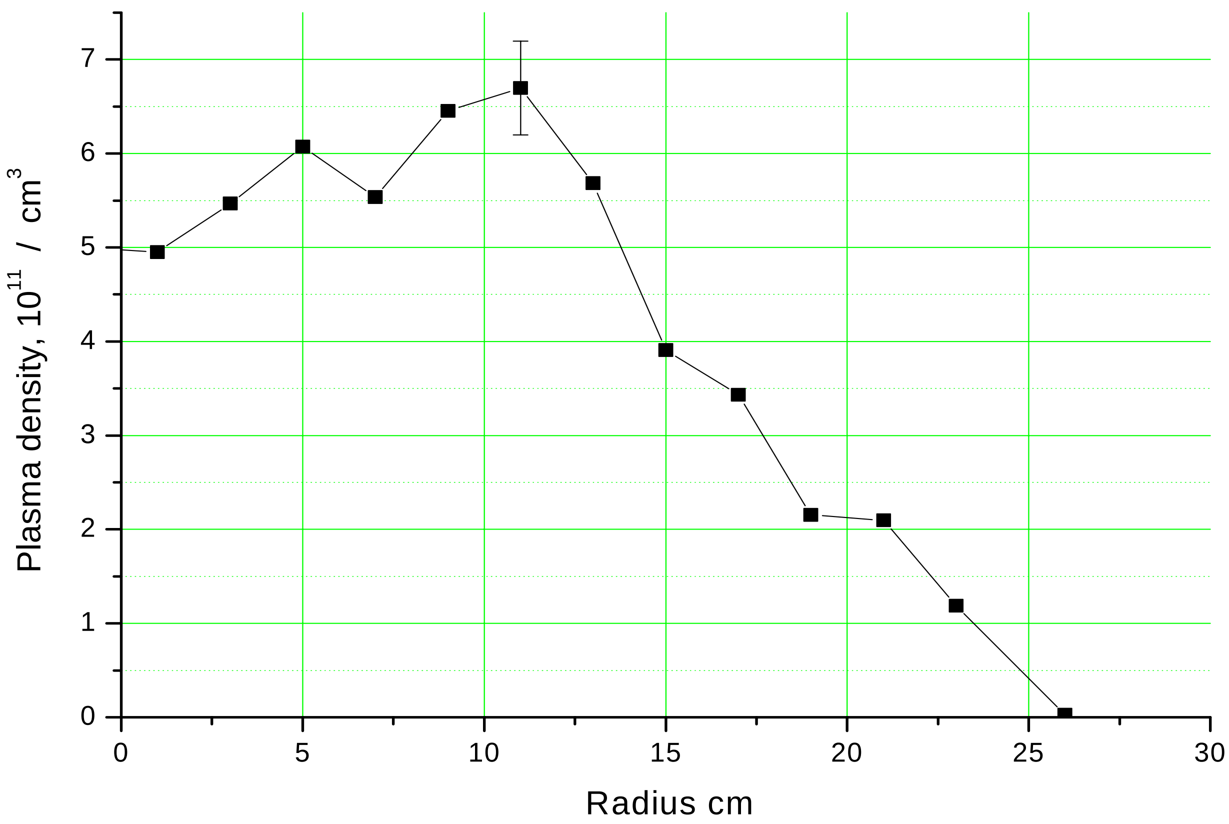
Typical dependence of averaged plasma density on microwave power input .



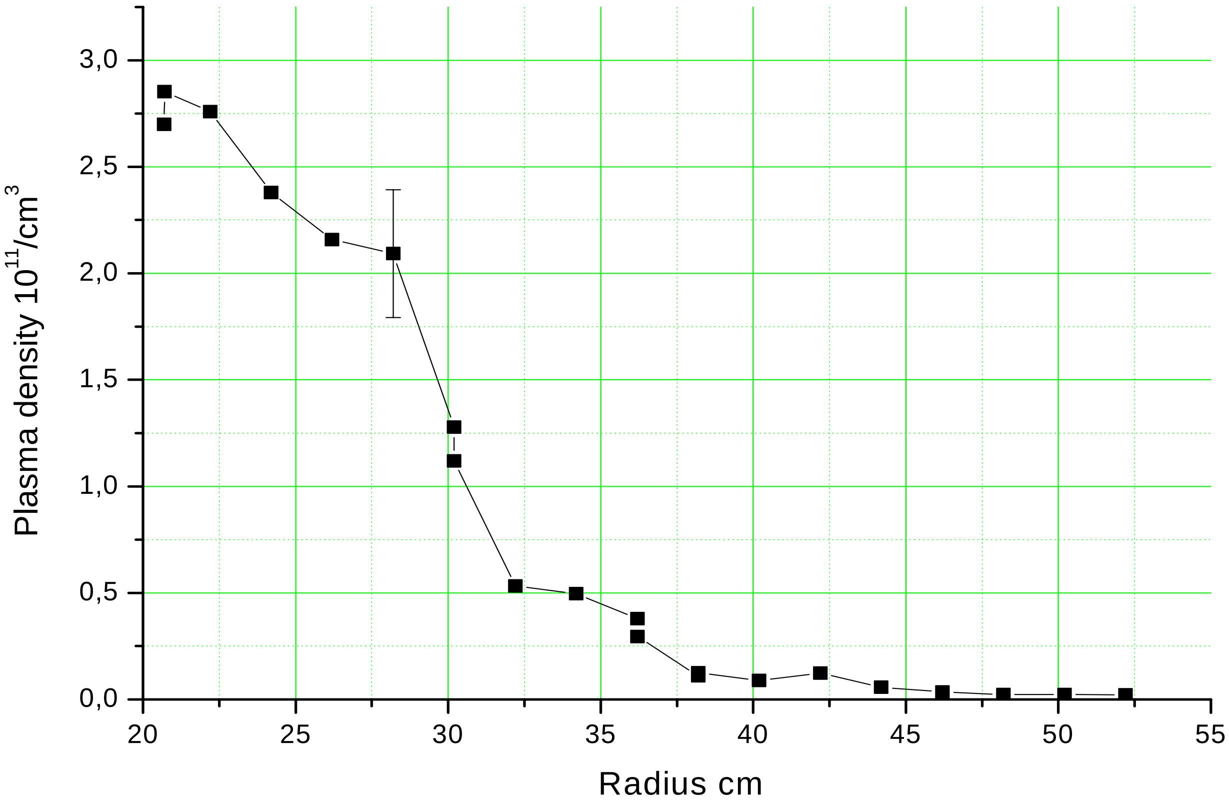
Average plasma density versus gas input



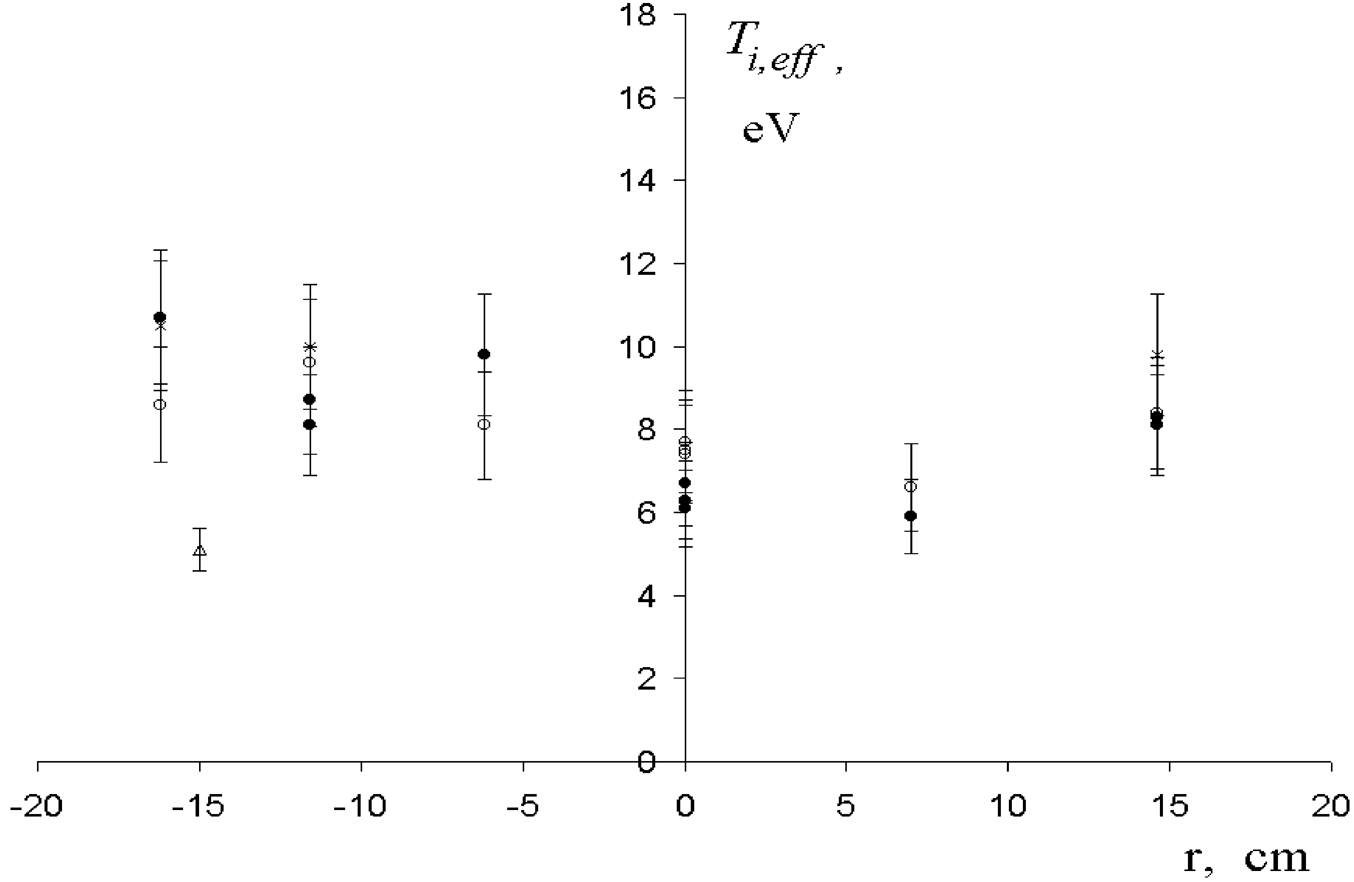
Plasma density radial profile in magnetic gap



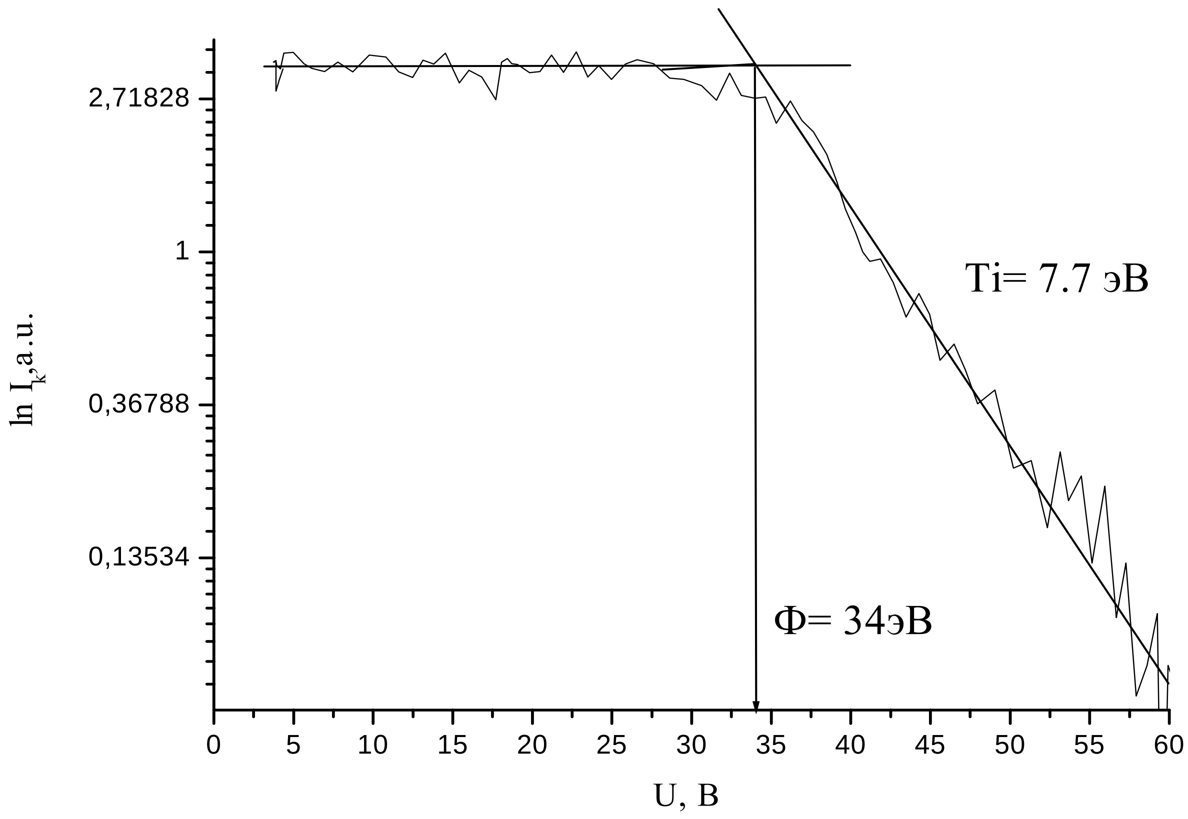
Radial plasma density profile along a magnetic slit in periphery region



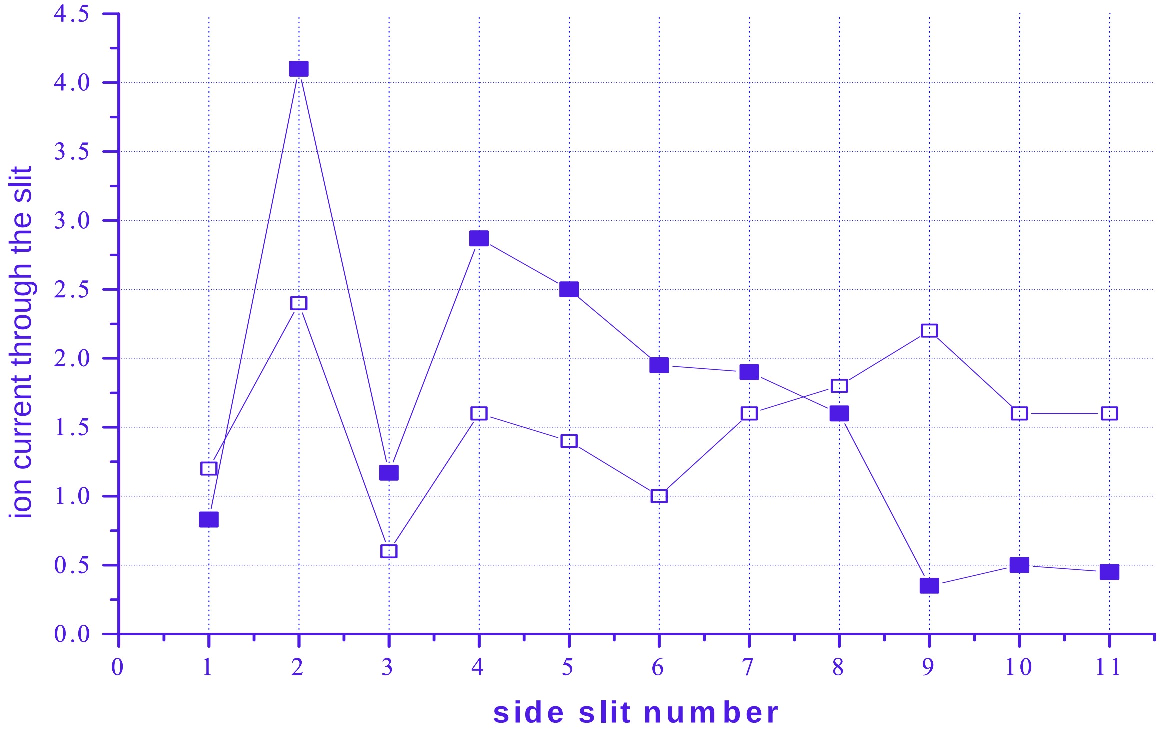
Ion temperature, T_i , radial distribution



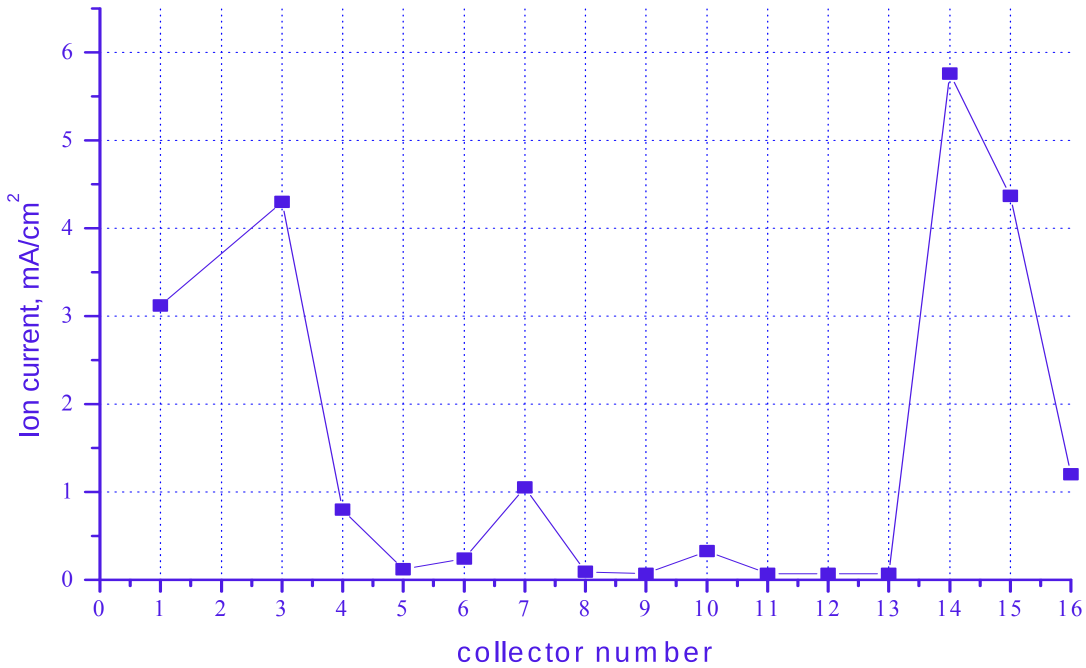
Grid analyzer ion current cut off curve



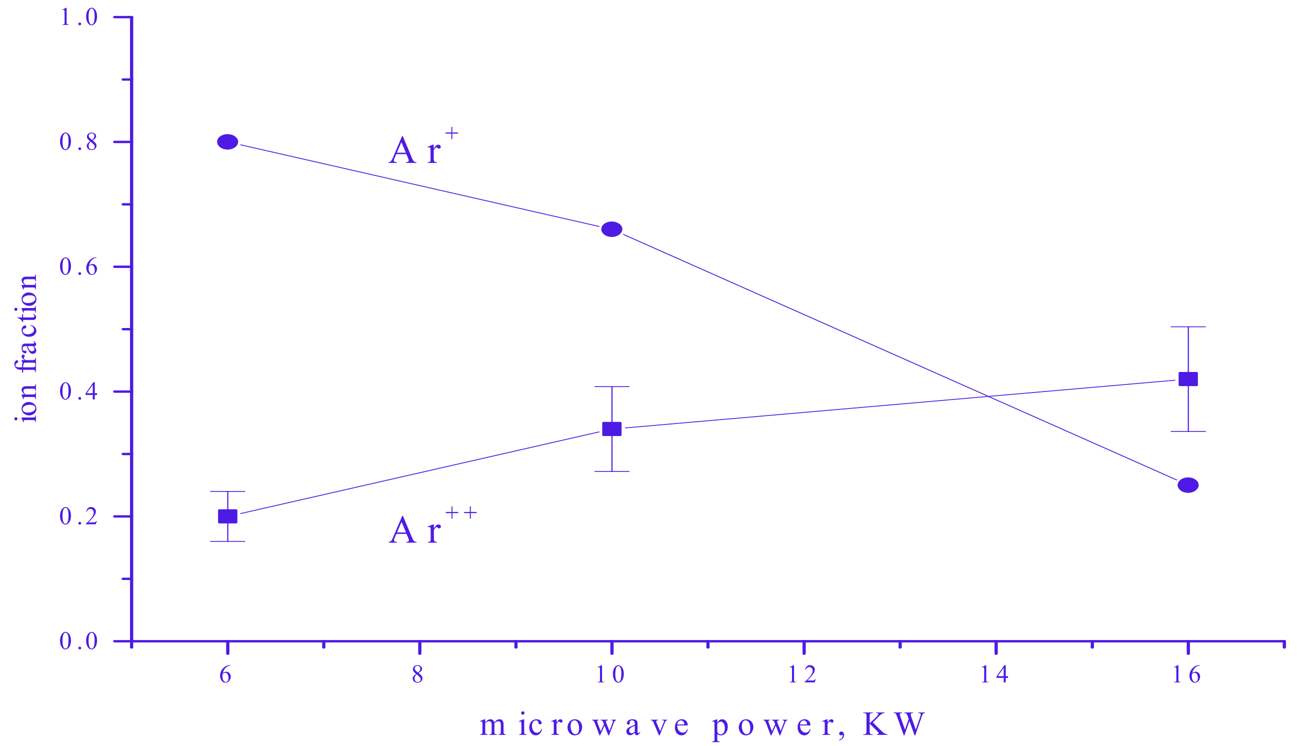
Side slits ion current distribution.
■ - without edge gas boxes, □ - with edge gas boxes.



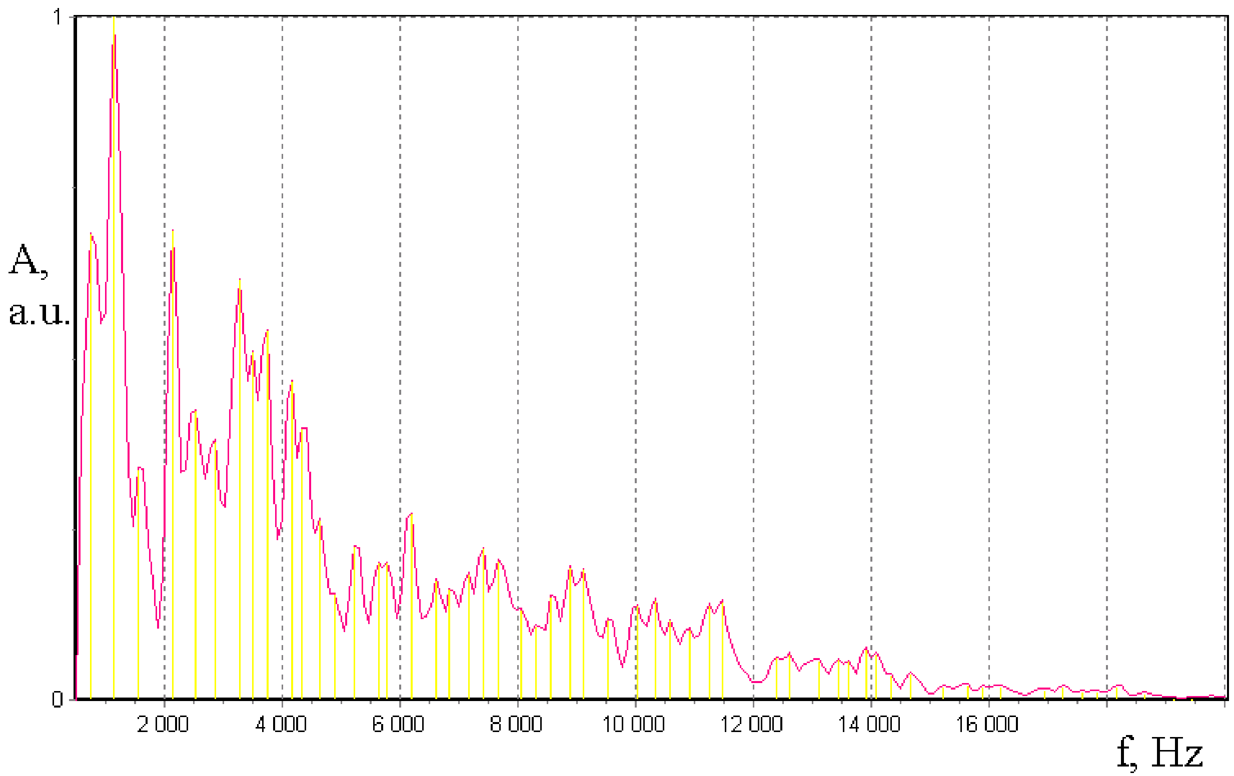
Ion flow profile along the inner magnetic coil boundary
Collectors 1,2,3 and 14,15,16 are located at magnetic slits, the others – at inner side of coils.



Ar^{+} and Ar^{++} fractions in ion flow versus microwave power



Spectrum of floating potential oscillations



Main Results (1)

•Energy confinement time estimations give us value ~0.5 ms being in acceptable agreement with the scaling

•The necessary specific power is not more than: 0.03 MW/m^3

•The result shows that the plasma ionization degree at the central region is close to unity: an Argon atom coming from the wall will be ionized at a distance ℓa ~3cm. That is much less than the plasma radius *R*. Only fast Argon atoms, with a temperature of order ~10eV, which are generated at a periphery because of charge exchange, can reach the central region. It is not large amount

Main Results (2)

•The low frequency fluctuations were observed let us a possibility to suppose that the radial density profile is forming mainly by two factors: turbulence transport and radial potential distribution. The last one in his turn is defined by mechanism of the periphery ECR heating and radiation ion cooling in central region.

Main Results (3)

•Plasma density profile is rather flat (or even with some downtrend toward the axis) up to radial point ~12 cm and then goes to zero at 22 – 25 cm.

Ion temperature is minimal at the axis

The electron temperature is close to the ion temperature and rises to periphery (to ECR region)

•Ar^{++} ion flow increased and Ar^{+} decreased correspondingly with microwave power input increasing.

Main Results (4)

•Gas recycling is a determinant for stable discharge maintenance.

•The density is limited at a level of cut-off one which is about $0.6 \cdot 10^{18} m^{-3}$ for used generator frequency. Maximal observed plasma density didn't exceed $1 \cdot 10^{18} m^{-3}$.

•No cross magnetic field plasma losses: practically all ion flow is coming through the magnetic slits.

CONCLUSION

•The experimental investigations, calculations and design developmental works demonstrate that the PN scheme on the base of multi-cusp magnetic trap with periphery ECR plasma generation is found rather perspective for further development as an element of N-NBI for full-scale fusion systems.