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Plasma Radiation with Impurity Injection into the Edge Plasma of the Stellarator W7-AS

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Abstract

Nitrogen was injected into separatrix-dominated discharges with magnetic islands at the plasma edge or limiter-dominated discharges with smooth open flux surfaces. The injection caused an increase of the plasma radiation and a strong decrease of the electron temperature at the plasma edge. The influence of the magnetic configuration at the plasma edge on the radiation pattern seems to be marginal in W7-AS.

Keywords:

stellarator W7-AS, boundary plasma, magnetic island, impurity, radiation asymmetry, MARFE

1. Introduction

The magnetic configuration of the stellarator W7-X contains five independent magnetic islands at the plasma edge outside the separatrix which are planned to be used for divertor action [1] and impurity radiation scenarios intended for target load reduction. Hence the influence of such natural islands on the transport and radiation behaviour of impurities is an important issue of W7-X operation.

The stellarator W7-AS has a flexible magnetic configuration allowing performance of separatrix-dominated discharges with natural magnetic islands at the plasma edge or limiter-dominated discharges without such islands depending on the choose of the rotational transform ι.

This paper reports on experiments with local impurity injection into a magnetic island at the plasma edge of W7-AS. The plasma response on short nitrogen pulses of a few ms duration injected into these islands by a reciprocating erosion probe [2] has been observed. In particular, the change of the plasma parameters at the edge and the radiation behaviour of the plasma has been studied.

A comparison is made with gas puffing experiments in limiter-dominated discharges without magnetic islands. In this case a feedback control system [3] applied for nitrogen injection allowed to establish quasi stationary operation with different radiation levels.

2. Experiments with a Magnetic Island Configuration

The experiments were performed in NBI-heated discharges (heating power up to 1.2 MW) with a 5/9-island configuration and limiters on the inboard side. The nitrogen was injected with the reciprocating erosion probe either near the O-point or the X-point of the magnetic island on the bottom side [2]. Due to the injection the electron temperature near the separatrix decreased from values of 60 eV to about 10 eV. The

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total radiation raised up to 95% of the heating power, however, particular enhancement of radiation from island regions could not be observed. The spatial distribution of the radiation after injecting nitrogen was found to be only slightly dependent on the location (X- or O-point). In contrast, the radiation pattern is much more sensitive to the plasma density. Figure 1 shows the line integrated radiated power before and during the nitrogen injection measured by the different channels of the bottom bolometer array. Generally, radiation enhancement mainly occurred on the inboard side. With increasing plasma density the poloidal asymmetry of the radiation is strengthened during impurity injection. Figure 2 presents radiation pattern for the discharge with a plasma density of 1.2×10^{20} m^{-3} (see also Fig. 1b)) demonstrating enhanced radiation to be localized on the inboard side below the equatorial plane. Radial plasma shrinking induced by the impurity injection was observed to start at line-averaged plasma densities of about 1.0×10^{20} m^{-3}. In Fig. 3 the temporal evolution of plasma density and electron temperature outside the separatrix measured by a Langmuir probe in the equatorial plane on the inboard side is shown for the discharge of Fig. 2. The plasma shrinking is indicated by a decrease of the plasma density after impurity injection.

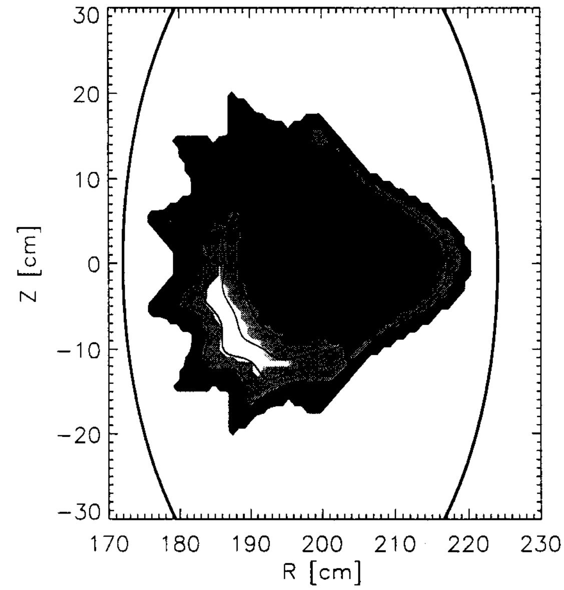

Fig. 2 2D-plot of radiated power during nitrogen injection for the discharge of Fig. 1b).

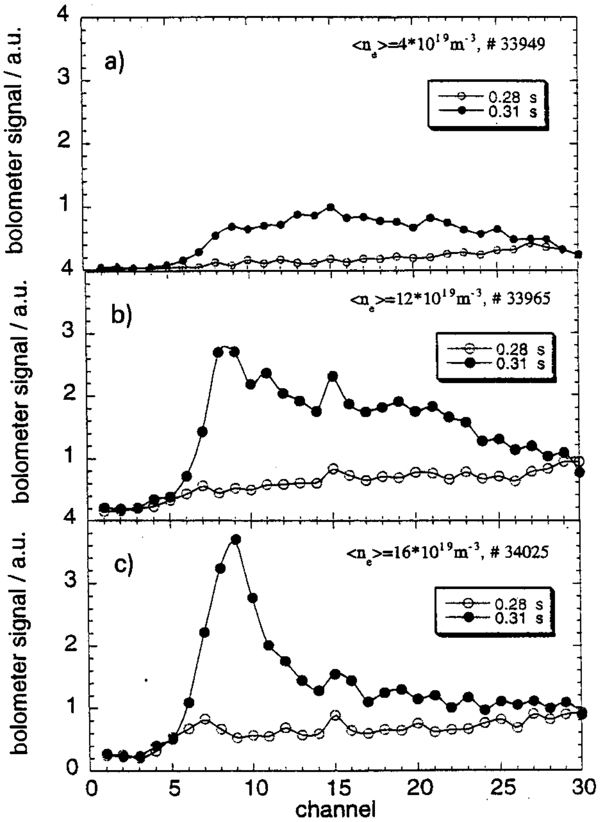

Fig. 1 Line integrated power before and after the injection measured by the bottom bolometer array; chords with a low number view the lower inboard side and chords with a high number view the upper outboard side (from top to bottom $<n_e>$ = 0.4, 1.2 and 1.6×10^{20} m^{-3}).

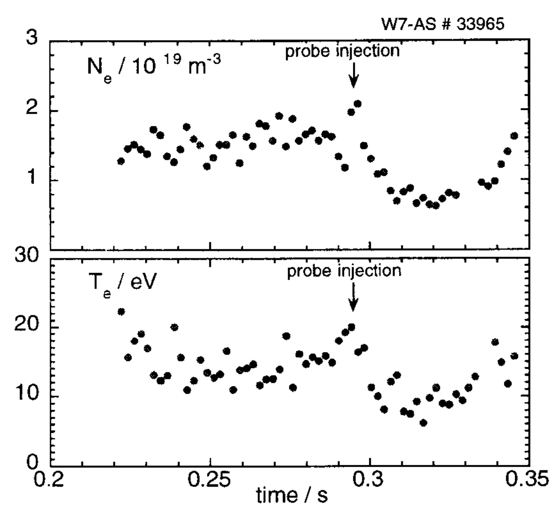

Fig. 3 Probe data taken outside the separatrix on the inboard side showing transient plasma cooling and shrinking for the discharge of Fig. 1b).

Unfortenately, the complex magnetic configuration and connection length effects cause strong 3D-effects in plasma parameters outside the separatrix [4] and do not allow direct comparison of plasma parameters measured at different poloidal locations. However, it seems to be likely, that poloidal asymmetries in density and electron temperature on magnetic flux surfaces outside and inside the separatrix, as found in the tokamak Alcator C [5], are responsible for the observed radiation pattern.

At plasma densities of 1.6×10^{20} m^{-3}, the density within the island measured by the injection probe itself on the bottom side decreased from 10^{20} m^{-3} to 10^{19} m^{-3} due to the injection. Simultaneously, strongly localized radiation zones (MARFE's) inside the separatrix at the inboard side have been observed (see Fig. 1c)) supporting the hypothesis of poloidal asymmetries of the plasma parameters [5,6].

In contrast to tokamaks the radiating region is not toroidally symmetric but seems to follow a helical line within a modular section similar to the helical edge observed earlier on the outboard side of W7-AS [4].

3. Experiments with a Limiter Configuration

These experiments were performed in ECR-heated discharges (heating power 400 kW) and in a configuration with iota of about 1/3 and active limiters on the top and bottom side of an elliptical cross section. Flat top phases of 0.7 s have been achieved at line-averaged densities of 4×10^{19} m^{-3} and moderate, controlled nitrogen injection using a feedback system via the NIV line emission at 76.5 nm. With gas injection a controlled increase of the total radiated power, a decrease of the electron temperature at the plasma edge and a reduction of the power flux to the limiter has been achieved [7], however always correlated with a reduction of confined plasma energy. Stationary plasma parameters could be obtained up to central nitrogen concentrations of about 2.5% and a radiated power fraction up to 220 kW. Further increase of the nitrogen injection rate caused a loss of stationarity and led to feedback induced oscillations of the plasma parameters and the radiated power (see Fig. 4). The instabilities occurred when the electron temperature measured by Langmuir probes near the last closed flux surface decreased to values lower than 20 eV. Figure 5 shows the temporal evolution of the electron temperature and the plasma density about 5 mm outside the LCFS for the discharge of Fig. 4. The nitrogen valve was opened at 0.30 s and closed temporarily by the control system at 0.565 s, 0.62 s and 0.68 s.

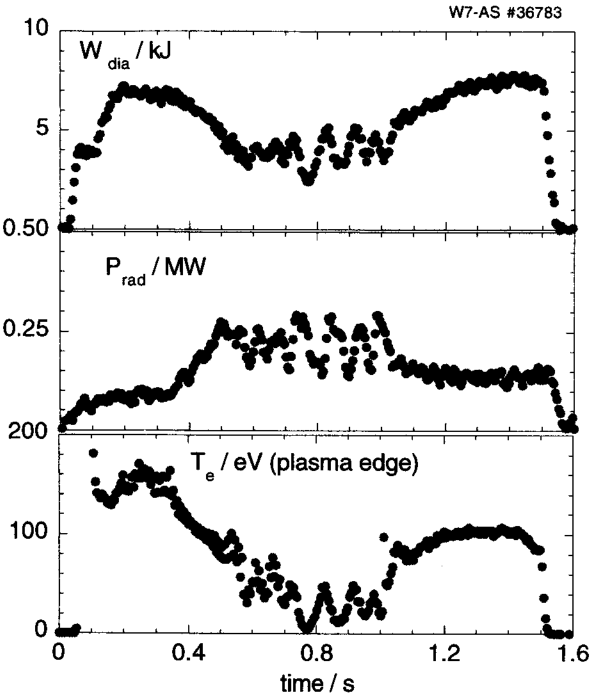

Fig. 4 Temporal traces of diamagnetic energy, total radiated power and edge temperature for an unstable discharge with nitrogen puffing starting at t=0.30 s; $<n_e>$ = 0.4×10^{20} m^{-3}.

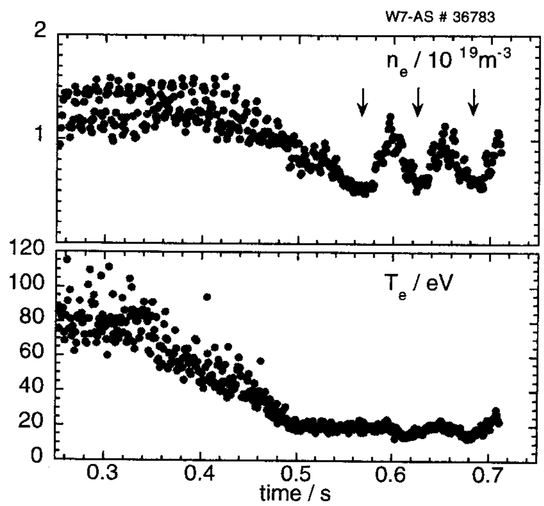

Fig. 5 Plasma density and electron temperature near the LCFS measured by a limiter probe showing plasma cooling and shrinking for the discharge of Fig. 4. The arrows indicate the reduction of the nitrogen influx.

The decrease of the SOL-plasma density as a sign of radial plasma shrinking started at 0.45 s when the electron temperature decreased to about 40 eV. The density in the SOL-plasma partly recovered after the nitrogen injection was reduced. Tangentially viewing CCD cameras evidenced this radial plasma shrinking and recovering. During the unstable phases of strong nitrogen injection the radiation pattern shows pronounced poloidal asymmetries with a higher radiation level on the inboard side as in the case of the probe injection. Figure 6 presents a 2D-plot of the radiation pattern during unstable phases with nitrogen injection for the oscillating discharge. The region of enhanced radiation at the inboard side is clearly inside the separatrix and is a typical MARFE-location at higher plasma densities [2].

Both phenomena, the density decrease in the SOL-plasma and the appearence of poloidal asymmetries, have also been found in experiments with programmed increasing nitrogen concentration at higher plasma density ($<n_e> = 8\times10^{19}$ m^{-3}) and higher heating power (960 kW by ECRH and NBI). In these discharges they appeared when the radiated power exceeded 500 kW and the electron temperature at the LCFS decreased from 100 eV to values below 40 eV.

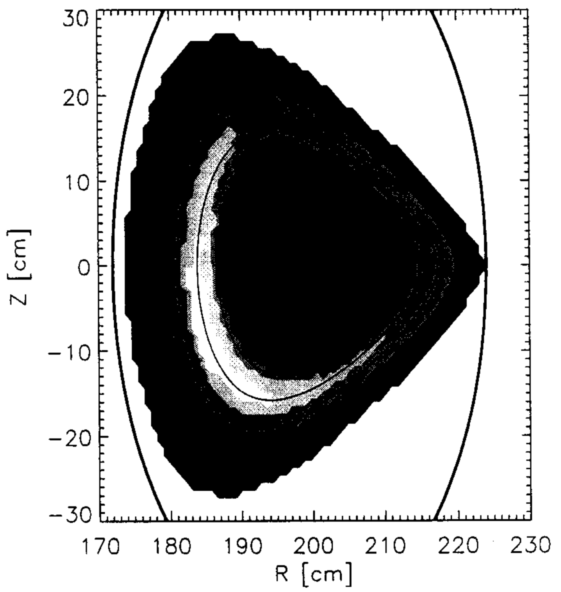

Fig. 6 2D-plot of radiated power during phases with nitrogen injection for the unstable discharge of Fig. 4.

4. Summary

Despite the quite different configurations the radiation pattern during impurity injection has been found to be quite similar. In particular, enhanced radiation from island regions has not been observed even after injecting nitrogen into a magnetic island.

Strong injection caused radial plasma shrinking and strong poloidal asymmetries of the plasma radiation inside the separatrix or LCFS. Both effects appeared when the electron temperature at the plasma edge decreased to values lower than 40 eV. They are stronger with increasing plasma density and decreasing temperature. It remains to investigate the possibilities and limitations of stabilizing such plasma conditions using a higher sophisticated feedback control system.

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