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Simulation of neutral particle fluxes from fast ions in the JET tokamak

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Accurate determination of plasma composition is a vital measurement both in present experiments as well as eventual burning plasma operation, where control of the isotope ratio of the deuterium and tritium fuels will be critical. One diagnostic method for determining the isotope ratio is neutral particle analysis (NPA), where neutral particle fluxes resulting from charge exchange reactions inside the plasma can be used to infer the isotope ratio. The measured neutral fluxes are, however, distorted by energetic particles such as those resulting from NBI heating. The fluxes from the slowing down beam ions mask the signal from the bulk plasma, hindering analysis of the main plasma ions, with the contamination increasing with greater NBI power. The work presented here aims to characterize the neutral fluxes due to the NBI ions in order to facilitate isotope ratio measurements under these conditions.

NPA diagnostics have previously been used to determine the isotope ratio at the JET tokamak with some limited simulations for the fast ion neutral fluxes [1, 2]. Some of the tools used in this study have also previously been used for simulating neutral fluxes from NBI ions in experiments at the ASDEX Upgrade tokamak [3, 4], where discrepancies between simulations and measurements were primarily attributed to the limited neutral density model used in the simulations. Thus in this work, the focus was on using detailed models for the neutral density profiles, particularly in the edge region.

JET NPA diagnostic and simulation tools

The low-energy neutral particle analyzer (KR2) [5] installed at JET simultaneously measures the neutral particle fluxes for hydrogen, deuterium and tritium at energies from 1 keV upwards. The diagnostic has a horizontal line of sight normal to the magnetic axis along the outer midplane (figure 1). Due to the radial orientation the diagnostic only measures fluxes due to trapped ions with a small pitch $\xi = v_{\|}/v$. In the results presented here, the NPA was configured to measure deuterium fluxes between 5-40 keV.

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[*] See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia.

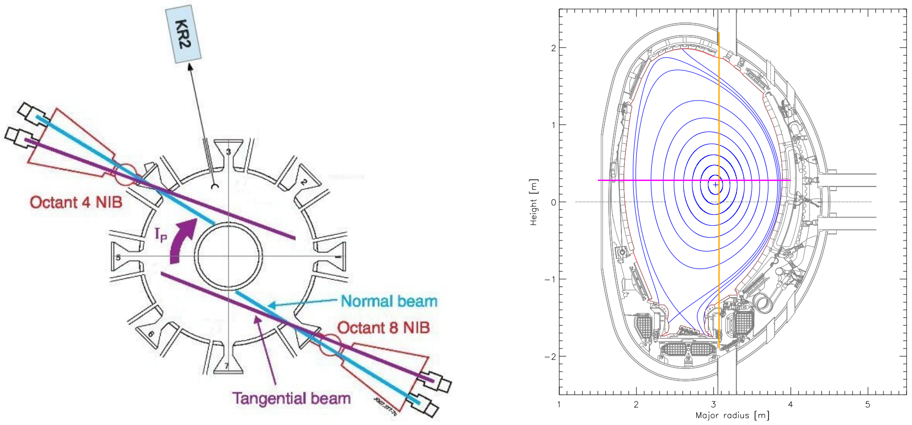

Figure 1: *Layout (left) of the neutral beams and the KR2 NPA diagnostic at JET and the sight lines (right) of the low-energy NPA diagnostic KR2 (magenta) and the high-energy diagnostic KF1 (orange).*

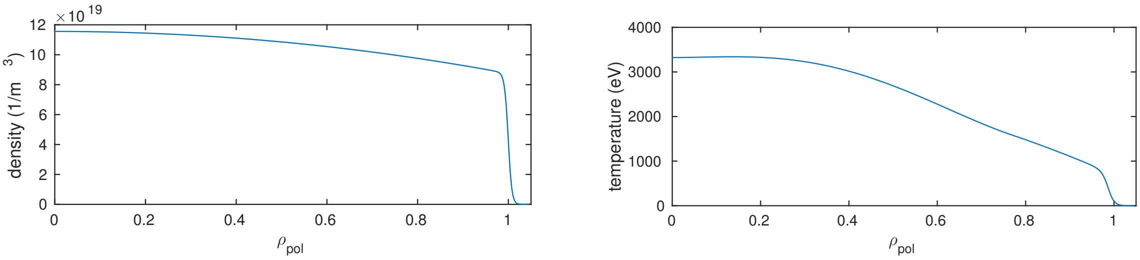

Figure 2: *Electron density (left) and temperature (right) profiles used in the simulations for the JET pulse #85413.*

The fast ion slowing down distribution resulting from the deuterium NBI injection was modelled using the NBI ionization code BBNBI [6] and the orbit-following Monte Carlo code ASCOT [7]. The recycling neutral densities were based on EDGE2D-EIRENE simulations [8], while the core recombination neutral density was scaled from results presented in [1]. The neutral densities due to the NBI beams intersecting the NPA line of sight were modelled using BBNBI.

The synthetic neutral fluxes were simulated using a standalone synthetic NPA diagnostic based on the ASCOT code. The code samples an arbitrary nonisotropic 4D distribution representing the fast ions within the diagnostic viewing cone. The neutral flux is accumulated from samples whose pitch is such that the resulting neutral can reach the detector. Attenuation of the signal is calculated using ADAS neutral beam-stopping coefficients. The synthetic diagnostic code can also separately simulate the neutral fluxes resulting from the isotropic thermal plasma ions.

Results

The JET discharge #85413 studied in this work features a high-density H-mode plasma with a core density of $12 \cdot 10^{19}$ 1/m^3 and temperature of 3 keV (figure 2). 20 MW of NBI power was

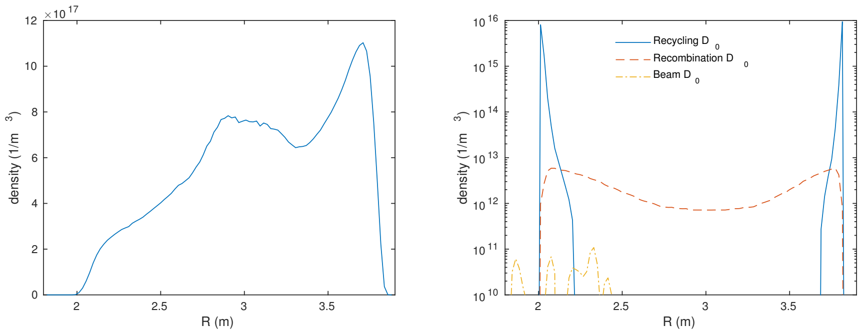

Figure 3: *ASCOT-simulated NBI ion slowing-down density (left) and EDGE2D-EIRENE and BBNBI predicted neutral densities (right) along the NPA sight line.*

applied in the pulse with no ICRH heating, making it well suited for ASCOT NBI modelling. Due to the high plasma density, the NBI beam cannot penetrate deep into the plasma, resulting in an NBI ion density that is peaked near the edge (figure 3, left). Likewise, the neutral density is peaked near the edge because of the high recycling neutral contribution (figure 3, right). Due to the high density and unfavourable geometry, with the NBI and NPA lines of sight intersecting only on the high field side of the plasma, the beam neutral density was found to be negligible. Because of these factors, the resulting neutral flux would be expected to primarily be attributed to CX reactions with the recycling neutrals.

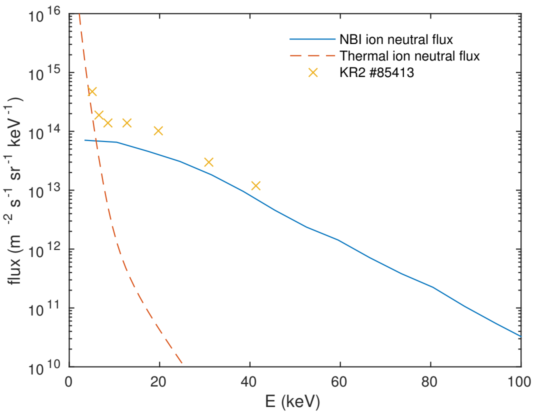

Figure 4: *Simulated neutral fluxes due to the thermal and NBI ions together with experimental results.*

The resulting simulated neutral fluxes were found to be within a factor of two of the measured fluxes (figure 4). The fluxes due to thermal ions agree well with the measurements at the two lowest energy channels, while the fluxes due to NBI ions dominate at energies greater than 10 keV. A sensitivity scan was performed by artificially changing the width of the recycling neutral profile while keeping the integrated density constant. This resulted in significant changes in the corresponding neutral fluxes from the fast ions (figure 5), indicating that the neutral flux indeed originates from the edge. Due to their low energy, and corresponding low plasma transparency, the neutral fluxes from thermal ions are likewise constrained to the edge of the plasma.

Discussion

While the synthetic neutral fluxes were found to be in good agreement with the experimental results in the simulations presented here, the sensitivity to the recycling neutral profile indicates

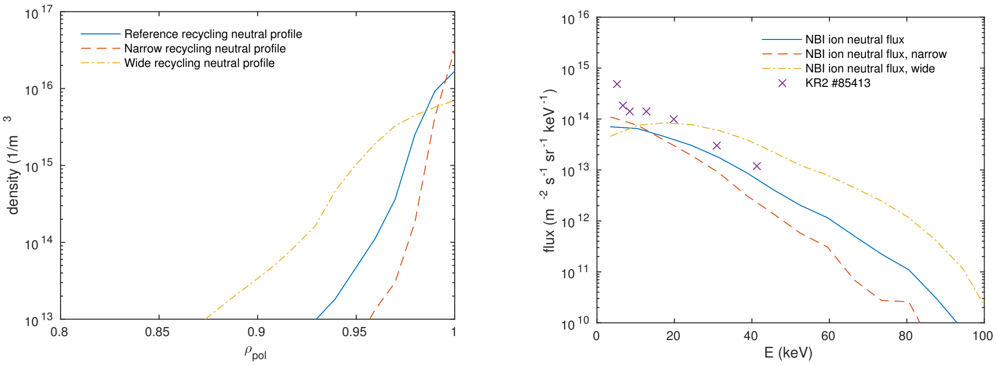

Figure 5: *Simulated fast ion neutral fluxes (right) using artificially narrowed and widened recycling neutral density profiles together with experimental results.*

that detailed modelling would be required to precisely model the fast ion NPA signal. However, the results indicate reasonable prospects for using the lowest energy channels for isotope ratio measurements of thermal ions, where the NBI contamination could likely be further lessened by reducing heating power during measurement and favouring the tangential NBI, with higher injection pitch angle, to reduce the near-zero pitch contribution. The higher energies could be used to diagnose the composition and characteristics of the injected beam ions themselves.

Aknowledgement

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