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Impurity transport studies in NSTX beam heated H-mode plasmas

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MOTIVATION

The transport properties of spherical tori (ST) must be studied for extrapolation to a next step ST device such as CTF [1] and for enabling a comparison to large-aspect ratio conventional tokamaks. The particle transport was estimated to be in the neoclassical range in CDX-U [2] by using intrinsic impurity profiles in short Ohmic discharges. The results from neon injection into L-mode plasmas at the National Spherical Torus Experiment (NSTX) also indicated core impurity diffusivity in the neoclassical range [3]. This paper discusses the first impurity transport experiments in beam-heated NSTX H-modes.

NEON INJECTION EXPERIMENTS

The operational parameters for the discharges discussed here are 1.0 MA current and 4.5 kG toroidal field with a deuterium beam heating power P_{NBI}=4-6 MW at 70-90 kV [see Figure 1a)] and a slowly evolving neutron rate of ~2×10^{14} n/s [see Figure 1b)]. An important requirement was to operate well below the ideal β limit and with q_0>1, thus avoiding sawteeth, internal reconnection events and large edge localized modes [see Figure 1b)]. The plasmas were double-null diverted (DND), with an average elongation (κ) and triangularity

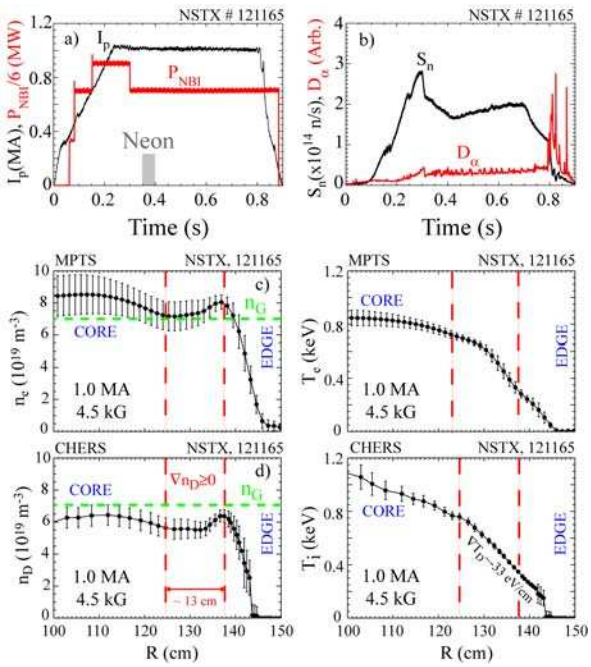

Fig. 1. a) I_p & P_{NBI}, b) S_n & D_α, 200 ms time-averaged c) MPTS & d) CHERS data for the neon-seeded H-mode shot.

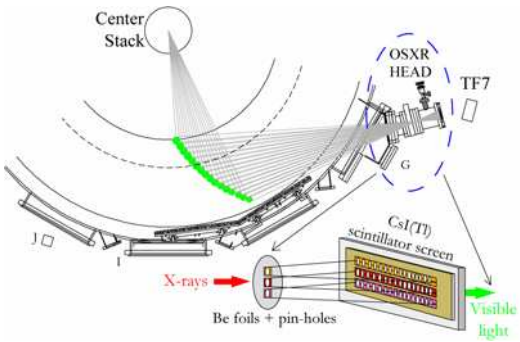

Fig. 2. "Multi-color" tangential OSXR array installed in NSTX-PPPL.

(δ) of 2.25 and 0.6, respectively.

The multi-point Thomson Scattering (MPTS) T_e and n_e profiles are broad and the Charge Exchange Recombination Spectroscopy (CHERS) T_i is more peaked. The central values are of the order ~6-8×10^{19} m^{-3} and ~0.8-1.1 keV [see Figures 1-c) & d)]. The average plasma stored energy is 230 kJ. The plasma β_t was of the order of 15% with an energy confinement time ~54 ms. The main diagnostic used in the present experiments was a newly-developed tangential "multi-color", optical (scintillator-based) soft X-ray (OSXR) array shown in Figure 2 [4,5]. The instrument has three midplane rows of detectors viewing the same plasma volume through three different beryllium (Be) foils with cutoff energies (for 10% SXR transmission) of ~780, 1690 and 2410 eV. Although this system was originally designed for fast electron temperature measurements and MHD studies [4,5], it is also filtered for energy bands covering the entire neon spectrum from NSTX [3,4]. The low energy array (L-PMT, Be 10 μm foil) observes mostly the He- and H-like (Ne^{8+}, Ne^{9+}) neon charge states dominant in the plasma pedestal while, the fully stripped Neon (Ne^{10+}) contribution is imaged by the medium- and high-energy detectors (M- and H-PMT) filtered by the thicker Be 100 and 300 μm foils. The line-integrated signals are illustrated in Figure 3. The signals in black represent the SXR background measured in subsequent reproducible discharges, and the ones in blue the neon seeded plasma. The neon puff (1.5 Torr·*l*/sec) begun at 350 ms and lasted for 50 ms as indicated by the shaded region. The experimental observations from the neon injection can be summarized as follows: *i)* the "multi-color" diagnostic enables good signal-to-noise-ratio in the SXR signals, both in the background plasma and when Neon was injected, *ii)* a fast edge versus slow core Neon build

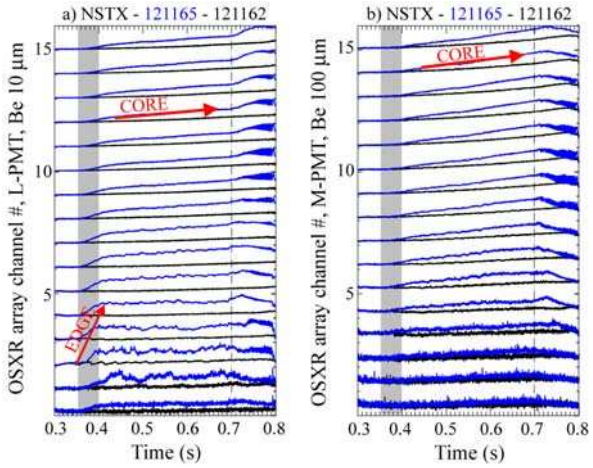

Fig. 3. "Multi-color" line-integrated signals from reproducible background (121162) and neon seeded (121165) H-mode plasmas.

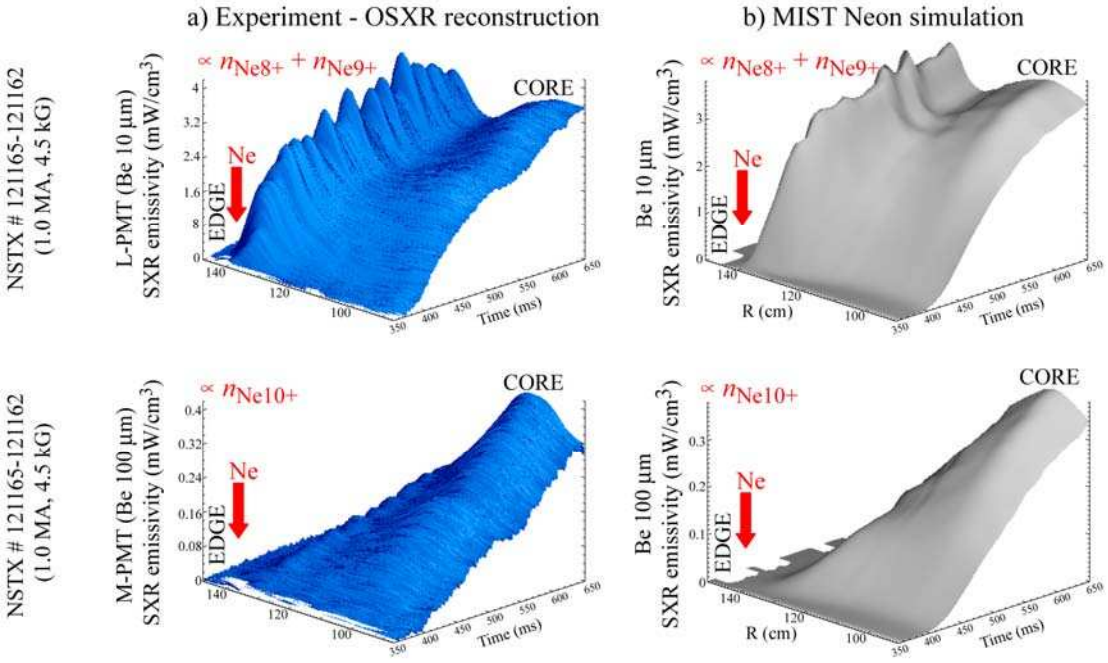

Fig. 4. a) OSXR reconstructed and b) simulated low- and medium-energy SXR emissivities for neon injection in a 1.0 MA and 5.5 kG H-mode plasma.

up, and *iii)* a strong peaking of impurities at late times (~0.7 s). Later in time the impurity accumulation triggers a (*1,1*) MHD mode which flattens T_e.

The contribution from the injected impurities to the SXR emission is obtained first by subtracting the intrinsic background from a reference reproducible discharge and then by reconstructing the radial profiles by use of a matrix-based 1-D Abel inversion technique [4,5]. Figure 4 presents the a) experimental (background subtracted) 1-D Abel inverted and b) the simulated SXR emissivities, each filtered by Be 10 and 100 μm foils. The time evolution of the neon emissivity after the injection shown in Figure 4b), was modeled using the time-dependent Multiple Ionization Stage Transport (MIST) code [6] in which electron ionization, excitation and recombination processes are included in the atomic physics transport calculation. MIST then computes the evolution of all charge states through the experimental

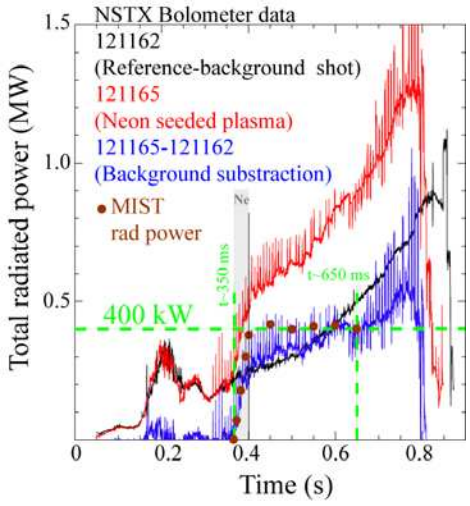

Fig. 5. Bolometer radiated power during background and neon-seeded plasmas

values of $n_e(R,t)$ and $T_e(R,t)$ (shown in Figure 1) assuming external profiles of neon diffusivity and charge independent convective velocity [3].

A self consistent transport solution was then adjusted until a best-fit is found between the OSXR emissivity reconstructions shown in Figure 4, and the neon emissivity computed through MIST including line and continuum radiative coefficients. Additional constraints were also imposed by use of the bolometer radiated power (shown in Figure 5) and the poloidal diode-based SXR arrays [3]. Both the background-subtracted neon radiated power (~400 kW) and the diode currents from the poloidal SXR system (not shown here), fit within 10% the values simulated by MIST 300 ms after the initiation of the gas feed. The core neon MIST diffusion coefficients are below 1 m^2/s inside $r/a \leq 0.7$ in order to account for the reduced particle flux to the core in the presence of a strong edge impurity gradient. The impurity diffusivity estimated inside $r/a \leq 0.7$ is in good agreement with the NCLASS predicted [8] neoclassical transport coefficients. The estimates in the shaded regions in Figure 6 are less well constrained. The neoclassical level of particle transport suggests that anomalous transport associated with long wavelength electrostatic turbulent ion transport must be largely suppressed in the NSTX core [3,7]. This work was supported by the United States DoE grants No. DE-FG02-99ER5452 at The Johns Hopkins University.

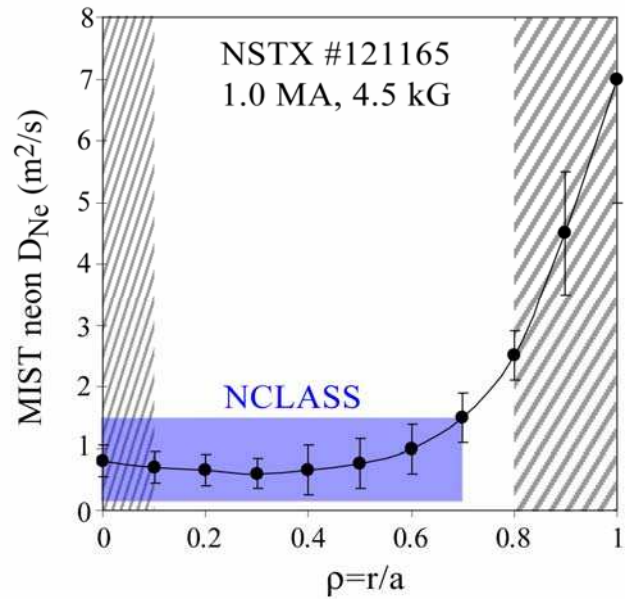

Fig. 6. MIST neon diffusivity.

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