STUDIES OF IMPURITY TRANSPORT IN NSTX WITH THE EDGE MULTI-ENERGY SXR DIAGNOSTIC

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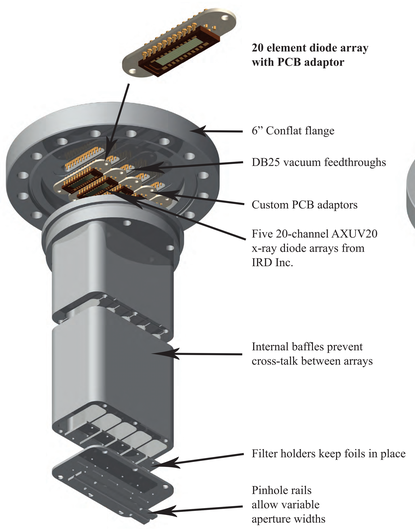
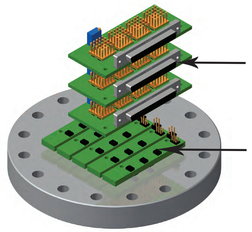
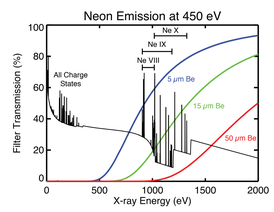
The Multi-Energy Soft-X-Ray Array is a Novel Compact Diagnostic that Provides T_e, n_e, and Impurity Profile Information with High Spatial Resolution (< 1 cm) and Fast Time Response (> 10 kHz)



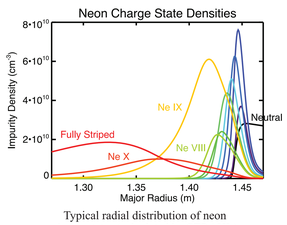
ME-SXR Diagnostic (actual size)



Electronics on back side of vacuum flange (actual size)



Transmission of Be filters overlaying a plot of important neon lines



Typical radial distribution of neon charge states (calculated by STRAHL)

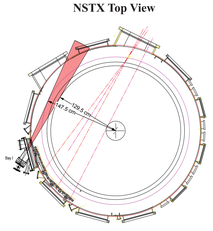
Each diode array looks through a different filter:

- Bolometer (no filter)
- 0.3 μm Ti
- 5 μm Be
- 15 μm Be
- 50 μm Be

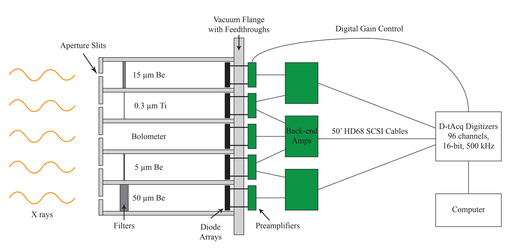
Gains	Bandwidth
25 kΩ	300 kHz
100 kΩ	120 kHz
500 kΩ	50 kHz
1 MΩ	35 kHz
2 MΩ	26 kHz
5 MΩ	16 kHz
10 MΩ	11 kHz
20 MΩ	6 kHz

Preamplifier gains are digitally controlled, with higher gains having providing less bandwidth

NSTX Top View



The ME-SXR diagnostic has a tangential view of the plasma edge (0.6 < r/a 1.1)

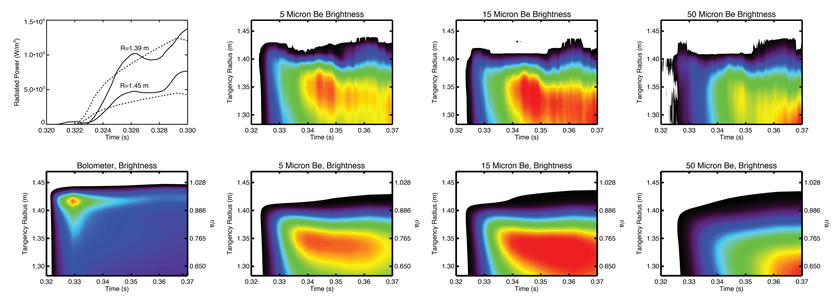


Impurity Transport Modeling with STRAHL is Used to Determine the Diffusive and Convective Transport Coefficients from X-ray Emission

STRAHL (R. Dux) is a radial impurity particle transport code

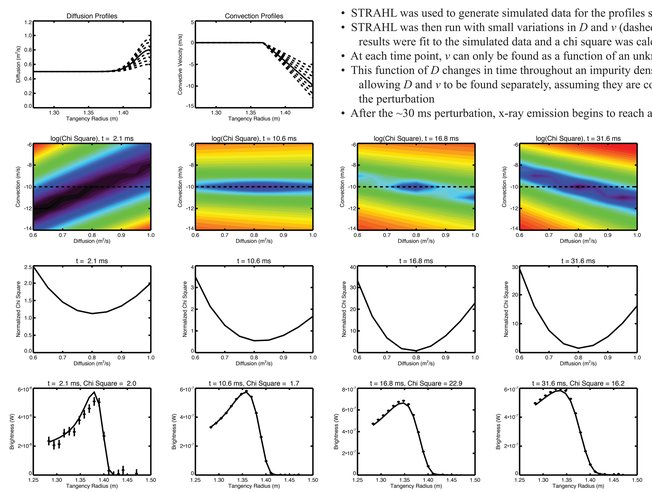
- Solves a radial transport equation for each charge state of an impurity, with source/sink terms due to ionization/recombination connecting them
- Ionization and recombination rates are from Atomic Data and Analysis Structure (ADAS)
- Neutral source is from user-defined gas puff at the plasma boundary and recycling of lost particles from the vessel wall
- Anomalous transport coefficients for diffusion (D) and convection (v) are provided by the user; neoclassical D and v may be calculated with NEOART, which is included with STRAHL
- Filtered x-ray emission from atomic lines and continuum are calculated using ADAS emission coefficients and routines
- A Levenberg-Marquardt fitting routine (MPFIT) is employed to find $D(r)$ and $v(r)$ that produce the best fit to the data

SXR Emissivity Measured with ME-SXR (top) Closely Matches Emissivity Calculated Using STRAHL/ADAS (bottom) (from NSTX #142184, 1.1 MA, 5.5 kG)



The bolometer measures low charge states of neon in plasma edge. *5 μm Be filter measures high charge states (H-, He-, Li-like) further in.* *15 μm Be filter measures high charge states and continuum from fully stripped neon.* *50 μm Be filter measures continuum from fully stripped neon in the core.*

The Time Evolution of Emission from an Impurity Perturbation is Needed to Distinguish the Effects of Diffusion from Convection



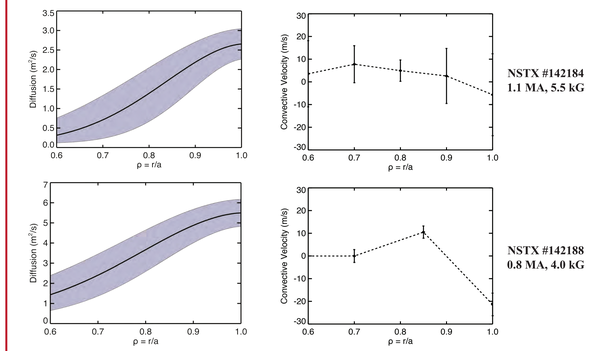
- STRAHL was used to generate simulated data for the profiles shown on the left (solid lines)
- STRAHL was then run with small variations in D and v (dashed lines) in the edge, the results were fit to the simulated data and a chi square was calculated in each case
- At each time point, v can only be found as a function of an unknown D
- This function of D changes in time throughout an impurity density perturbation, thus allowing D and v to be found separately, assuming they are constant on the timescale of the perturbation
- After the ~30 ms perturbation, x-ray emission begins to reach a steady state

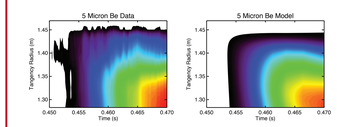
Chi square of fits to simulated data for an array of D and v values at four points in time

A cut along the dashed line from the plots above, showing how chi square varies as a function of D (constant v)

Radial profiles of 5 μm Be emission from simulation (points) with $D = 0.8$ m²/s and a fit (line) with $D = 1.0$ m²/s

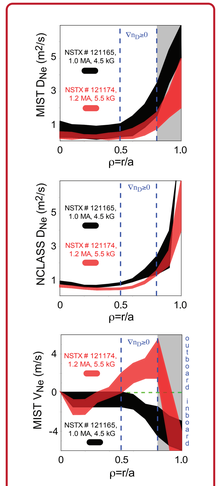
The ME-SXR Diagnostic and Analysis have been Successfully Implemented for High-Resolution Edge Impurity Transport Measurements in NSTX





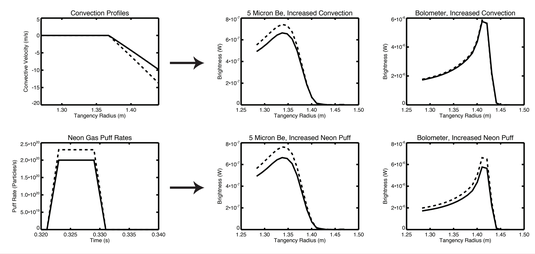
Measured and Modeled SXR Emission from NSTX #142188 (0.8 MA, 4.0 kG)

- Plasma conditions were chosen to minimize MHD activity: NBI was stepped down from 6 MW to 4 MW to reduce fast ion driven modes, Li was applied to suppress ELMs
- Edge diffusion coefficients, now with much-reduced error, are found to be consistent with previous measurements matching neoclassical transport (see previous results with a core ME-SXR diagnostic to the right)
- Convective velocities appear anomalous inside pedestal, and are poorly constrained towards the core without an accompanying core measurement



L. Delgado-Aparicio et al., Nucl. Fusion 51, 083047 (2011).

A Bolometer is Needed to Determine the Neon Source Term in the Plasma Edge



An increase in edge convection increases emission from higher charge states seen with the Be-filtered arrays, the same result as with increasing the total particle source from gas puffing. However, the bolometer signal remains relatively unchanged.

With an actual increase in gas puffing, emission increases uniformly across all array. Thus, the bolometer aray is needed to separate the effects of the two.

Two Proposed Diagnostic Systems Would Further Improve Edge Transport Measurements in NSTX-Upgrade

Two Arrays with Core and Edge Sub-Arrays would Constrain the Inner Boundary

- Edge sub-arrays (as described here) and core sub-arrays (coverage of the full plasma volume with coarser spatial resolution) would provide transport measurements across the entire plasma radius, providing a constraint on the inner boundary of the edge measurement
- Two toroidally-displaced ME-SXR arrays would provide measurements of non-axisymmetric effects
- ME-SXR arrays will also be used to measure temperature perturbations for electron thermal transport measurements
- **See PP9.00067 (Tritz *et al.*) and PP9.00068 (Stutman *et al.*)**

A Laser Blow-off Injection System would Constrain the Source Term

- A diagnosed time history of the injection would provide a better constraint on the impurity neutral source term
- 10 Hz pulsed laser system injecting non-recycling impurities would provide multiple transport measurements per discharge
- Non-recycling impurities would eliminate contamination of the impurity source from wall recycling
- More impurities to choose from for Z scaling experiments and tests of fusion-relevant materials
- **See PP9.00068 (Stutman *et al.*) for more details**