Measurement of MHD-induced Energetic Ion Loss during H-mode Discharges in the National Spherical Torus Experiment*

S. S. Medley, N. N. Gorelenkov, R. Andre
and A. L. Roquemore,
Princeton Plasma Physics Laboratory

Supported by

Abstract

P2-200

Measurement of MHD-Induced Energetic Ion Loss during H-mode Discharges in the National Spherical Torus Experiment *

S. S. Medley, N. N. Gorelenkov, R. Andre and A. L. Roquemore
Princeton Plasma Physics Laboratory, Princeton, New Jersey, 08543, USA

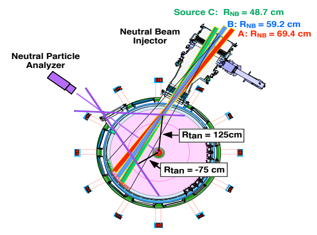
This presentation focuses on MHD-induced ion loss during H-mode operation in NSTX [1]. A rich variety of energetic ion behavior resulting from magnetohydrodynamic (MHD) activity is observed in NSTX using a horizontally scanning Neutral Particle Analyzer (NPA) whose sightline views across the three co-injected neutral beams. For example, onset of an n = 2 mode leads to relatively slow decay of the energetic ion population (E ~ 5 - 100 keV) and consequently the neutron yield. The effect of reconnection events, sawteeth and bounce fishbones [2] differs from that observed for low-n tearing-type MHD modes. In this case, prompt loss of the energetic ion population occurs on a time scale of ≤ 1 ms and a precipitous drop in the neutron yield occurs. During H-mode discharges with low-n activity, the NPA charge exchange spectrum usually exhibits a significant loss of energetic ions only for $E > E_b/2$ where E_b is the beam injection energy. The magnitude of the energetic ion loss was observed to decrease with increasing tangency radius, R_{tan}, of the NPA sightline, increasing toroidal field and increasing NB injection energy, E_b. Increasing values of these parameters reduces the fraction of trapped particles that is either generated or viewed by the NPA. TRANSP modeling suggests that MHD-induced ion loss is accelerated during H-mode operation due to an evolution of the q and beam deposition profiles that feeds both passing and trapped ions into the region of low-n MHD activity.

*This work was supported by PPPL by DoE Contract DE-AC02-76CH03073

[1] S. S. Medley, *et al.*, "MHD-induced Energetic Ion Loss during H-mode Discharges ...," PPPL Report PPPL-3931 (2004)
[2] E. D. Fredrickson, L. Chen and R. B. White, 2003 Nucl. Fusion **43** 12

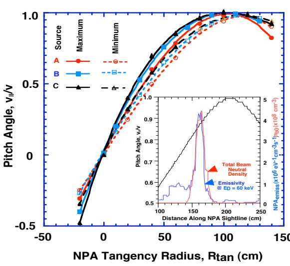
See related poster P2-196 by N. N. Gorelenkov and S. S. Medley for ORBIT analysis of MHD-induced Energetic Ion Loss.

The Neutral Particle Analyzer (NPA) on NSTX Scans Horizontally Over a Wide Range of Tangency Radii on a Shot-to-Shot Basis



• Covers Thermal (0.1 - 20 keV) and Energetic Ion (≤ 150 keV) Ranges

NPA Measurements are Spatially Localized by Beam Injected Neutrals



• The beam injected neutrals spatially localize the NPA signal (insert).

• Approximately 2/3 of the line-integrated flux originates in the NB region.

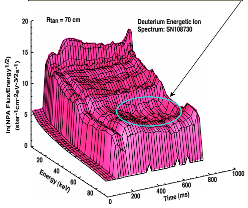
• This spatial localization constrains the range of pitch angles viewed by the NPA (main panel).

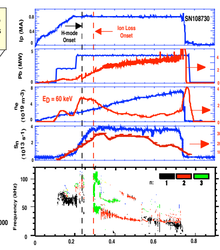
• Spatial localization weakens with increasing NB penetration distance (due to attenuation of the beam neutrals).

Illustration of MHD-induced Ion Loss during H-mode

B_T = 4.8 kG, I_P = 0.8 MA, Source A & B @ 90 keV, Low MCP Bias

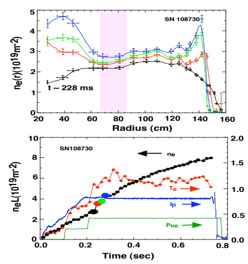
• ***Following H-Mode onset at 230 ms, the NPA spectra show significant loss of energetic ions only for $E>E_b/2$.***





Discharge Parameters for SN108730

B_T = 4.8 kG, I_P = 0.8 MA, NPA R_{TAN} ~ 70 cm, Low MCP Bias

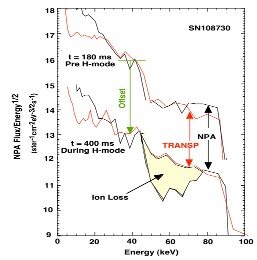


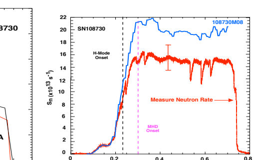
• MPTS electron density profiles (upper panel) correspond to time flagged by colored circles on the line integral density cure (lower panel).

• Sources A & B @ 90 keV, P_B = 4.2 MW.

• The NPA is spatially localized around R ~ 75±10 cm by the beam primary and halo neutrals (shaded region in upper panel).

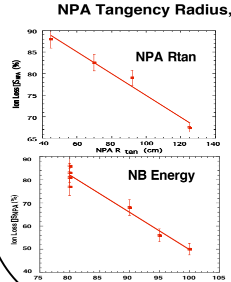
TRANSP Simulation of the NPA Energetic Ion Spectra and the Measured Neutron Rate





• In a quiescent L-mode plasma, good agreement is observed between TRANSP simulation and NPA spectra (upper curves in left panel), but not during H-mode plasmas with MHD-induce ion loss (lower curves).

MHD-induced Ion Loss Decreases with Increasing NPA Tangency Radius, NB Energy and Toroidal Field



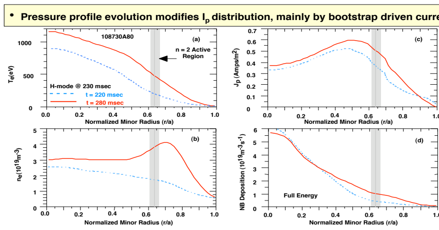
• NPA R_{tan} scaling:
Orbit code modeling showed MHD-induced ion loss occurs only for passing particles (not trapped). Increasing R_{tan} corresponds to viewing an increasing fraction of passing particles, thus greater apparent loss.

• E_{NB} scaling:
Beam-driven core current increases with E_{NB} which modifies the q-profile and MHD activity to reduce resonant ion loss.

• B_T scaling:
Increasing B_T modifies the MHD mode structure and reduces the mode amplitude $\Delta B/B$ and hence the resonant ion loss.

Evolution of T_e, n_e (and hence Pressure) Profiles during H-mode Drives other Profile Changes

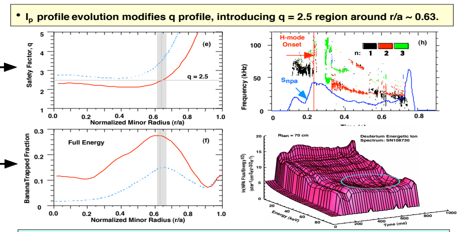
• Pressure profile evolution modifies I_p distribution, mainly by bootstrap driven current.



• Density profile evolution increases full energy NB deposition in outboard region.

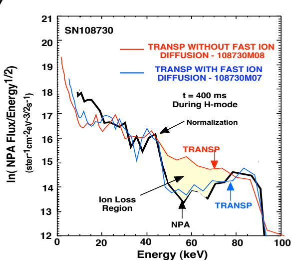
q-profile Evolution Introduces Low-n MHD activity: Out-shifted NB Deposition Feeds Ion Loss Region.

• I_p profile evolution modifies q profile, introducing q = 2.5 region around r/a ~ 0.63.



• Out-shifted NB deposition increases full E ions in m/n = 5/2 MHD active region.

A TRANSP Fast Ion Diffusion Model was used To Emulate MHD-induced Energetic Ion Loss…



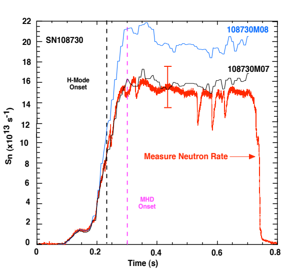
• The TRANSP energetic ion distribution without fast ion diffusion (red curve) does not reflect the observed ion loss (black curve) in the energy range 45 keV < E_D < 75 keV.

• The fast ion diffusion can be specified as a function of ion energy, time and space.

• A radially constant fast ion diffusion, D ~ 4 m^2s^{-1}, was turned on after the H-mode transition and constrained within the energy range 45 keV < E_D > 75 keV.

• This prescription yielded a TRANSP energy spectrum (Blue curve) in good agreement with the NPA measurement (black curve).

…and Simultaneously Match the Measured Neutron Rate

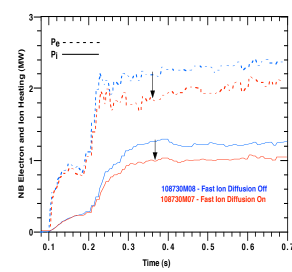


• In some cases, TRANSP modeling overestimates the neutron rate (blue curve).

• The fast ion diffusion model in TRANSP could be 'tuned' to simultaneously match both the observed energetic ion loss in the NPA spectrum and the measured neutron rate.

• As will be shown in subsequent slides, a proper accounting of energetic ion loss is important for accurate TRANSP analysis of power balance and transport in plasmas exhibiting MHD-induced energetic ion loss.

MHD-induced Ion Loss Reduced Beam Heating of Elections and Ions



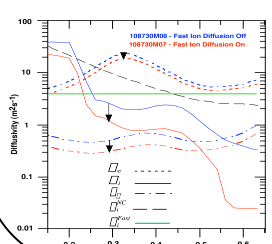
• TRANSP calculations of neutral beam power to electrons and ions without fast ion diffusion (blue curves) and with rast ion diffusion (red curves).

• Approximately 2/3 of the NB power goes to the electrons.

• Accounting for MHD-induced ion loss reduces power to the electrons by ΔP_e = 0.4 MW but the power reduction to the ions is only ΔP_i = 0.2 MW.

• Thus MHD-induced energetic ion loss preferentially reduces electron heating.

MHD-induced Energetic Ion Loss Affects Power-balance-inferred Diffusivities

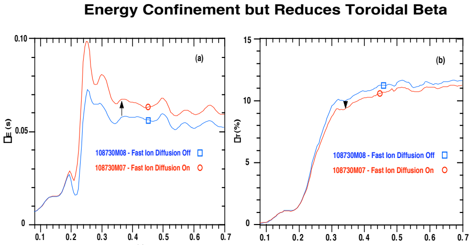


• TRANSP calculation of power balance diffusivities at t = 400 ms with (red curves) and without (blue curves) fast ion diffusion for SN108730 is shown.

• In the core region, << χ_e □ χ_i^{Fast} < χ_i □□χ_i^{NC} with and without fast ion diffusion.

• In the mid-radius region, < χ_i < χ_i^{NC} ~ χ_e □ χ_i^{Fast} both with and without the fast ion diffusion model, though it can be seen that fast ion diffusion modestly reduces χ_e but markedly reduces χ_i.

MHD-induced Ion Loss Increases Thermal Energy Confinement but Reduces Toroidal Beta



• Accounting for energetic ion loss increased τ_E by ~ 15% but reduced β_T by ~ 7%.

Summary

• Energetic Ion Loss during H-modes: Observations

During H-modes, the NPA commonly observes significant ion loss at $E \geq E_b/2$ but little or none at lower energies. Loss decreases with increasing R_{tan}, B_T and E_b.

• Energetic Ion Loss during H-modes: Mechanism

TRANSP modeling indicates that the effect is driven by the high, broad density profiles endemic to H-modes. The postulated mechanism is that a pressure-driven evolution of the q profile introduces low-n MHD activity whilst the beam deposition profile broadens to feed passing and trapped ions into the MHD active region.

It must be emphasized the MHD-induced ion loss mechanism is a pressure profile effect, which can sometimes occur in unusually high density L-mode discharges, but almost always is observed in H-mode discharges because of the nature of the electron density profile.

Accounting for MHD-induced energetic ion loss increases the plasma energy confinement time, but reduces the neutron yield and the toroidal beta. A proper accounting of energetic ion loss is therefore important for accurate analysis of power balance and transport in plasmas exhibiting MHD-induced energetic ion loss.

* Work supported by US Department of Energy Contract No. DE-AC02-76CH03073