UT-BATTELLE

Fueling

W.A. Houlberg

Toward an Integrated Fusion Simulation

7-9 November 2006

Oak Ridge, TN

Fueling Sources

Neutral beam injection

- Covered in presentation by McCune

Neutral gas and recycle

- Generally an edge source with uneven poloidal and toroidal distribution
- Continuous
- Neutrals treated as test particles in background plasma

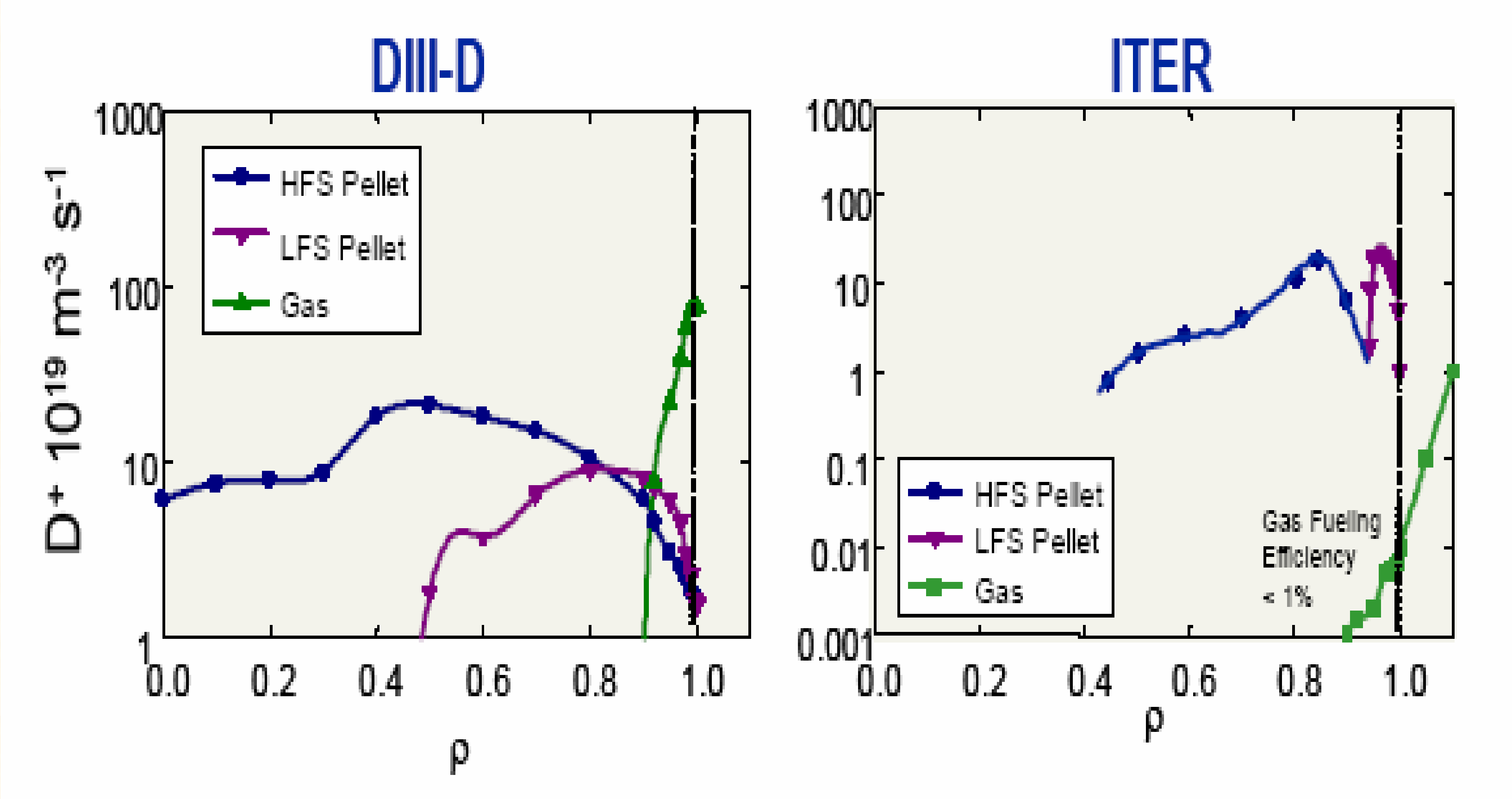
Frozen hydrogenic pellets

- Deeper source
- Short pellet lifetime (~1 ms), periodic event (1 – 100 s^{-1})
- Plasma electrons treated as test particles in dense neutral cloud
- Ionized ablatant cloud initially ~10^4 more dense than plasma, expands along magnetic field line in 3-D structure and usually distributes over a flux surface within a few ms (unless deposited in an island)

Other

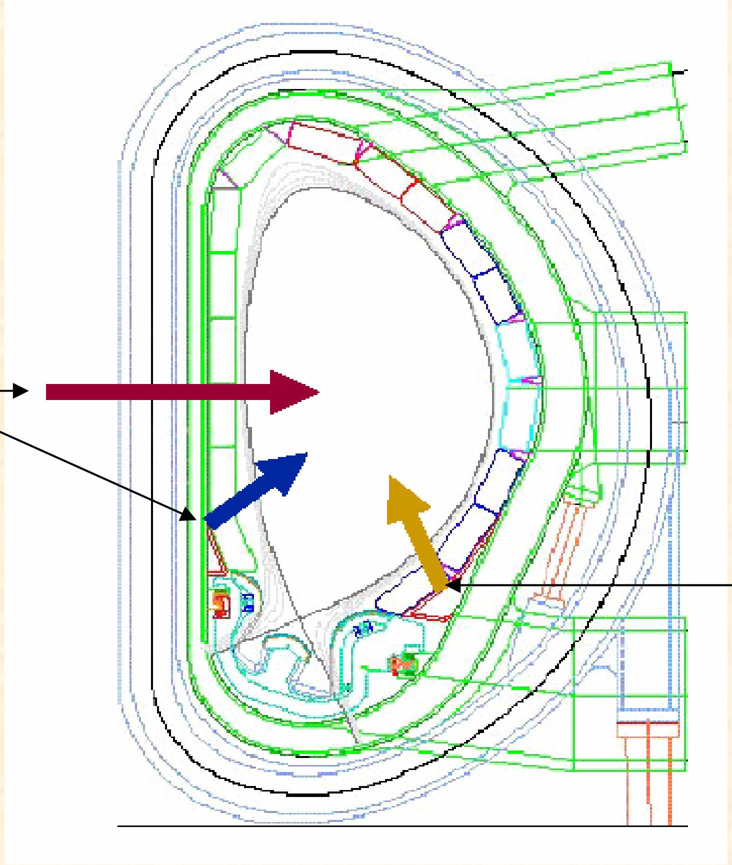
- Impurities (edge source)
- Fusion (species conversion)

Examples of Net Flux-Surface-Averaged Particle Source Profiles



ITER Pellet Injection Locations

High Field Side
injection of
larger pellets
for fueling
~few Hz



Low Field Side
injection of small
pellets for ELM
triggering
~50-100 Hz

Neutral Gas and Recycle – General Description

Equations:

- Boltzmann equation in integral or diffusion form

Needed information:

- Plasma electron and all ion densities, plasma ion and electron temperature
- Plasma geometry, detail depending on dimensionality of neutral module
- Cross-section library for electron and ion impact ionization, charge-exchange, dissociation, …

Returned information:

- Source/loss of thermal ions and electrons (flux-surface average)
- Source/loss of thermal ion and electron energy, ion momentum (flux surface average)
- Spatial and energy distribution of neutrals (more detail required for interpretation of diagnostics, e.g. Charge Exchange Recombination Spectroscopy)

Neutral Gas and Recycle – Codes

Many available, examples include:

- 1-D (radial)
  - FRANTIC (cylindrical, integral equations, NTCC Module)
- 2-D (radial, poloidal)
  - GTNEUT (similar to FRANTIC, integral equations, NTCC Module)
- 3-D (axisymmetric plasma)
  - NUT (similar to FRANTIC, integral equations, NTCC Module)
- 3-D (non-axisymmetric plasma)
  - Monte Carlo techniques

Pellet Injection – General Description

Equations:

- Fluid transport equations for dense gas and cloud
- Treated as ‘fast event’ – instantaneous on plasma evolution timescale
- Sometimes triggers MHD activity – e.g., ELMs (Edge Localized Modes) are reliably triggered by small pellets to control the peak energy load on the divertor

Needed information:

- Pellet size, velocity, composition, injection trajectory
- Plasma electron and density along pellet trajectory
- Plasma differential volumes along pellet trajectory
- Optional – fast ion distribution

Returned information:

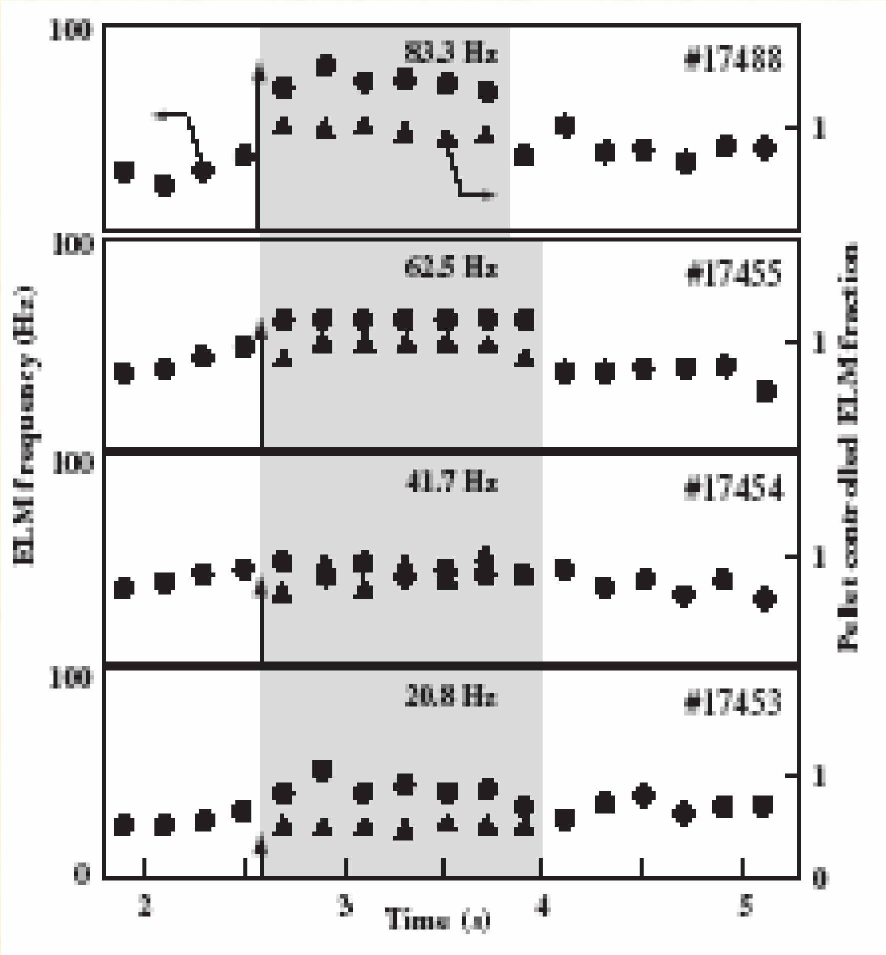
- Source thermal ions and electrons (flux-surface average)
- Loss of thermal electron energy from ionization

ELM Pace Making by Pellets in ASDEX Upgrade (Control of Fast MHD Events)

P.T. Lang, *et al, Nucl. Fusion* 44 (2004) 665

Demonstration of ELM pace making by pellet injection

- Pellet phases (shaded areas) at different nominal frequencies (solid arrows) show up higher ELM frequencies (•) than pre- and post-pellet reference phases.
- For highest pellet frequencies complete external control is established as indicated by the fraction of pellet controlled ELMs (number of pellet-triggered ELMs/number of ELMs)



Pellet Injection – Codes

PELLET:

- New F90 modules
  - PELLET module calculates pellet ablation to obtain local source of cld plasma, then call PRL module
  - PRL module calculates expansion of cold plasma along magnetic field and drift across the magnetic field
  - To be submitted to NTCC Module Library
- PRL (Pellet Relaxation Lagrangian) module for ablatant drift
  - Dense ionized ablatant drifts outward in direction of major radius in agreement with DIII-D experimental observations
  - P.B. Parks, L.R. Baylor, Phys. Rev. Lett. 94 (2005) 125002
  - Example simulation of single cloudlet: PRL_density_anim.gif
  - Cloudlet solution is stored as private data in PRL that can be retrieved through a subroutine call (output port)