Initial Off-Axis Neutral Beam Characterization and Physics Experiments on DIII-D

by

M.A. Van Zeeland


1General Atomics
2University of California-Irvine
3Oak Ridge National Laboratory
4Lawrence Livermore National Laboratory
5University of Texas-Austin
6Princeton Plasma Physics Laboratory
7University of Wisconsin-Madison
8University of California-San Diego
9Oak Ridge Institute for Science Education
10University of California-Los Angeles

Presented at the
53rd Annual Meeting of
the APS Division of Plasma Physics,
Salt Lake City, Utah

November 14-18, 2011
In 2010-2011, One of DIII-D’s Beamlines was Modified to Allow Off-Axis Injection – Enabling A Broad Range of Profile Control

16.5 Deg. Max Beamline Tilt

*Engineering Challenge - Required major source modifications to fit beam through reduced aperture

Calculated Profiles

*Figures showing calculated profiles for energy density, torque density, and current density for on-axis and off-axis injection (5 MW each).*

M.A. Van Zeeland/APS/November 2011
Initial Experiments Focused on Characterizing the Beam and Developing Models to Describe it

- Trajectory, shape, divergence, power, confinement, fast ion profile etc. were measured
  - Imaging of beam injection into gas
  - Beam blips into Ohmic discharges
  - MHD quiescent low beam power discharges

- Subsequent experiments focused on
  - Off-axis neutral beam current drive (J.M. Park)
  - Impact on Alfvén eigenmodes
  - High $q_{\text{min}}$ steady state discharges (C.T. Holcomb)
To Support Beam Characterization, an Imaging View the Off-axis Neutral Beam Was Installed

- Camera view spans from outer to inner wall
Images show beam emission and yield neutral profile

Range of angles and tilts allows check on steering

Some clipping of beam on portbox is evident as beam tilt increases
NUBEAM* Model Based on Imaging Data was Developed that Accurately Describes Off-axis Beam Profile Throughout Tilt Range

- Off-axis beam is described by four sources with several collimators that change with tilt – previously only one source was required
- Model properly describes beam profile modification and power loss due to clipping as beam and source are tilted

Short Beam Blips Were Used to Investigate Beam Fueling, Prompt Loss, and Confinement

- Neutron rise depends on number of confined beam ions injected and target density
- Decay depends on slowing down & losses on $\tau_s$ timescale
- Minimal beam power leaves essentially Ohmic plasma, free from large MHD

Beam Blip Neutron Measurements Are Compared For Several Beams

- Off-axis beams clearly produce less neutrons than on-axis beams
  - Some reduction expected with deposition at larger radii (lower density and temperature)
TRANSP* Predictions Reproduce Trends but Show Off-axis Beams Produce Fewer Neutrons Than Expected

- Simulations are consistent with less neutron emission from off-axis beam
- Decay timescales generally match well indicating no losses on slowing down timescale
- Overall peak neutron rate is below expectations from off-axis beams

* w3.pppl.gov/transp
Experiments Were Also Carried Out to Compare Neutron Emission For Pulses Comparable to Slowing Down Time

- Longer pulses mitigate sensitivity to density profile uncertainties
- Beams were cycled through for entire discharge
- Diagnostic beams were blipped after ~ one slowing-down time and beams switched
- Current ramp was used to alter fast ion confinement/prompt losses
- Single beam heated L-mode discharges like this are typically free from large MHD – ideally classical behavior
Long Beam Pulse Data Show Plasma Current Dependence as Well as Lower Neutron Emission From Off-Axis Beams

![Graph showing plasma current and neutron rate against time for on-axis and off-axis beams.](Image)

- **Beam Layout**
- **On-Axis**
- **Off-Axis**

**Time (ms)**
- 1000
- 2000
- 3000
- 4000
- 5000

**Neutron Rate (a.u.)**
- 0.0
- 0.5
- 1.0
- 1.5
- 2.0

**IP (MA)**
- 0.0
- 0.5
- 1.0
- 1.5

M.A. Van Zeeland/APS/November 2011
TRANSP Reproduces Trends but Overpredicts Neutron Emission from Off-Axis Beams

- Current dependence is correctly captured for all beams but relative emission of off-axis beams is low
- For collection of similar discharges Off-axis Expt/TRANSP ~0.7-0.95
FIDA Measurements Clearly Show Off-Axis Peak in Fast Ion Profile

- FIDA (Fast Ion D-alpha) is used to measure fast ion density in portion of phase space
- Data will be compared to FIDA simulation code to evaluate expected emission

B. Grierson, Wed. 11:30, NI2.00005
Initial Physics Expt. Tested Variation in Alfvén Eigenmodes as Beam Injection Was Varied From On to Off-Axis

- Variety of Alfvén Eigenmodes are typically observed with beam injection during current ramp
- Modes are driven by gradients in the fast ion pressure
Near $q_{\text{min}}$, RSAEs are Driven Strongly By On-Axis Beams but Weaker Gradient From Off-Axis Beams Provide Less Drive

- Reversed shear Alfvén eigenmodes are typically weak or not observed during discharges with only off-axis beams
- Consistent with weaker fast ion gradient near $q_{\text{min}}$
TAEs Are Observed During Both On and Off-Axis Beam Injection

- Toroidal Alfvén eigenmodes (TAE) typically unstable at larger minor radii where fast ion gradients are comparable
Conclusions

• One of DIII-D’s beamlines was tilted allowing up to 5MW off-axis injection and experiments clearly show radial shift in deposition profile

• Initial experiments included careful characterization of beam profile and focus on developing model to describe beam

• Predicted neutron rate from beam blips and single beam low power discharges appears to be high for off-axis beam
  – Next talk will discuss comparisons with current drive and stored energy

• In Alfvén eigenmode current ramp experiments, off-axis beams produce weaker drive for RSAEs than on-axis beams while TAEs at larger radii are often unstable during both on/off axis injection