Energetic particles study in MAST with a neutron emission profile monitor

M. Cecconello\textsuperscript{1}, M. Turnyanskiy\textsuperscript{2}, S. Conroy\textsuperscript{1}, R. Akers\textsuperscript{2}, G. Ericsson\textsuperscript{1}, S. Sangaroo\textsuperscript{1}, I. Wodniak\textsuperscript{1}, C. Hellesen\textsuperscript{1}, E.A. Sunden\textsuperscript{1}, C. Marini-Bettolo\textsuperscript{1} and the MAST Team

\textsuperscript{1}EURATOM/VR Association, Department of Physics and Astronomy 
Division of Applied Nuclear Physics, Ångström Laboratory, Uppsala University, Sweden

\textsuperscript{2}EURATOM/CCFE Fusion Association, Culham Science Centre, Abingdon, UK
Summary

Fast particles and neutron emission at MAST

Collimated neutron flux monitor diagnostic

First results

Modelling and interpretation

Future directions

Conclusions
Fast particles diagnostics at MAST

Exploit specific capabilities of MAST:

Super-Alfvénic beams, $V_{\text{NBI}} \sim 2.5 \, V_A$

Large fast ion fraction with high $\beta$ (above ITER values)

Wide range of fast ion driven modes observed

Operating:

Fast Ion D-alpha diagnostic (FIDA)

Compact NPA

Collimated Neutron Camera

Design stage:

Lost proton detector
Neutron emission and detection at MAST

Most of the fusion neutron production is due to injected neutral deuteron reacting with the thermal deuteron population (beam-thermal) while the beam-beam term accounts for 10 -20 % of the total and the thermal-thermal contribution is negligible.

\[ D + D \rightarrow ^{3}\text{He} \ (0.82 \text{ MeV}) + n \ (2.45\text{MeV}), \ Q = 3.27\text{MeV} \]

Document fast particle driven collective instabilities

AE: TAE, EAE, BAE, Alfvén cascades, high frequency CAE energetic particle modes, chirping modes

Effects of other instabilities upon fast ions

Typically \( n = 1 \) internal kink: sawteeth, fishbones, infernal modes, long-lived modes

\(^{235}\text{U Fission Chamber}\)
Neutron emissivity and design choices

The neutron emissivity profile is strongly dependent on the fast ion spatial and energy distribution.

Separation between LOSs chosen to be approximately 20 cm, roughly corresponding to the spatial scale of the location of the projected co-passing orbits of the fast ions.
Lines of Sight and Fields of View layout

Plasma edge

Vessel

Central column

Impact parameters

Line of sight and field of view

NBI South-West PINI (2.5 MW, 5 s)

NBI South PINI (2.5 MW, 5 s)

Collimators

Detectors

Shielding

Rail

Collimators, shielding and simulated neutron fluxes
Installation in the MAST area

Back shield closed on the 6th June 2011.
Detectors and Data Acquisition System

Liquid scintillator coupled to PMT
2 x 5 x 1 cm³ active volume

14 bit, 256 MB memory
250 MHz sampling rate

CH 0 CH 1

SEK 468 - Cf252 Pulse Shapes

SEK 468 - Cf252
Pulse Shape Discrimination

Separating gammas from neutrons

Collimator blocked

Collimator open

NCR (0.5x10^5 s^-1)
NBI (MW)
IP (MA)
Effects of MHD instabilities on fast ions

Parasitic radial scan on M8-IPS-005
q-profile evolution during current ramp
NBI timing for MSE, good pulse repeatability
n = 1,1 snake

Plasma region on the equatorial plane probed by radial scan in 4 pulses.
Core vs edge comparison

![Graph comparing count rates over time for two different locations (0.834 m and 1.032 m) on the core side (top) and two different locations (1.014 m and 1.204 m) on the edge side (bottom).](image-url)
Fields of view volume integrated emissivity

Convoluted neutron pulse height spectrum with the detector response function
Neutron yield and energy distribution effects

H-mode plasma with 3.2 MW NBI a $1.4 \times 10^{14}$ n/s

Pulse 25087

L-mode, sawtoothing, NTM activity.

NBI (MW)
Plasma current (MA)
Line integrated density ($\times 10^{20} \text{ m}^{-2}$)

Fission chamber

Neutron camera
(1 ms time resolution, 1 line of sight only, 0.64 m)

SXR, equatorial on-axis

Mirnov coil

Pulse 25004
L-mode, sawtoothing, NTM activity.

- Fission chamber
- Neutron camera (1 ms time resolution, 1 line of sight only, 0.64 m)
- SXR, equatorial on-axis
- Mirnov coil

Pulse 25004
Fishbones and long-lived modes

Parasitic radial scan on M8-IPS-005
Resonant Magnetic Perturbation
Good pulse repeatability

![Graphs and images showing the results of the scan and modes]

260 ms
245 ms
260 ms
Long lived modes and profile effects

Neutron camera equatorial lines of sight

Central column
Outboard plasma edge
Impact parameter
Pivot point
Lines of sight
Rail

Lines of sight:
1
2
3
4, 5
6

Impact parameter:
6E5

Count Rate (1/s)

70-90 ms
200-220 ms
270-290 ms

Count Rate (1/s)

6E5

0.418 m
0.630 m
0.777 m
0.977 m
1.005 m
1.196 m

Time (s)
Fishbones

Pulse 26460

Fission chamber

Neutron Camera (4 Khz)

Neutron Camera (4 Khz)

xmc_omv/210
Modelling of beam-thermal neutron spectra

Beam-thermal neutron energy spectra for different NBIs and angles between the lines of sight and the beam injection direction.

Spectra folded with a generic neutron response function for a liquid scintillator.

Cautionary notes:

1) 5 – 10 % uncertainty in total fluxes due to the shift in PHS for fixed threshold.

2) Anisotropy in DD cross-section for beam-thermal reactions can affect fluxes making the comparison of measured fluxes along different lines of sight tricky.
Field of view modelling: LINE2.1

Full 3D Monte Carlo simulation of the contribution of each voxel to individual fields of view.

Example:
field of view weighting for the diagonal collimator using 1 cm³ voxel size.

XY projection of a field of view

RZ projection of a field of view
Voxelized field of view for a radial scan

Equatorial lines of sight

![Equatorial lines of sight graphs](image-url)
Modelling the count rates: TRANSP x LINE21

Neutron emissivity integrated in the volume within the field of view of each collimator.

TRANSP (18821)

Voxel weight (0.654 m)

Count Rate per voxel (0.654 m)

TRANSP profile used to generate a synthetic profile to be used for comparison with experimental data.
Comparison with experimental data, using a synthetic neutron emissivity profile:

1) detector efficiency, pile-up rejection
2) thin flange attenuation
3) back-scattering
4) anisotropic neutron emission
Future activities and developments

1] Absolute flux and pulse height spectra calculations:
   controlroom
   Directional RELativistic Spectrum Simulator (DRESS)
   LOCUST
   TRANSP

2] Detector response functions:
   NRESP7, PRES4, MCNP

3] Participation to experimental campaign M8
   Neutral Beam Current Drive experiment

   A neutron camera is on the list of high-priority diagnostics for MAST-U and space has been already reserved.
Conclusions

Relatively young diagnostic (about 100 pulses old, no dedicated experiments to date) but:

1) fully operational (minor glitches being fixed soon) 4 lines of sight with scanning capability for full radial coverage;

2) MAST pulses repeatability allows for full radial scan, with optimal positioning in between pulse;

3) Time resolution, at present, can be pushed below 1 ms for flux measurements with appropriate statistical error; pulse height spectra require much longer integration time;

4) Preliminary evidence of MHD effects on the volume integrated neutron emissivity that can be coupled to changes in the neutron profile emissivity following fast ions redistribution;

5) Still many exciting things to do!