TRANSP modelling of neutron emissivity on MAST

I.Wodniak[1], M. Gorelenkova[2], S.Conroy[1], M.Cecconello[1], R.Akers[3], M.Turnyanskiy[3]
S.Sangaroon[1], D. Keeling[3], C.Michael[3], G.Colyer[3], G.Ericsson[1] and the MAST team

[1] *Department of Physics and Astronomy, Uppsala University, EURATOM-VR Association, Uppsala, Sweden*

[2] *Plasma Physics Laboratory, Princeton University, Princeton, USA*

[3] *EURATOM/CCFE Fusion Association, Culham Science Centre, Abingdon, United Kingdom*

Abstract

The aim of this paper is to validate a set of methods to model the measured neutron emission on Mega Amp Spherical Tokamak (MAST) using TRANSP. Neutrons are measured along a set of collimated lines of sight (LoS) at MAST by a Neutron Camera (NC). The neutron emissivity is modeled with TRANSP [1] for different plasma discharges using a self-consistent data set produced by a data preparation and analysis tool. The modeled neutron emissivity is then compared with NC experimental data using a full 3D solid angle calculation to model the transport of neutrons from plasma to detector. A good agreement between the modelled and experimental neutron rate was found.

1. Introduction

Neutrons are generated in fusion experiments such as MAST in deuterium plasmas through the fusion reaction ${}^{2}_{1}\mathrm{D} + {}^{2}_{1}\mathrm{D} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$ ($E_\mathrm{n} \approx 2.45$ MeV). The neutrons born in fusion reactions carry information on the spatial and temporal distributions of deuterium ions. All ions with large pitch angle will be trapped at the outboard plasma region due to magnetic field configuration. This is important in MAST because neutrons are mainly generated in fusion reactions between the ionized injected deuterons and the thermal ions in the bulk plasma (beam-thermal contribution) and between injected deuterons themselves (beam–beam contribution). The contribution to the neutron emission from thermal fusion reactions is negligible due to low temperatures. As a result, in the presence of a significant trapped fast ion population, the neutron emissivity on the plasma outboard side will be higher. Standard TRANSP output contains flux surface averaged neutron emissivity, however, a special TRANSP output was prepared which contains the poloidal projection of neutron emissivity. The obtained neutron emissivity is used for predicting the neutron count rate at each detector which is then compared to the measured one.

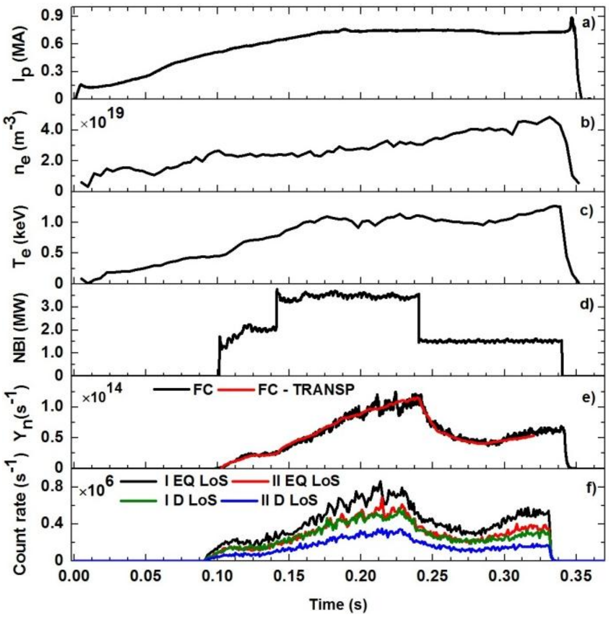

Figure 1. Global plasma parameters for pulse 27527: a) plasma current, b) and c) central electron density and temperature, respectively, d) NBI power, e) neutron count rate measured by fission chamber, f) neutron count rate measured by NC for four LoS.

2. Experiment and diagnostics

MAST is a midsize fusion research device with an aspect ratio of ~1.3. A typical MAST pulse lasts about 0.5 s, plasma current can reach up to 1.3 MA whilst the plasma density and temperature range from 0.1 to 1×10^{20} m^{-3} and 1-3 keV, respectively. Auxiliary heating is provided by two neutral beam injectors (NBI) which can deliver up to 5 MW of 75 keV deuterons. There is a comprehensive set of plasma diagnostics at MAST such as: a Thomson scattering systems (TS), a multi-channel motional Stark effect diagnostic, a linear D_α camera, a charge exchange recombination spectroscopy, a two-dimensional visible bremsstrahlung camera and a calibrated ^{235}U fission chamber (FC). The NC installed at MAST consists of four liquid scintillation detectors surrounded by specially designed shielding having two equatorial and two vertically inclined (diagonal) lines of sight (LoS) [2]. Assembly of the NC on a rail enables movement of the NC between plasma pulses, providing different LoS through the plasma from inboard to the outboard side of the MAST vacuum vessel. A measurement of the neutron emission requires highly repeatable plasma parameters during pulses. A set of four plasma pulses has been selected for this study (pulses 27525-27528 with impact parameter p ranging from 0.58 to 1.2 m) satisfying this requirement [3]. The global plasma parameters such as plasma current I_p, central electron density n_e and temperature T_e, NBI power and total neutron rate measured by the FC for pulse 27527 are presented in figure 1. The time evolution of the neutron count rate measured by the four LoS of the NC is shown in panel f) of figure 1.

3. Modeling of neutron emissivity

The modeling of the neutron emissivity has been carried out using TRANSP for pulse 27527 in time interval 0.23 -0.24 s. Matching the total neutron rate predicted by TRANSP to the one measured by FC (shown in panel e) of figure 1) requires either setting Z_{eff} = 3 or using two-dimensional Z_{eff} profile (Z_{eff} on/off axis around 1.5 - 2 and around 5) and setting the anomalous fast ion diffusion coefficient D_f = 1.5 $m^{-2}s^{-1}$. The second scenario was adopted in the presented TRANSP simulation because Z_{eff} = 3 is too large compared to the measured one in the plasma core and the anomalous fast ion diffusion coefficient has to be introduced to match FC data. As it is seen in panel e) of figure 1 the TRANSP predicted total neutron rate closely matches the neutron rate measured by FC. The large drops in neutron rate measured by the FC are caused by the onset of fishbones (0.19 – 0.23 s), which are not modeled here. TRANSP simulation predicts that about 85% of neutrons are generated in beam-thermal reactions, the remaining 15% are generated by beam-beam reactions. The contribution to the neutron emission from thermal fusion reactions is negligible. The neutron emissivity ε_{n} and the flux surface averaged neutron emissivity ε_{nfa} are presented in figures 2a) and 2b), respectively.

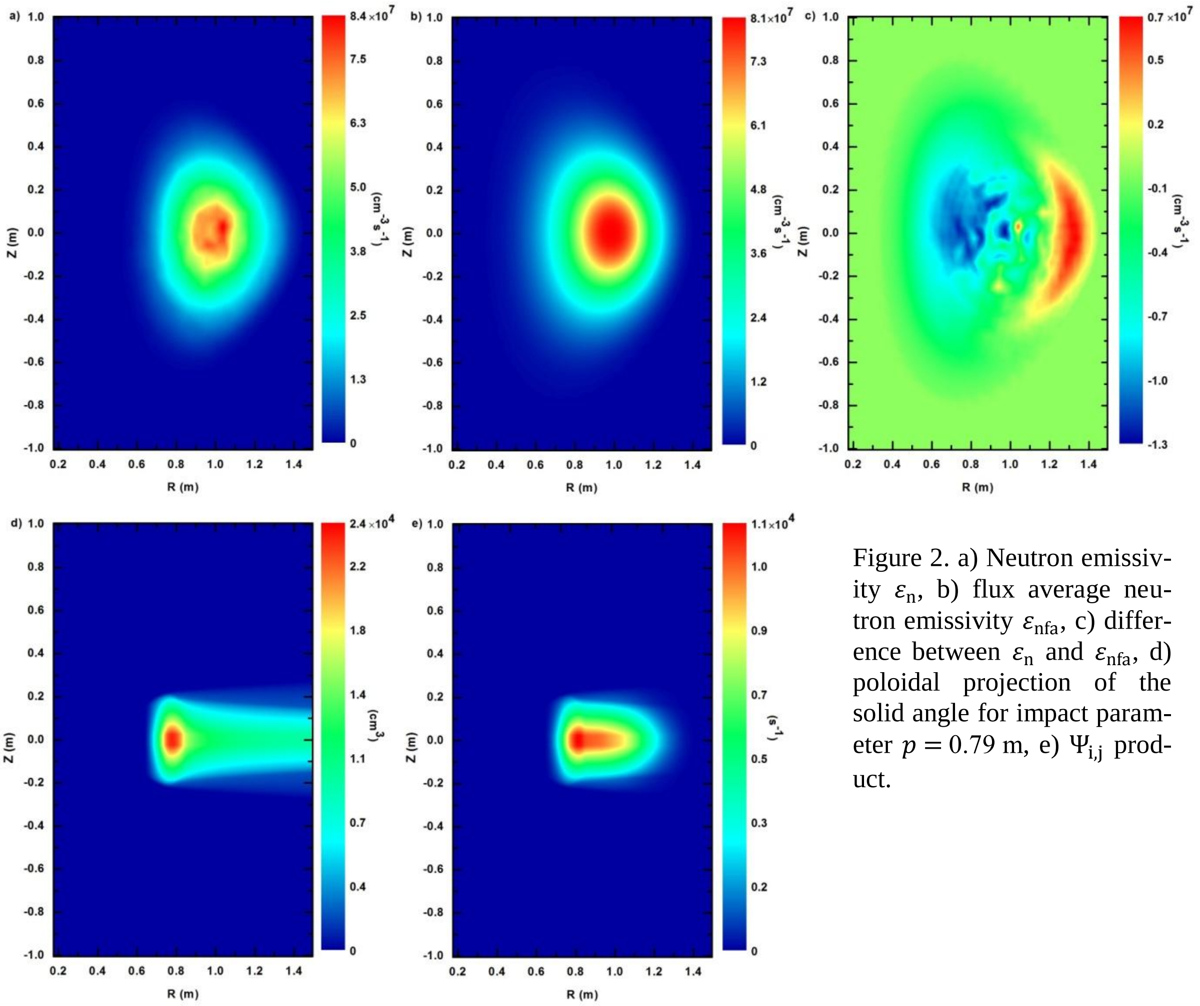

Figure 2. a) Neutron emissivity ε_{n}, b) flux average neutron emissivity ε_{nfa}, c) difference between ε_{n} and ε_{nfa}, d) poloidal projection of the solid angle for impact parameter $p = 0.79$ m, e) $\Psi_{\text{i,j}}$ product.

The difference between ε_{n} and ε_{nfa} is shown in figure 2c). A population of trapped ions at the plasma edge is clearly visible. In the calculation the assumption has been made that neutron emissivity is toroidally-symmetric. The simulated neutron count rate is calculated as $CR(p)_{sim} = d_{\text{eff}} \sum_{i,j} \Psi_{\text{i,j}}$, where $\Psi_{\text{i,j}}(p) = \varepsilon_n\,(R_i, Z_j)\,\Omega_\Theta(p; R_i, Z_j)$ yields the number of neutrons emitted in R_i, Z_j; Ω_Θ is the poloidal projection of solid angle between 1 cm^3 voxels and a detector calculated by LINE2 code [4] for a given impact parameter p and d_{eff} is a detector efficiency. An example of a solid angle computed for a given impact parameter p = 0.79 m projected on poloidal plane is shown in figure 2d) whilst the product $\Psi_{i,j}$ is shown in figure 2e). The simulated neutron count rate has been calculated for all four LoS for all impact parameters used in pulses 27525-27527.

4. Results and discussion

NC measurements and the TRANSP simulated neutron count rates as a function of the impact parameter for equatorial (EQ) and diagonal (DIAG) LoS are shown in figure 3. The measured neutron rate contains only neutrons with energies higher than 1.5 MeV in order to remove a significant part of low energy scattered neutrons. An average detector efficiency $d_{\mathrm{eff}} = 3.74\ \%$ was used to match the measured and simulated by TRANSP neutron rates. The neutron count rate calculated using ε_{n} shows better agreement with measurements than $\varepsilon_{\mathrm{nfa}}$, especially at the inboard and outboard edge of the plasma. The work presented here validates the LINE2 simulation code and demonstrates the importance of considering non-flux surface averaged neutron emissivity in fusion devices where most neutron production comes from a significant trapped fast ion population.

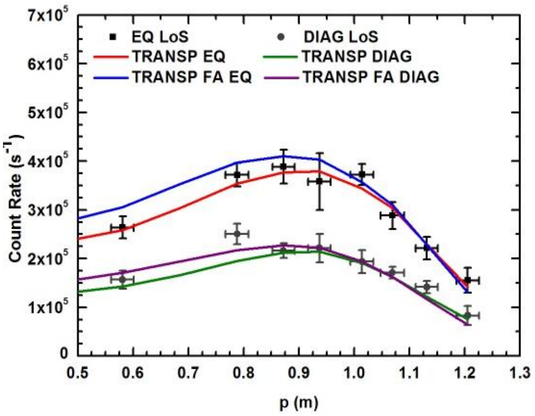

Figure 3. Comparison between the measured (black and grey points for EQ and DIAG LoS, respectively) and predicted by TRANSP (red and green solid lines for EQ and DIAG LoS respectively) neutron count rates as a function of the impact parameter. The neutron count rates computed using flux averaged neutron emissivity are presented as blue and purple solid lines for EQ and DIAG LoS, respectively.

Acknowledgements

This work was funded jointly by the United Kingdom Engineering and Physical Sciences Research Council and by the European Communities under the contract of Association between EURATOM and CCEF, and by the Swedish Research Council and by the European Communities under the contract of Association between EURATOM and VR. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] A. Pankin, D. McCune, R. Andre, Comput. Phys. Commun.,**159**, 157, (2004)
[2] M. Cecconello, M. Turnyanskiy, S. Conroy, Rev. Sci. Instrum. **81**, 10D315 (2010)
[3] M. Cecconello, S. Sangaroon, M. Turnyanskiy, accepted for publication in Nucl. Fusion (August 2012)
[4] S. Conroy, *Department of Physics and Astronomy, Uppsala University, EURATOM-VR Association, Uppsala, Sweden*