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# Improvement of neutron yield predictions in JET with ASCOT

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There is a large scatter between measured and predicted neutron yields in JET plasmas. The measured neutron yield in neutral beam (NBI)-heated plasmas often falls below predictions by commonly used simulation tools that assume neoclassical transport of fast ions. This is often referred to as a "neutron deficit" [1]. In radiofrequency (ICRH)-heated plasmas the opposite is often observed. Due to the acceleration of NBI ions by the ICRH, measured neutron yields tend to exceed predicted values [2]. In this contribution we present improvements to the Monte Carlo fast ion code ASCOT [3], aimed at tackling these deficiencies in modelling.

**Can fast ion redistribution due to NTMs explain the neutron deficit?** The neutron deficit can be mitigated by prescribing an ad-hoc anomalous diffusion fast ion coefficient in simulations [4]. This suggests additional fast ion transport is the cause of the deficit, but it does not explain the source of the transport, and has little predictive capability. A possible source of anomalous transport are long-lived MHD modes, such as neoclassical tearing modes (NTM)s. Earlier simulations with ASCOT [5], using realistic island parameters ($w = 10$ cm, $\Omega = 15$ kHz), derived from electron cyclotron emission (ECE) and Mirnov coil measurements, have shown that the redistribution of fast ions by a single stationary NTM reduces the predicted neutron yield but is not sufficient to explain the neutron deficit. This is illustrated in Figure 1a that shows the DD neutron rate from an interpretive JETTO/ASCOT simulation as a function of the width of a 3/2 island in JET discharge 77269 previously analyzed in [5]. In this work, we fix the temperature and density profiles to the ones measured by Thomson Scattering and focus only on the transport of fast ions. The profiles do not respond to changes in the NBI heating profile, for example. It is seen that even an unrealistically large island width is not enough to bring down the prediction to the measured level. We also include the rotation of the island, neglected in [5]. The result of a scan over the rotation frequency is shown in 1b. We find that the rotation of the island has a negligible effect on the predicted neutron yield. However, its effect in redistributing the fast ions can be clearly seen in the neutron profile, shown in Figure 1b. We can conclude that the local effect of a single island is not sufficient to significantly alter the total neutron yield. The temperature and density gradients of the background plasma are small due

*See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA FEC 2014, St. Petersburg, Russia

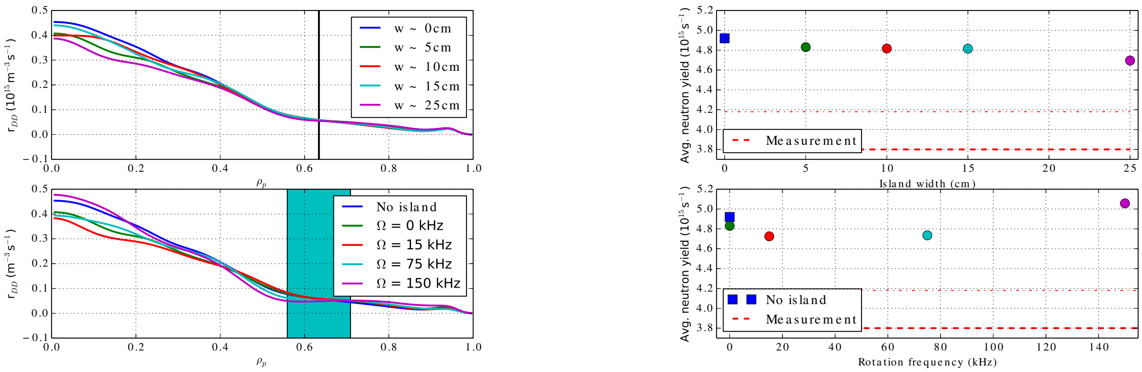


Figure 1: Scan of predicted (a) radial neutron profile and (b) volume integrated neutron rate in the width and rotation frequency of a 3/2 island. The experimentally measured width was approximately 10 cm and the frequency was approximately 15 kHz. The measured neutron rate is indicated by the dashed red line in (b).

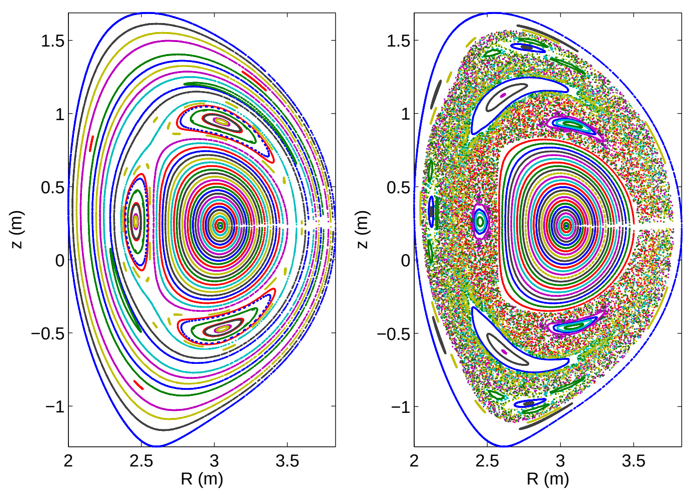


Figure 2: Poincare plots of magnetic field lines using (a) a signle 3/2 island and (b) a partially overlapping chain of three islands (3/2,2/1,3/1).

to the island and transporting fast ions across the island will not, therefore, significantly change their probablity of undergoing fusion reactions with the background. We therefore repeat the excercise with a string of 3/2, 2/1 and 3/1 islands connecting each other to create a channel for the fast ions to be transported from inside mid-radius to the top of the pedestal. A poincare plot of the magnetic geometry, obtained by field line tracing, is shown in Figure 2. It shows that the islands overlap in large parts of the plasma cross-section, creating stochastic field regions that would, in reality, lead to the termination of the discharge before developing to this stage. Therefore, these results most likely overestimate any realistic decrease in neutron yield due to magnetic islands. Even so, we find the total simulated neutron yield still overestimates the measurement. Figure 3 shows a comparison of simulated density, neutron and fast ion JxB torque profiles between simulations with no island, single island and three islands. The chain of three islands reduces the neutron deficit from 25 % to 18 %, and including rotation further reduces it

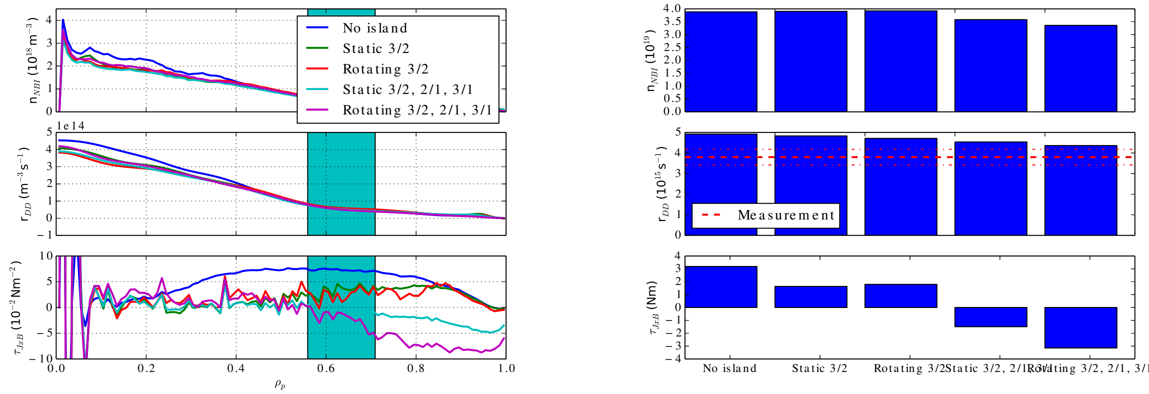


Figure 3: Scan with one or mutliple static and rotating islands. (a) profiles of beam ion density, DD neutron rate and beam JxB torque in simulations with static and rotating islands. (b) Volume-integrated values of the profiles. The measured neutron rate is indicated by the dashed red line in the middle panel.

to 13 %. However, even this extreme case still leaves half of the deficit unaccounted for. There is, however, a redistibution of fast ions outside mid-radius due to the islands that reverses the JxB torque of the NBI ions and induces a loss fraction of 10 %. In the extreme case of three islands, this reversal is strong enough to cancel the collisional component of the NBI torque.

**First results of modelling NBI/ICRH coupling with ASCOT/RFOF** The ASCOT code has been coupled to the RFOF library [6] to calculate RF heating by a Monte Carlo “kick” operator that resolves the acceleration of both thermal and NBI ions. The advantage of a Monte Carlo method is that it can include any number of particle species with different source profiles and resolve higher harmonic frequency heating schemes. In this work, we present ASCOT/RFOF modelling results of a 3rd harmonic D heated JET discharge 86459, with 3MW ICRH power and 4.5MW NBI power. The NBI deposition is calculated with the BBNBI module [7] and the RF deposition is simultaneously calculated by RFOF. The ASCOT simulation has been performed without coupling to a full wave-field solver for simplicity, the PION code has been used to determine the power absorbed by the ions and the amplitude of the accelerating electric field is assumed constant over the plasma cross-section. The simulated fast ion distribution, compared to the SPOT and PION codes, is shown in Figure 4a. We note that ASCOT predicts a slightly lower gradient for the distribution in the 1 MeV to 2 MeV range, but there is reasonably good agreement on the cut-off of the distribution at 2.2 MeV. The analyzed discharge was designed to study fusion products and, therefore, exhibits a high neutron rate. Due to the heating mix, the measured neutron yield significantly exceed what would be predicted by NBI or ICRH modelling alone, as is illustrated in Figure 4b. It shows that a neutron rate of $1 \cdot 10^{15}\mathrm{s}^{-1}$ is predicted by modelling the NBI heating with the PENCIL code, and a neutron rate of $2 \cdot 10^{15} s^{-1}$ is predicted by modelling the ICRH heating only with ASCOT/RFOF. The measured neutron rate, $6 \cdot 10^{15}\mathrm{s}^{-1}$, is well matched by an ASCOT/RFOF simulation of both NBI and ICRH simultaneously. These calculations do not include the beam-beam component of the neutron rate,

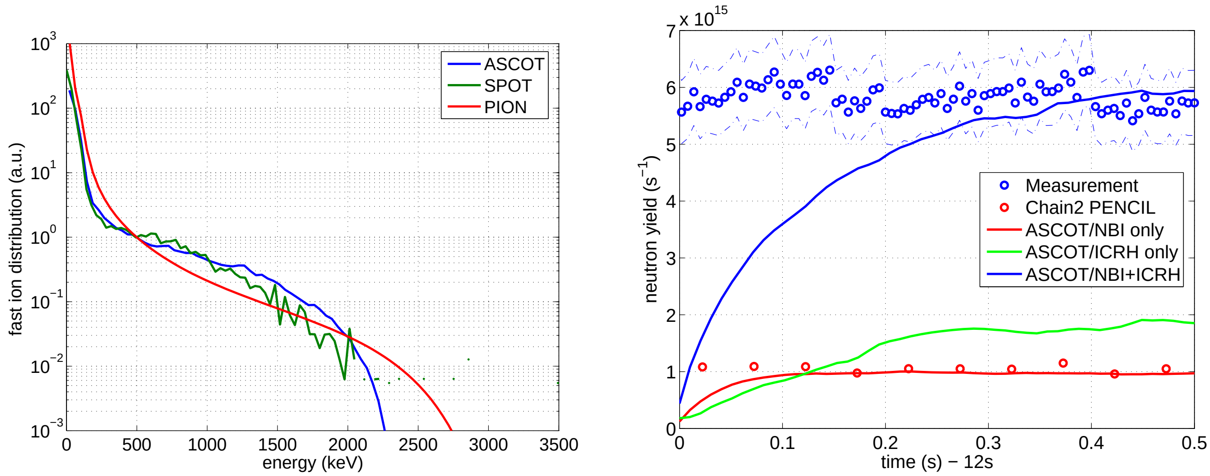


Figure 4: (a) Comparison of normalized fast ion energy distribution between ASCOT/RFOF, SPOT/RFOF and PION. (b) Measured neutron yield in 86459 and ASCOT simulations with NBI, ICRH and NBI+ICRH.

including it would most likely lead to a slight overestimation of the neutron yield, consistently with the NBI results.

**Conclusions** ASCOT can be used to simulate complex fast-ion dynamics, including 3D effects and wave-particle interactions. In this work we have applied it to neutron rate calculations in JET, which will be important in the upcoming DT campaign. We have found that magnetic islands due to NTMs can cause local redistribution of fast ions, large enough to reverse the sign of the JxB torque due to the radial ion flux. However, the redistribution does not significantly change the integrated neutron yield, and is unable to explain the neutron deficit observed in JET experiments. In ICRH and NBI heated plasmas, ASCOT can reproduce the measured neutron rate by self-consistently modelling both ICRH and NBI heating. Further benchmarking is ongoing.

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**References**

[1] H. Weisen, et. al., This Conference
[2] G. Tardini, et. al., 41th EPS Conference on Plasma Physics (2014), O2.103
[3] E. Hirvijoki, et. al., Computer Physics Communications 185 (2014), pp. 1310-1321
[4] Y. Baranov et al, Plasma Phys. Control. Fusion 51 (2009) 044004
[5] C. Marchetto, et. al., 41th EPS Conference on Plasma Physics (2014), P1.018
[6] T. Johnson et. al., AIP Conference Proceedings 1406 (2011), p.373-376
[7] O. Asunta et. al., Computer Physics Communications 188 (2015), pp. 33-46