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Benchmarking Neutral Beam Injection codes within the European Integrated Modelling framework

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Introduction

Auxiliary heating systems are vital to reach fusion relevant temperatures in tokamaks. One of the most prevailing heating sources is neutral beam injection (NBI). Hence, reliable simulations of NBI sources in fusion plasmas are essential for preparing scenarios and predicting performances of future fusion devices.

The European Integrated Modelling (EU-IM) framework is developed for providing a standardized platform for the development of integrated modelling suits [1]. This framework offers a high level of modularity with standardized input and output enabling the selection between multiple combinations of simulation models.

NBI modelling requires two modelling steps: first, the injection and ionization of fast neutrals are estimated by beam deposition codes; secondly, the dynamics of NBI ions is simulated by Fokker-Planck solvers. At present two deposition codes are integrated in the EU-IM framework, the Monte Carlo code BBNBI [2] and the narrow-beam model NEMO [3]. They can be associated with four Fokker-Planck solvers, ASCOT [4], NBISIM [5], RISK [6] and SPOT [7], which are also integrated inside the EU-IM framework and used for the present benchmark. ASCOT and SPOT are Monte Carlo codes with a high level of accuracy including orbit width effects, while NBISIM is a simple 1D analytic model and RISK is a 2D Fokker-Planck code that combines finite elements and an eigenfunction expansion. Hence, the two latter are much faster but less accurate than ASCOT or SPOT since they operate in the zero-banana-width limit.

The Heating and Current Drive workflow combines codes for NBI, ICRH, ECRH and alpha-heating with a design that makes it easy to include synergies between the heating schemes. This workflow is used both as a standalone tool and to handle heating and current drive pro-

*See http://www.euro-fusionscipub.org/eu-im cesses inside the European Transport Solver. The present study reports the results of the NBI benchmark activity using this Heating and Current Drive workflow and the codes mentioned above, covering all possible combinations between the deposition and Fokker-Planck codes, for ASDEX-Upgrade, JET and ITER and plasmas.

Beam deposition and ionization

Typical equilibrium and kinetic profiles for ASDEX-Upgrade, JET and ITER discharges have been used for this benchmark. The two deposition codes BBNBI and NEMO have been extensively benchmarked in order to verify their deposition in the multi-dimensional phase space. They are found to agree well, given their different approaches (Monte Carlo versus narrow beam model), as illustrated in Figures (1) and (2) showing the 1D and 2D profiles of the neutral beam deposition. Their total source rates are in very good agreement (below 1% difference, attributed to shine-through predictions).

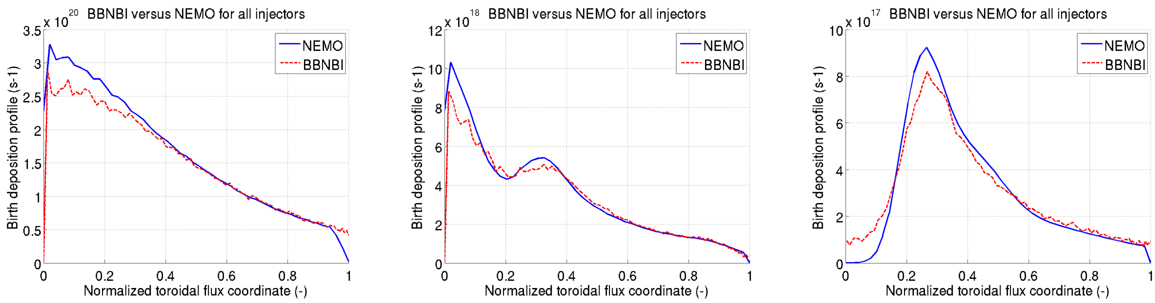

Figure 1: *BBNBI and NEMO 1D-ionization profiles, for ASDEX-Upgrade, JET and ITER plasmas, from left to right.*

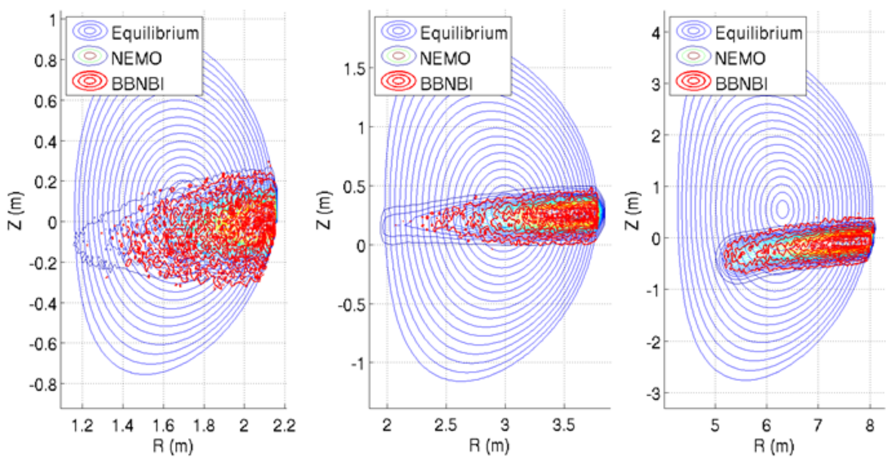

Figure 2: *BBNBI and NEMO 2D deposition profiles, for ASDEX-Upgrade, JET and ITER plasmas, from left to right.*

The second stage of NBI modelling after neutral beam deposition is the simulation of the dynamics of confined ions using Fokker-Planck codes, as presented in the next section.

Power to the bulk and Neutral Beam Current Drive (NBCD)

All the combinations between the deposition and Fokker-Planck codes have been tested and compared in the fast ion slowing down steady-state. The resulting 1D profiles for the power to the bulk and the neutral beam current drive are presented in Figures (3) and (4) for ASDEX-Upgrade, JET and ITER. The total power to the bulk differs from less than 7% between all combinations while the total NBCD differs from less than 20%. As can be seen, RISK and NBISIM predict narrower profiles compared to SPOT and ASCOT along with small differences in the NBCD profiles. The reason is that orbit width effects are neglected both in RISK and NBISIM. Including an ad-hoc orbit width correction in RISK leads to a better agreement for power 1D-profiles compared to SPOT, as shown in Ref. [6]. However, NBCD profiles cannot be improved using this correction since a part of the NBCD is due to a diamagnetic current driven by fast ion finite orbit width and pressure gradients. It means caution is needed when using simple models like RISK for current drive modelling.

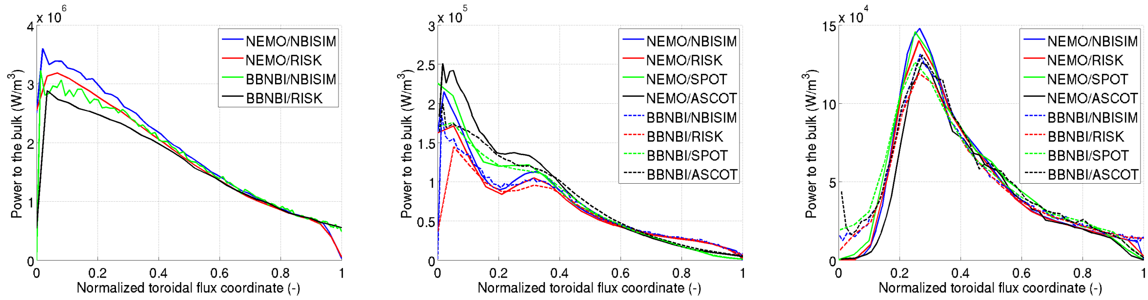

Figure 3: *Power to the bulk, for ASDEX-Upgrade, JET and ITER plasma, from left to right.*

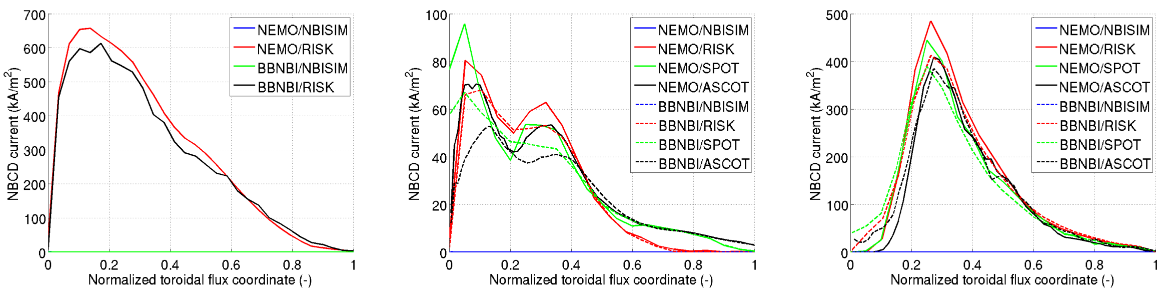

Figure 4: *NBCD profiles for ASDEX-Upgrade, JET and ITER plasmas, from left to right.*

Ramp-up towards the fast ion steady-state

Accurately modelling transitory phases of fast ion heating and current drive is essential for predicting the full dynamics of a discharge inside a transport solver. The Fig. (5) shows the time evolution of the power to bulk electrons and ions for JET, as predicted by SPOT and RISK Fokker-Planck codes, showing an overall good agreement between the two codes.

Conclusion

The comparison of the involved simulation codes for modelling heating and current drive induced by NBI fast ions evidences an overall good agreement between the physics models. The main discrepancies between the codes arise from orbit width effects that are not included in simple Fokker-Planck calculations.

This benchmark allows to trustfully choose the adapted NBI model according to the required accuracy and computation time for simulating a full plasma discharge in the context of integrated modelling frameworks, here within the European platform, and will be continued on the ITER Integrated Modelling and Analysis Suite [8].

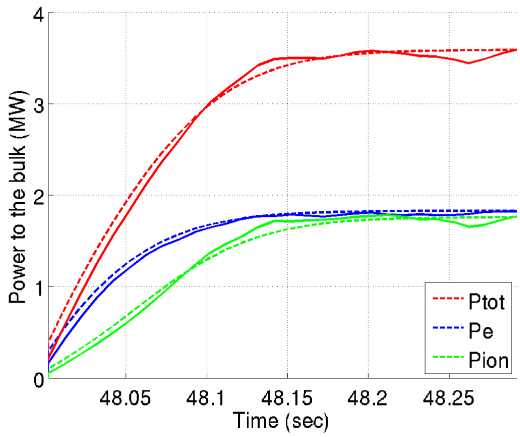

Figure 5: *Ramp-up of power to bulk electrons and ions for JET using SPOT (solid lines) and RISK (dashed lines) Fokker-Planck codes.*

Aknowledgments

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References

[1] G.L. Falchetto et al, Nucl. Fusion 54 (2014) 043018

[2] O. Asunta et al, Computer Physics Comm. 188 (2015) 33-46

[3] M. Schneider et al, Nucl. Fusion 51 (2011) 063019

[4] E. Hirvijoki et al. Computer Physics Communications 185 (2014) 1310-1321

[5] From equation (5.4.12) of Wesson J. 2004 Tokamaks 3rd ed. (Oxford: Clarendon)

[6] M. Schneider et al, Nucl. Fusion 55 (2015) 013003

[7] M. Schneider et al, Plasma Phys. Control. Fusion 47 (2005) 2087-2106

[8] F. Imbeaux et al, Proc. 25th IAEA Fusion Energy Conference, TH/P3-41 - St-Petersburg (2014)