ASCOT-AFSI simulations of fusion products for the main operating scenarios in JT-60SA

J. Varje[1], T. Kurki-Suonio[1], M. Vallar[2], P. Sirén[1,3], K. Särkimäki[1], J. Garcia[4], T. Bolzonella[2]

[1] *Department of Applied Physics, Aalto University, FI-00076 AALTO, Finland*

[2] *Consorzio RFX, Corso Stati Uniti 4, 35127 Padova, Italy*

[3] *VTT Technical Research Centre of Finland, P.O Box 1000, 02044 VTT, Finland*

[4] *CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France*

JT-60SA will be a large device with a plasma volume 50 % larger than JET, and up to 34 MW of NBI heating power. High-performance deuterium plasmas in planned operating scenarios are expected to produce neutron rates in excess of 10^{17} n/s. The NBI heating includes 24 MW of 85 keV positive neutral beams (PNB) and 10 MW of negative neutral beams (NNB) with up to 500 keV energy [1]. A significant fraction of the fusion reactions is expected to be produced by the fast NBI ions reacting with the thermal bulk plasma, in particular due to the NNB ions for which the D-D fusion cross section is significantly higher compared to the PNB ions [2].

Tritons produced in the D-D reactions will have a Larmor radius similar to that of D-T alphas. Studying their confinement will help improve the predictability of alpha particle behaviour in view of ITER and DEMO. Furthermore, the 14 MeV neutrons produced in D-T reactions during the slowing-down of the 1 MeV tritons could be used to diagnose the transport of the tritons similar to experiments performed on JT-60U [3].

In this contribution we present studies for fusion products in JT-60SA. The ASCOT-AFSI fusion product workflow, recently developed at JET [4, 5], is applied to the main operating scenarios planned for JT-60SA and predictions are given for the neutron sources as well as triton confinement and burn-up.

The ASCOT-AFSI fusion product workflow

The fusion products are simulated with the calculation chain of BBNBI [6], ASCOT [7] and AFSI [8] codes (Figure 1). The beamlet-based Monte Carlo NBI code BBNBI was used to calculate the fast ion source from the 85 keV PNB and 500 keV NNB injectors. After this, the Monte Carlo orbit-following code ASCOT was used to solve the 4D slowing-down distribution function of the reactants in an axisymmetric magnetic field. The ASCOT fusion source integrator AFSI was used to calculate the resulting fusion product distributions for thermonuclear, beam-thermal and beam-beam reactions using the 4D distribution functions.

The D-D tritons could then be investigated further with another ASCOT simulation to solve

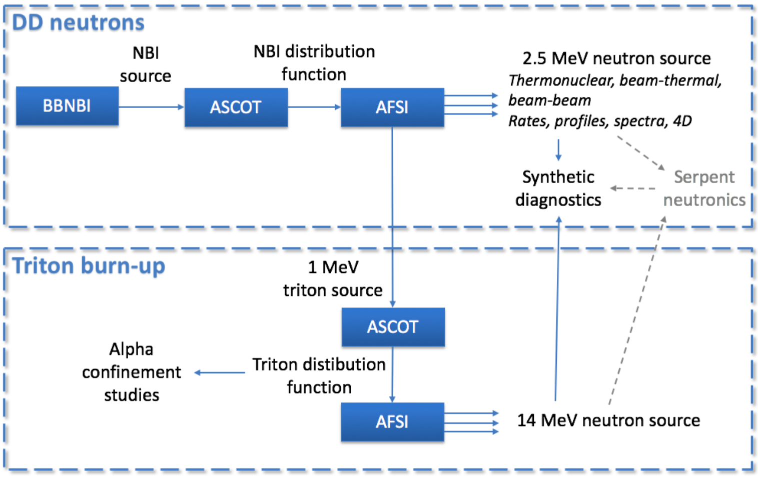

Figure 1: The ASCOT-AFSI fusion product calculation chain.

their slowing-down distribution and losses. The triton distribution was used in another AFSI calculation to produce the 14 MeV neutron source due to the triton burn-up. Furthermore, the neutron sources could be coupled to synthetic neutron diagnostics, including neutron cameras and neutron spectrometers, or neutron transport simulations with Monte Carlo neutronics codes such as Serpent.

Neutron sources in JT-60SA operating scenarios

Neutron sources were calculated for all main operating scenarios planned for JT-60SA, ranging from the baseline-type scenarios #2 and #3 to the hybrid-type scenario #4 and the advanced scenario #5 (Figure 2) [9]. In all scenarios, the neutron sources are dominated by beam-thermal neutrons, of which up to 80 % are produced by the NNB ions (Figure 3). As expected, the spectra for the NNB beam-thermal neutrons is wider by a factor of 2-3 compared to the PNB neutrons (Figure 4). Approximately 2-3 % of the total neutron rate are 14 MeV neutrons due to the triton burn-up.

The largest differences are observed between scenarios #2 and #5. In scenario #5, the fraction of thermonuclear neutrons is significantly smaller due to the lower temperature and density.

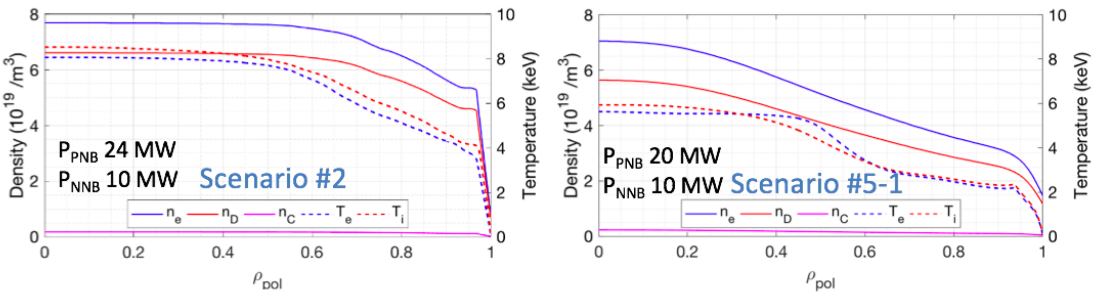

Figure 2: Kinetic profiles for the baseline scenario #2 and the advanced scenario #5. [9]

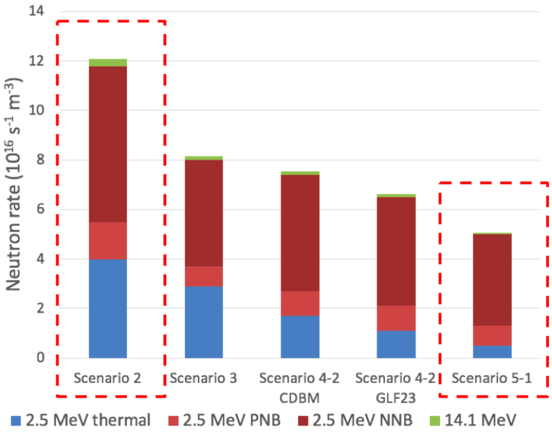

Figure 3: Thermonuclear, NBI and triton burn-up neutron source rates in main scenarios. Largest differences are observed between scenarios #2 and #5.

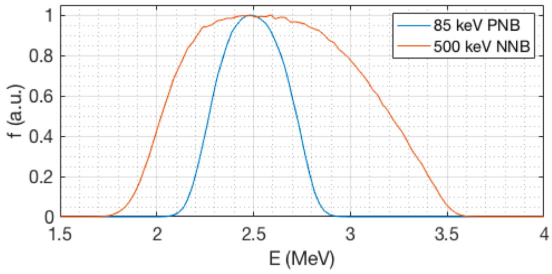

Figure 4: Volume-averaged spectra for 85 keV PNB and 500 keV NNB beam-thermal neutrons.

Because of the lower density, the beams also penetrate deeper into the plasma and the neutron source profile is more peaked compared to scenario #2 (Figure 5). In both cases, the dominant contribution due to the off-axis-injected NNB ions is apparent.

Triton confinement and burn-up

As the Larmor radii and orbit width of 1 MeV DD tritons and 3.5 MeV DT alphas are similar, their neoclassical transport and resulting fast ion losses are also expected to be similar. Thus, the tritons can be used as proxies for fusion alpha particles in confinement studies. The higher current and toroidal field in scenario #2 reduce the triton losses by approximately an order of magnitude compared to scenario #5.

Comparing the neutron source profiles for the 2.5 MeV and 14 MeV neutrons can yield additional insight to the triton transport. The 2.5 MeV source corresponds to the DD reaction rate and, thus, closely approximates the triton source profile. The 14 MeV neutron rate, on the other hand, implicitly describes the slowing-down distribution of the tritons. Both in scenario #2 and #5, the 14 MeV profile is significantly more peaked because of redistribution due to the finite orbit width of the tritons (Figure 6). Additionally, reduction in the source rate due to the prompt triton losses can be seen near the edge of the plasma.

Conclusion

With the greater neutron fluxes and higher beam energies, the JT-60SA will present new opportunities for fast ion studies using neutron diagnostics. The machine is planned to include both a neutron profile monitor as well as a neutron spectrometer, which together with detailed

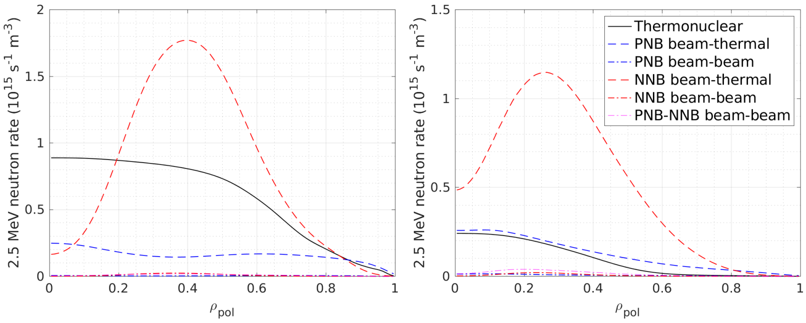

Figure 5: DD neutron source profiles for scenarios #2 (left) and #5 (right).

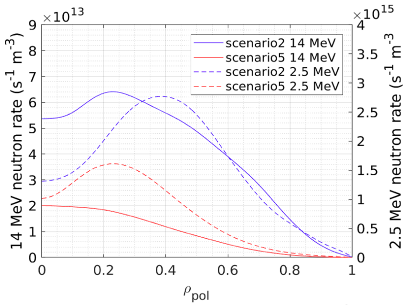

Figure 6: Total neutron source profiles for 2.5 MeV and 14 MeV neutrons.

modelling and synthetic diagnostics can be used to gain new insight into fast ion transport mechanisms. Further predictive studies with the ASCOT-AFSI fusion product calculation chain, with the inclusion of additional physics mechanisms such as toroidal field ripple and MHD induced transport, can be used to prepare for fast ion studies in upcoming JT-60SA experiments.

Acknowledgement

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the EURATOM research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission. The authors gratefully acknowledge members of the JT-60SA Integrated Project Team for data exchange and fruitful discussions. The calculations were performed using computer resources within the Aalto University School of Science “Science-IT” project.

References

[1] JT-60SA Research Plan Version 4.0, September 2018, JT-60SA Research Unit

[2] H.-S. Bosch, G.M. Hale 1992 Nuclear Fusion 32 611

[3] K. Ishii et al 2010 Plasma and Fusion Research 5 S1043

[4] P. Sirén et al 2017 Journal of Instrumentation 12 C09010

[5] P. Sirén et al 2019 In Press Fusion Engineering and Design

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

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

[8] P. Sirén et al 2018 Nuclear Fusion 58 016023

[9] J. Garcia et al 2014 Nuclear Fusion 54 093010