Fast ion transport simulations for the Spherical Tokamak for Energy Production (STEP)

A. Snicker, K. Särkimäki, S. Saari
VTT Technical Research Centre of Finland Ltd.
Espoo, Finland
Email: antti.snicker@vtt.fi

K. McClements, A. Prokopyszyn
UKAEA
Culham Campus, United Kingdom

This contribution presents simulations to model the transport of fusion-born alpha particles in the spherical tokamak for energy production (STEP). The work is carried out by two Monte Carlo codes ASCOT [1] and LOCUST [2]. In this contribution, ASCOT results are compared against earlier LOCUST simulation results [3] for toroidal field (TF) ripple and resonant magnetic perturbations (RMPs). Furthermore, simulation results are shown for inclusion of resistive wall modes (RWM) in the simulations. In the effort of producing quantitative estimate of the effect of fast ions to the tungsten sourcing, fast ion losses are recorded as a function of the incidence angle and energy for the sputtering yield calculations. These results show that the current design point of the STEP is stable in terms of basic fast ion transport calculations and no major showstoppers have been identified during the work.

STEP is a spherical tokamak prototype power plant with a design point [4] (SPP-001, R_{geo}=3.6m) producing roughly 1.5GW fusion energy and 100MW net energy. This translates to a significant alpha particle population. To achieve Q>1, alpha particles need to be well confined. Furthermore, alpha particle losses can pose a threshold for safe machine operation. Therefore, it is vital to understand how fast particle losses scale as a function of main design parameters. Last, but not least, the effect of lost alphas on the tungsten first wall can be detrimental in terms of erosion and associated core plasma radiation. This contribution studies these numerically.

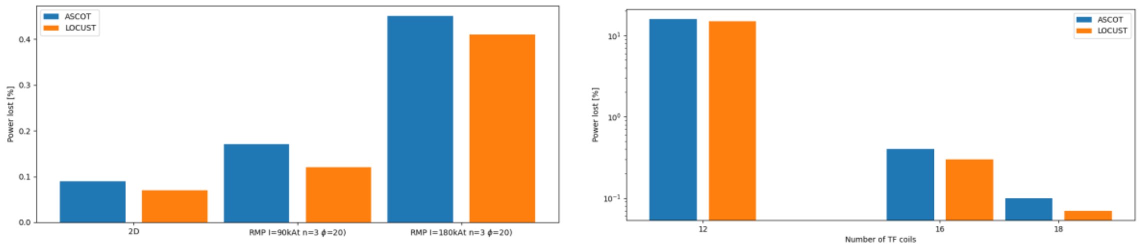

FIG. 1. Comparison of ASCOT and LOCUST for an axisymmetric magnetic field and for two RMP cases with 90 kAt current and for 180 kAt current (left) and for the TF ripple with different number of TF coils (right).

To study the impact of the number of TF coils, ASCOT was used to repeat the earlier LOCUST simulations to gain further confidence on these simulations. For a wide range of coil parameters, ASCOT results were found consistently above LOCUST results. The absolute error decreased with increasing losses, being less than 5% for losses of around 3.5%. Similarly, ASCOT repeated the earlier finding of the resonant magnetic perturbation field calculations, codes were found to have a similar trend also here in terms of discrepancy. Despite ASCOT being consistently above LOCUST, the two produced a similar scaling as a function of main design parameters such as number of TF coils, radial location of the TF coil leg and parameters of the RMP perturbation. Thus, building trust in numerical analysis. Two RMP cases, together with an axisymmetric scenario, are shown in Figure 1. The figure presents also the scaling of losses as a function of the number of TF coils.

In Figure 2, alpha particle losses caused by a resistive wall mode are illustrated. Here ASCOT is above LOCUST consistently as well. The scaling factor was used to scan the amplitude of the RWM perturbation, as the saturation amplitude was not obtained with the linear MARS-F simulations. Interestingly, here the relative error is not converging with increased losses. Further analysis shows that the magnetic field with the higher scaling factors have a significant divergence, making these cases vulnerable to numerical diffusion.

To complement these basic fast ion transport calculations, ASCOT was used to record the exact loss location of all lost alphas. In addition to the location, the incidence energy and incidence angle were recorded. These quantities are needed to further calculate the spatial tungsten sputtering yield thus enabling calculation of the source of tungsten atoms due to alpha particle impact on the first wall. Figure 2 illustrates the typical alpha particle energy and incidence angle spectrum for a selected STEP RMP scenario. As can be seen, a wide energy range up to 3.5 MeV with mainly incidence angles around 70-80 degrees are recorded. Basic sputtering yield calculations using SDTrimSP code [5] show that tungsten sputtering yield is of the order of 0.1, much higher than it would be for hydrogenic species. Integrating over the full first wall for all alpha particle losses, this results in tungsten source rate of roughly 1e18 tungsten/s. Next, these simulation results will be fed to impurity transport simulations to estimate the amount of tungsten atoms making their way to core STEP plasma and to assess their impact on plasma performance.

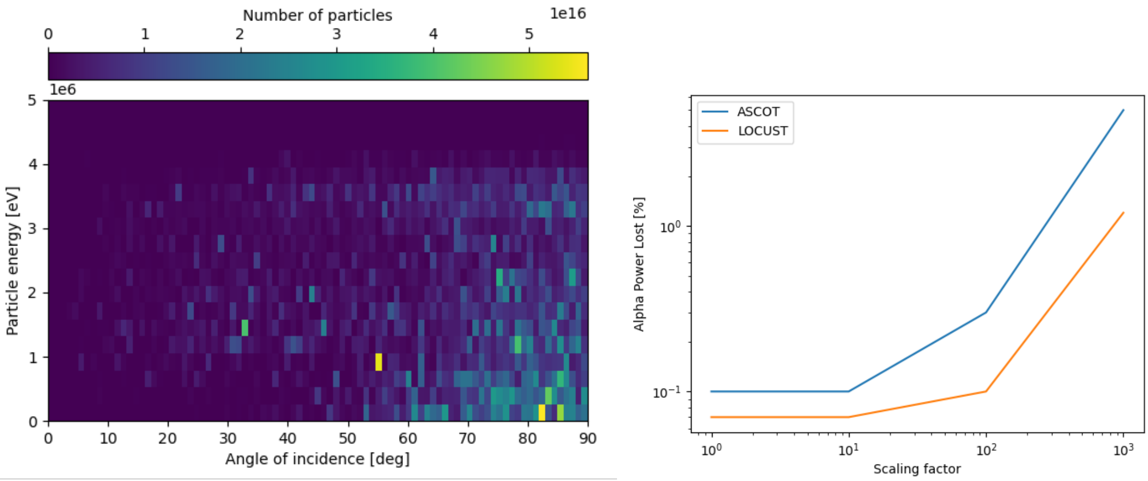

FIG. 2. Alpha particle energy and angle of incidence when alphas are lost to the first wall. The simulation is shown for the RMP 180 kAt, n=3 and phase shift of 20 degrees (left). Scaling of the losses as a function of the RWM saturation amplitude calculated by the ASCOT and LOCUST codes (right).

To conclude, ASCOT and LOCUST codes have been used to study alpha particle physics in STEP. Both codes agreed well for losses due to TF ripple, RMP and RWM perturbations. For both TF and RMP cases, ASCOT results were above LOCUST, with relative error decreasing with increasing losses. However, this decreasing trend was not observed for RWM case. All in all, these two Monte Carlo codes produce similar scaling as a function of main design parameters, building confidence on the numerical results. Besides the comparison study, ASCOT was used to record basic properties of the lost alpha particles to use this information for the sputtering calculations of the first wall tungsten atoms. Further work is needed to quantitatively analyse the tungsten source due to alphas and compare it against thermal sources.

REFERENCES

[1] E. Hirvijoki et al.2014 *Comp. Phys. Comm.* **185** 1310

[2] S.H. Ward *et al* 2021 *Nucl. Fusion* **61** 086029

[3] A. Prokopyszyn et al. Confinement of fusion alpha-particles and alfven eigenmode stability in STEP. In 29th IAEA Fusion Energy Conference, London, United Kingdom, 2023

[4] H. Meyer et al. 2024, Phil. Trans. R. Soc. A. 20230406

[5] A. Mutzke et al. , “SDTrimSP Version 6.00,” IPP report, 2019.