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Fast Particle Losses in ITER

T. Kurki-Suonio[1], O. Asunta[1], V. Hynönen[1], T. Johnson[2], T. Koskela[1], J. Lönnroth[1], V. Parail[3], M. Roccella[4], G. Saibene[5], A. Salmi[1], and S. Sipilä[1]

[1] *Helsinki Univ. of Technology, Assn Euratom Tekes, PO Box 4100, 02015 TKK, Finland*

[2] *EURATOM-VR Assn, Fusion Plasma Physics, EES, KTH, 10044 Stockholm, Sweden*

[3] *EURATOM/UKAEA Fusion Assn, Culham Science Centre, Abingdon, OX14 3DB, UK*

[4] *L.T. Calcoli S.a.S., Piazza Prinetti 26/B, 23087 Merate (Lecco), Italy*

[5] *F4E, c/ Josep Pla n° 2, Torres Diagonal Litoral B3, 08019 Barcelona, Spain*

The Monte Carlo guiding-center following code ASCOT has been upgraded to work with fully 3D magnetic backgrounds in order to simulate fast ions in ITER. The primary task was to simulate 3.5MeV fusion alphas and 1MeV NBI deuterons in a realistic ITER magnetic backgrounds and determine the resulting distribution of the heat load to the walls. About 100 000 test ions per simulation was required to acquire reasonable statistics and they were simulated down to 100 keV. The test ions were weighed according to the fusion power density calculated separately for each scenario to get the number of real ions. *Selective timescale acceleration* in which only strongly passing ions participate in the acceleration was used [1].

The wall loads due to fast ions were calculated for two ITER Scenarios: Sce-2 representing an inductive, standard H-mode operation of ITER, and Sce-4 representing a steady-state operation. Four ion species were simulated: I) fusion alphas from thermonuclear reaction, dubbed *thermal* alphas, II) NBI ions, III) ICRH ions, and IV) alphas produced in beam-target reactions. These ions were simulated in seven different magnetic backgrounds: 1) *no-ripple*: an axisymmetric field, 2) *no-FI*: a 3D field with ripple, but no Ferritic Inserts, 3) *FI*: the original FI configuration, 4) *opt-FI*: the optimized FI configuration , 5) *opt-FI half-field*: optimized FI with halved magnetic field strength and profiles, 6) *opt FI, 1 TBM*: optimized FI with one Test Blanket Module (TBM), and 7) *opt FI, 2 TBM*: optimized FI with 2 TBM's, located 80° from each other. The 3D vacuum field was calculated including relevant ferromagnetic structures, and the 2D equilibrium field, same for all the above cases, was superimposed on it.

Figure 1 shows the characteristic distribution of heat load on individual tiles due to fusion alphas. Figure 2 shows the birth location and loss energy of ions hitting the wall. The losses to divertor, limiter, and other wall tiles are identified. The histograms sum up to 1, so they give the probability of a lost ion having a certain energy and initial location, not the probability of the ion being lost.

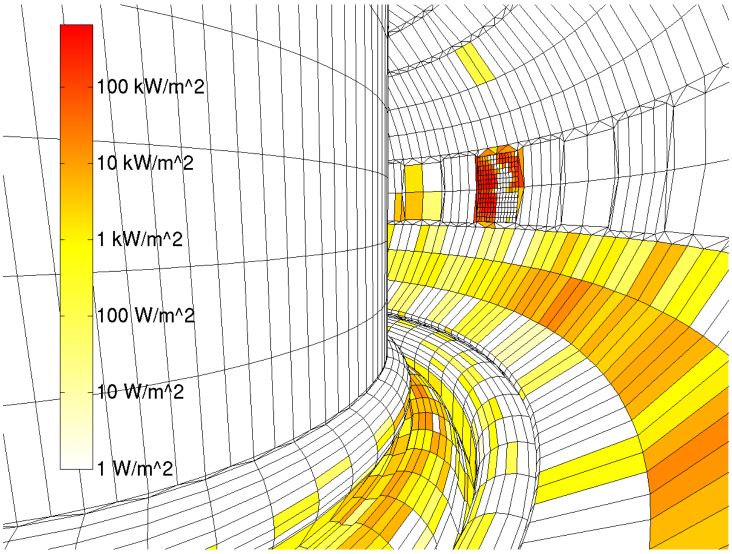
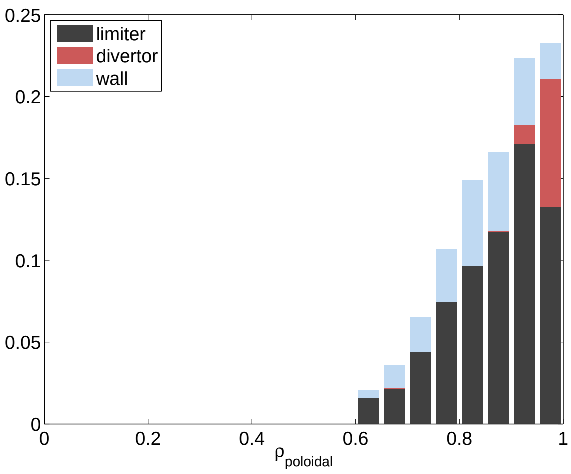


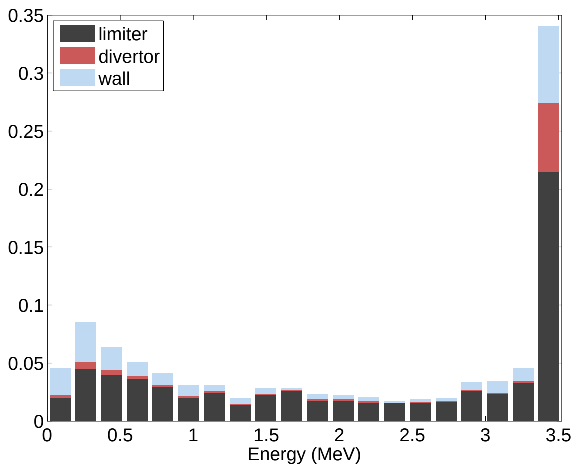
Figure 1: *Power load to the wall tiles due to alpha particles produced in thermonuclear reactions in ITER Sce-2 plasma with uncompensated ripple.*

The most important results, those obtained for thermal alphas, from the simulations of Sce-2 and Sce-4 are summarized in Table 1. In Sce-2 (Sce-4) the thermal fusion power is 470 MW (310 MW) of which the alphas carry 93.6 MW (52 MW). In Sce-4, the fusion reactions are concentrated in the central region and the rate drop rapidly near the edge. In Sce-2 the fusion density gradually decreases towards the edge. In Sce-4, the alpha confinement is weaker than in Sce-2 due to the weaker plasma current (9MA vs 15MA).

No ripple In Sce-2 almost all of the thermal alphas are lost from very close to the separatrix and with energy close to their initial energy. The orbit losses are distributed quite evenly between the limiter and the divertor, with only a small number hitting the rest of the wall. In Sce-4 the load is practically zero. No NBI ions were lost in either scenario.



(a) initial location probability distribution



(b) final energy probability distribution

Figure 2: *The distributions of a) the initial location and b) the final energy. The probabilities of a limiter hit, a divertor hit and a regular wall hit are separated by color.*

Table 1: *Wall loads from thermal alphas in Sce-2 and Sce-4*

Magnetic background	Maximum ripple (%)	Total lost power (MW)	% of total alpha power	Limiter load (MW)	Divertor load (MW)	Peak load (MW/m^2)
no ripple	0/0	0.25/0.02	0.27/0.03	0.13/0.01	115/5	0.20/0.01
no FI	1.09/1.11	1.04/2.30	1.10/3.69	0.75/2.00	0.12/0.00	0.49/0.98
FI	0.319/0.328	0.42	0.45	0.25	0.16	0.44
opt FI	0.203/0.208	0.30/0.03	0.32/0.05	0.18/0.25	0.11/0	0.21/0.05
opt FI half field	0.696/0.712	0.04/0.10	0.69/2.55	0.02/0.09	0.01/0	0.02/0.07
opt FI, 1 TBM	1.07/1.10	0.65/0.08	0.70/0.16	0.36/0.07	0.28/0	0.38/0.10
opt FI, 2 TBM	1.07/1.10	0.78/0.08	0.83/0.17	0.41/0.07	0.36/0	0.53/0.10

No-FI's The most notable difference in alpha load is the difference in magnitude, but also the amount of non-limiter, non-divertor hits increases, forming a "belt" below the limiters. Sce-4 gave the highest power density achieved in all simulations. The power load on the limiters reaches almost 1 MW/m^2 on the hot spots and the divertor gets very little load. The wall load from NBI ions is roughly one-fourth of the alpha load and practically all the power goes to the limiters. Since the initial pitch of all NBI ions is above 0.5, they are mostly on passing orbits.

FI Only Sce-2 has been simulated for this configuration. The two notable differences to the no-FI case are the drop in total wall loads by over a factor of 2 and a slight increase in the divertor load. The NBI contribution is close to zero.

Opt-FI The ferritic inserts have a much greater effect in Sce-4 than in Sce-2. The total power load drops from the "no FI" case by almost a factor of 100, whereas in Sce-2 the factor is about 5. The reason most likely is the large difference in plasma current. In Sce-4 two clear peaks are observed in the final energy. The direct orbit losses constitute the energy peak at 3.5 MeV, and losses from deeper inside the plasma form the peak at low energies. The NBI contribution is close to zero.

Opt-FI half-field The absolute magnitude of the wall load is small, but also the fusion source is 1/16th of the original. The ratio of lost power to power source actually increases from the full-field case, particularly for Sce-4, where the total power to the walls is 2.5% of the source term, a factor of 50 larger than with full field. Highest loads are still on the limiters, but the "power belt" below the limiters is more evenly distributed and the probability distribution of initial location of the lost ions shows that losses originate from much deeper than in the Opt-FI case. All the lost NBI-ions originate from close to the edge with the maximum energy of about 500 keV and they contribute only to the leading edges of the limiters. The NBI power to the limiters is about half of the corresponding alpha load.

Opt-FI, 1 TBM In these simulations the effect of the TBMs was calculated on the vacuum field only, which magnifies the effect. In reality, the island structures generated by TBM [1] will be smaller and, thus, the results presented here should probably be viewed as the worst scenario estimates. What makes this case special is that the NBI load (700 kW)in Sce-2 is as large as the alpha load in Sce-2 with most of the power going to the divertor. In Sce-4 the NBI load vanishes. In both scenarios the alpha wall load increases significantly, but the distribution on the limiter and the divertor remain the same. These results have to be confirmed with newly calculated magnetic fields [1].

Opt-FI, 2 TBMs There is very little difference to the 1 TBM case. It could be argued that the first TBM shadows the second one, so that there are less ions left in the phase space.

Beam-target alphas and ICRF-heated ions A fusion reactivity model, based on parameterized cross-sections, was constructed for beam-target reactions. However, the wall loads from beam-target fusion were found to be insignificant compared to the loads from thermal fusion. The ICRF-heated fast ions consist of ^{3}He and ^{3}H with mean energies in the MeV range. Their initialization was calculated with the SELFO code. In Sce-2, no ICRH ions are lost to the walls, even with uncompensated ripple, because the ions are accelerated so deep in the plasma that they cannot diffuse to the wall before getting thermalized. Over 90% of the wall hits of both species are registered on the limiters, while the divertor gets no power at all. Optimized inserts reduce the loads to zero.

Conclusions In all simulated cases the fusion alpha load in ITER was found to be in the manageable level. The power flux from NBI ions was even less. These results agree with the earlier analysis with OFMC code.

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References

[1] T. Koskela et al., P5.001 in this conference.