Development of impurity seeding for divertor power flux handling in Wendelstein 7-X long pulse scenarios

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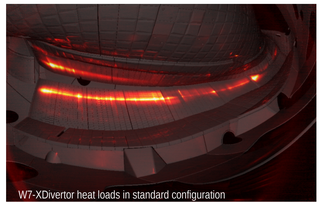
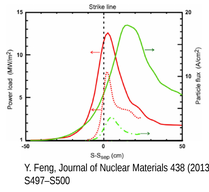
High power fluxes predicted for future W7-X reactor scenarios and next-step 3D devices



Reactor extrapolation

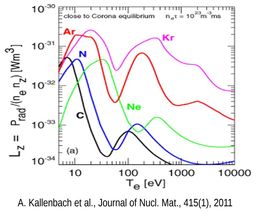
(still low power: P_{SOL} = 200 MW)



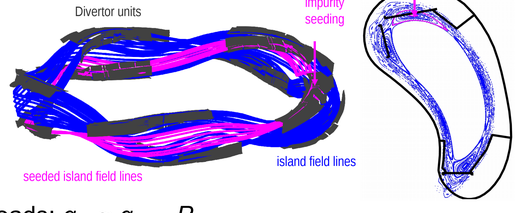
Y. Feng, Journal of Nuclear Materials 438 (2013) S497–S500

→ Avoid overload of PFCs during high-performance/long pulse scenarios
→ Stable, high-radiating divertor to be developed for reactor scenarios
→ Substitute intrinsic radiators when using high *Z* materials (e.g. W)

Impurity seeding explored for radiative power exhaust and detachment control

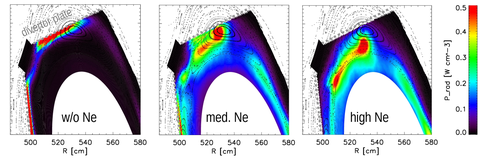


A. Kallenbach et al., Journal of Nucl. Mat., 415(1), 2011



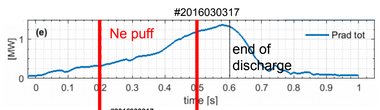
→ Control divertor loads: $q_{div} \sim q_{SOL} - P_{rad}$
→ Optimize trade-off between performance & safety by choice of impurity species

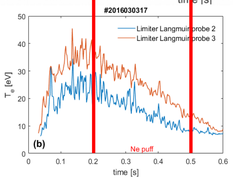
Predictive and interpretative 3D modeling for radiative divertor scenarios

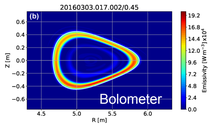


→ Island divertor scenarios with C and Ne/N2 modeled with EMC3-EIRENE
→ Power losses due to Ne in the island results in reduction of divertor particle and heat fluxes
→ Emission layer (C+Ne) moves upstream at high P_{rad}

Limiter: Neon showed high recycling and radiation efficiency

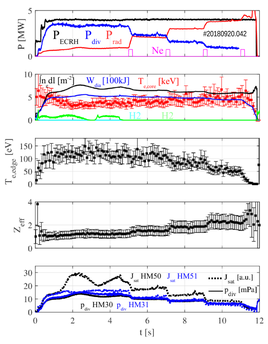






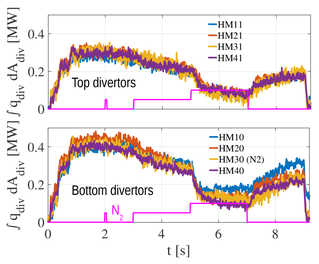
→ Uniform increase in edge line radiation during Ne puff
→ Frequent radiative instabilitis in limiter configurations

Divertor: short Neon injections establish sustained radiative mantle and edge cooling

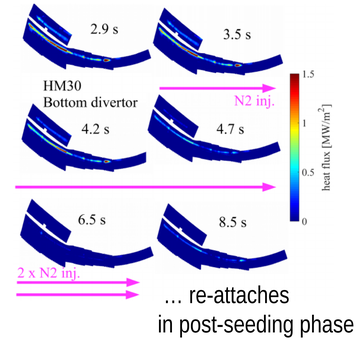


→ stationary 'steps' in power balance ~ *O*(10s) due to high recycling of Ne
→ ΔW_p~-15% at highest f_{rad} of ~80%
→ Z_{eff} increases from 1.2 to 2.2
~75% of injected Ne particles retained in SOL
→ reduction of divertor particle fluxes and neutral pressure (w/o active density control)

Detachment and re-attachment with N2 seeding promising for feedback control

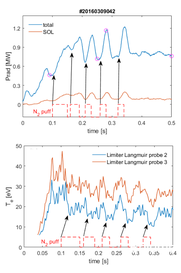


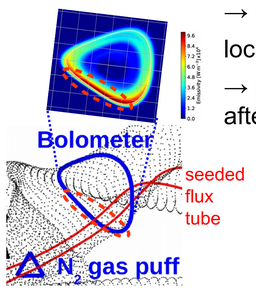
→ symmetric cooling, absolute offsets due to drift and heating



… re-attaches in post-seeding phase

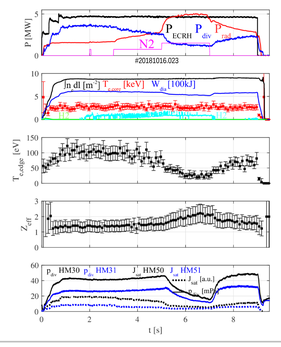
Limiter: low level N2 seeding showed fast and local response in edge parameters





→ Short N_2 injections show local increase in P_{rad}
→ prompt decay in Prad after each N_2 pulse

Divertor: continuous N2 puff causes effective recycling and uniform radiative power exhaust



→ΔWp~-12% at maximum P_{rad}
→ Z_{eff} increases from 1.2 to 2.1 suggesting a max. core impurity concentration of ~2.5%
→ divertor particle fluxes drop, neutral pressure increases first, drops at high P_{rad} (w/ density control)
→ Plasma parameter recover after N_2 puff

Summary

Radiative power exhaust with Ne and N2 seeding has been investigated during first limiter and island divertor scenarios

Radiation enhancement in limiter configurations less stable, but strong and stable enhancement with global detachment of heat and particle fluxes has been demonstrated in the island divertor

Ne features a higher radiation efficiency and higher recycling while N2 shows better neutral compression and lower recycling → N2 more suitable for feedback control because of pumping

F. Effenberg et al 2019 Nucl. Fusion 59 106020
T. Barbui et al 2019 Nucl. Fusion 59 076008
Y. Feng 2013 Journal of Nucl. Mat. 438 S497-S500

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