HELIUM ASH REMOVAL IN DEMO-FNS

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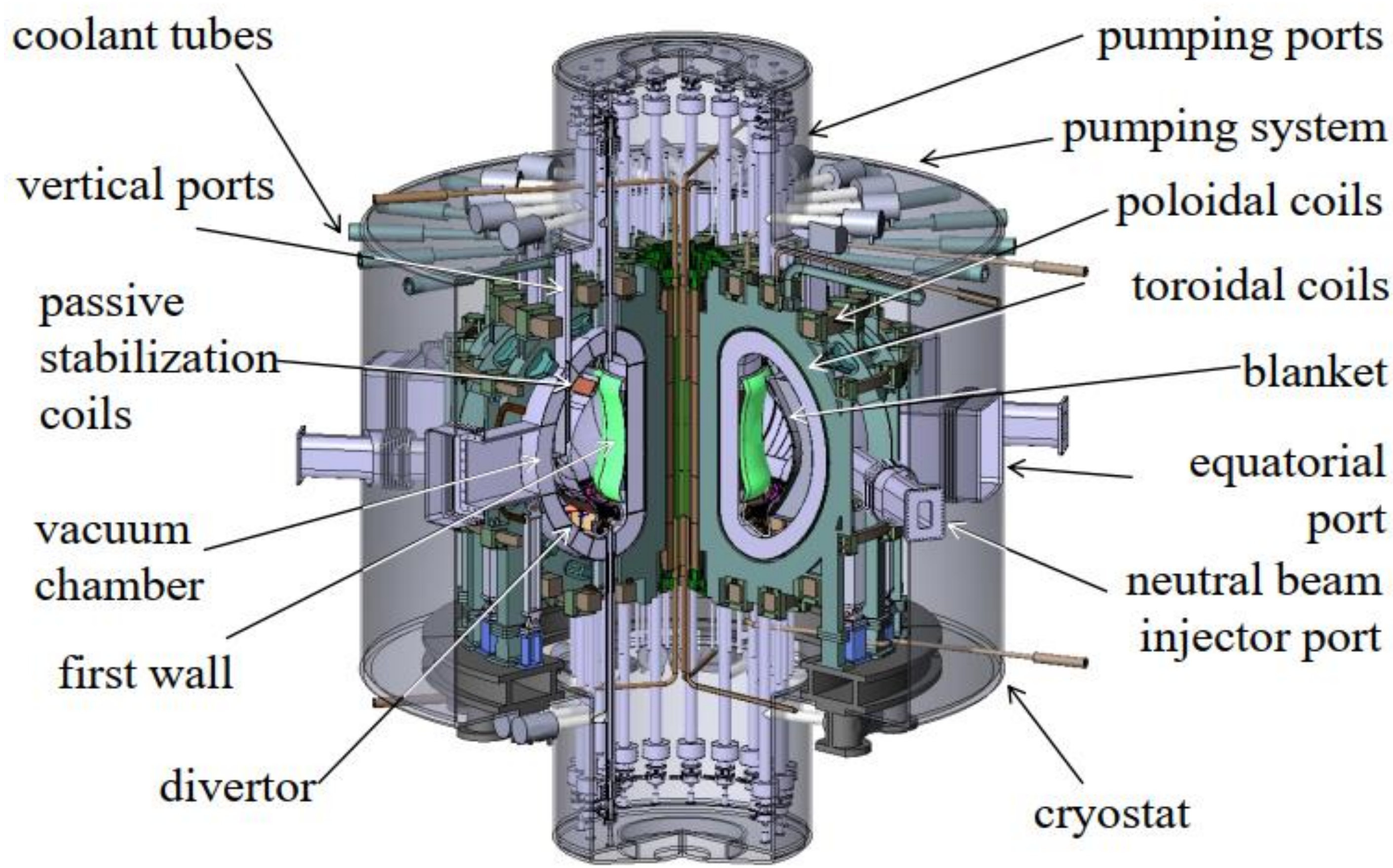


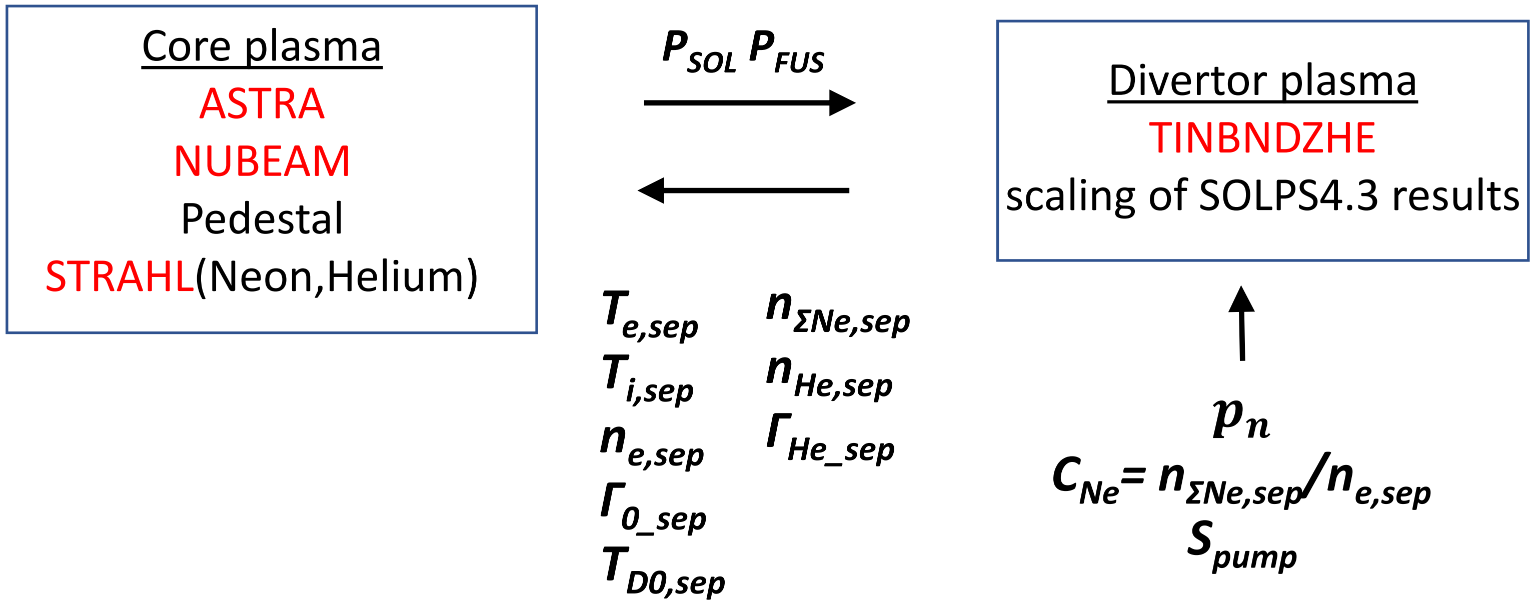
Yury Shpanskiy et al, Development and integration study of fusion-fission hybrid systems into nuclear power fuel cycle, *This Conference Poster session*

Yury Shpanskiy et al., Progress in design of DEMO-FNS hybrid facility, *Nucl. Fus.* **59** (2019) 076014

Aspect ratio, R/a	**3.2m/1m**
Toroidal magnetic field	**5T**
Electron/ion temperatures, Te(0)/Ti(0)	**11.5/10.7 keV**
Beta normalized, β_N	**2.1**
Beta poloidal, β_p	**0.96**
Plasma current, I_{pl},	**4-4.5 MA**
Maximal neutron source, Γ_N	**10^{19}/s**
NBI power/energy,	**30 MW/500keV**
ECR heating,	**6 MW**
Pulse duration,	**5000 s**
Gain factor, Q_{fus}	**1**

Consistent model for divertor and core plasma

[A.Y. DNESTROVSKIY et al., Nucl. Fus. **59** (2019) 096053]



- ✓ Edge and divertor plasma by **SOLPS4.3** code
- ✓ Core plasma by **ASTRA** code with IPB(y,2) scaling law
- ✓ Neutral beam by **NUBEAM** code
- ✓ Neon and Helium impurity by **STRAHL** code

SOLPS4.3 result scaling laws

For boundary conditions

$$n_{e,sep} = 3.20 \cdot 10^{-2} \times \mu^{0.122} \times P_{SOL}^{0.537} \times C_{Ne}^{-0.204}$$

$$T_{e,sep} = 6.98 \cdot 10^{+1} \times \mu^{-0.048} \times P_{SOL}^{0.350} \times C_{Ne}^{0.094}$$

$$T_{i,sep} = 2.33 \cdot 10^{+2} \times \mu^{-0.075} \times P_{SOL}^{0.335} \times C_{Ne}^{0.200}$$

$$\Gamma_{D,sep} = 9.33 \cdot 10^{+2} \times \mu^{0.550} \times P_{SOL}^{-0.082} \times C_{Ne}^{0.912}$$

For divertor condition

$$\mu = 3.93 \cdot 10^{-3} \times p_n \times P_{SOL}^{-0.242} \times C_{Ne}^{-1.513}$$

For power peak load to divertor targets

$$q_{pk} = 5.47 \cdot 10^{-3} \times \mu^{-0.401} \times P_{SOL}^{1.674} \times C_{Ne}^{-0.367}$$

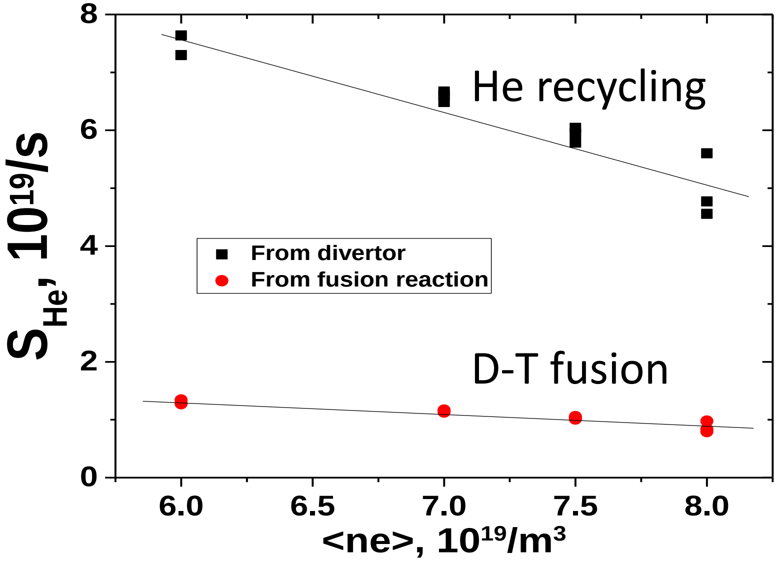
Helium balance

For helium balance boundary conditions

$$n_{He,sep} = 7.72\cdot 10^{-7} \times \mu^{-0.686} \times P_{SOL}^{0.182} \times C_{Ne}^{-2.266} \times P_{Fus} / C_{pump}$$

$$\Gamma_{He,sep} = 1.66\cdot 10^{-4} \times \mu^{-0.756} \times P_{SOL}^{-0.269} \times C_{Ne}^{-2.349} \times P_{Fus} / C_{pump}$$

Contribution to the helium source from recycling is 5-7 times larger than that from the fusion reactions. Therefore, the He level in the core must be sensitive to the pumping speed.



Diffusion coefficient for core to be taken from experiment

D_{eff}/χ_e=?

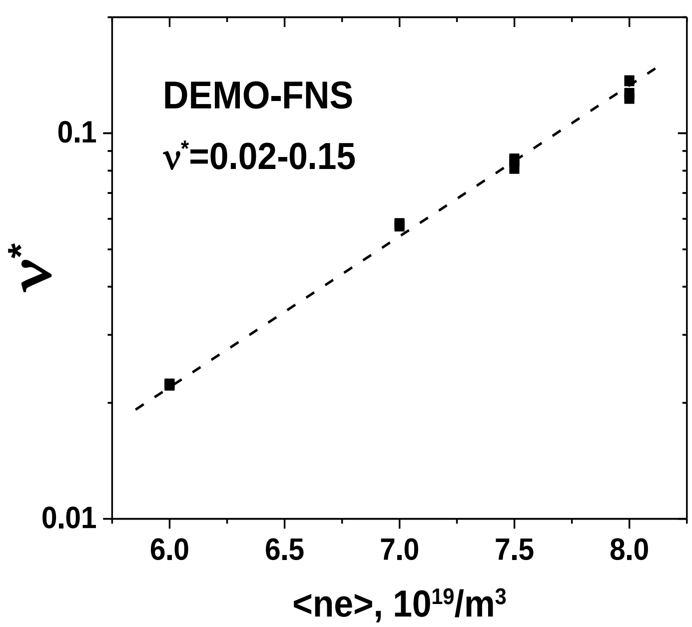
ITER: ν^*=0.01-0.7 D/χ_e=0.2-0.75 [A.Polevoi 2005]

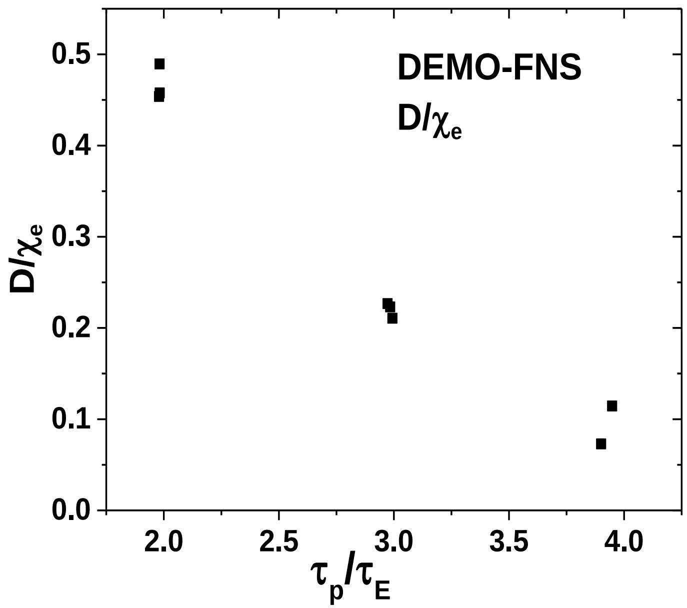
CTF: ν^*~0.1 D_{eff}/χ_e=0.4 [M.Valovic 2005]

DEMO-FNS: ν^*= 0.02 – 0.1 corresponds to DIII-D, JET and MAST

=> *D/χ_e* = 0.2÷0.5

$$\nu^* \sim \bar{n}_e R q_{eng} Z_{eff} (R/a)^{3/2} \langle T_i \rangle^{-2}$$





Global requirements for acceptable window of plasma parameters

(1) Pellet source to maintain the tritium fraction in the core

$$S_{pel} > \frac{f_T}{1 - f_T} S_{NB}$$

(2) Neutral pressure normalized to the allowable maximum value

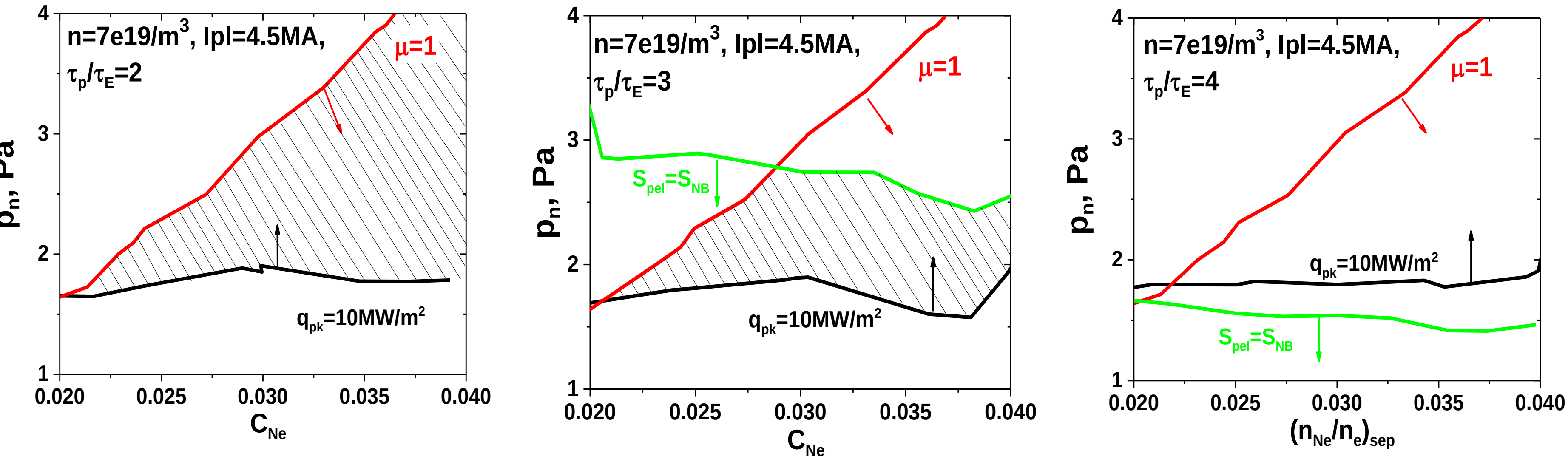
$$\mu < 1$$

(3) Power load to the divertor targets

$$q_{pk} < 10 \text{ MW/m}^2$$

Working window for divertor parameters

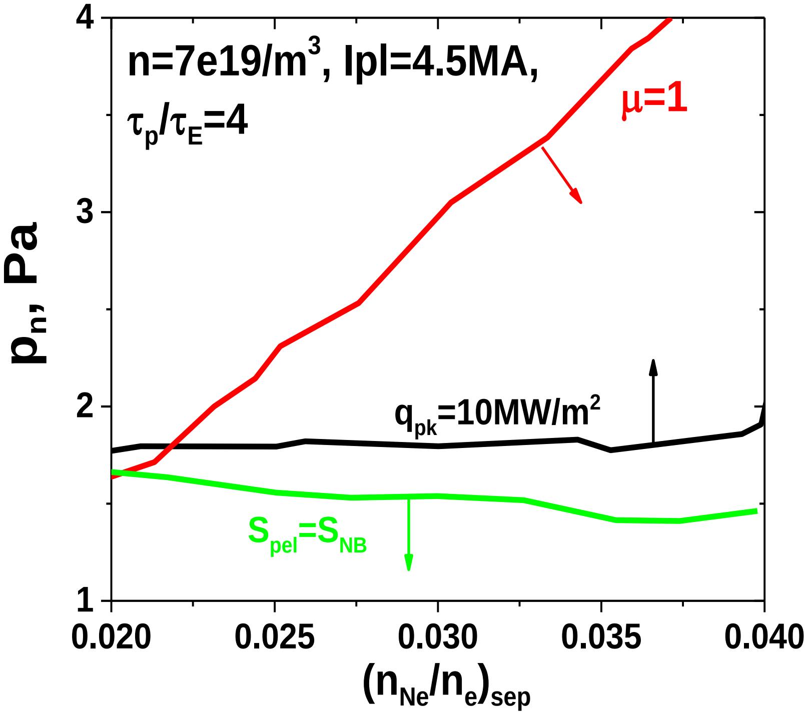
$\tau_{p/}\tau_E$ increasing

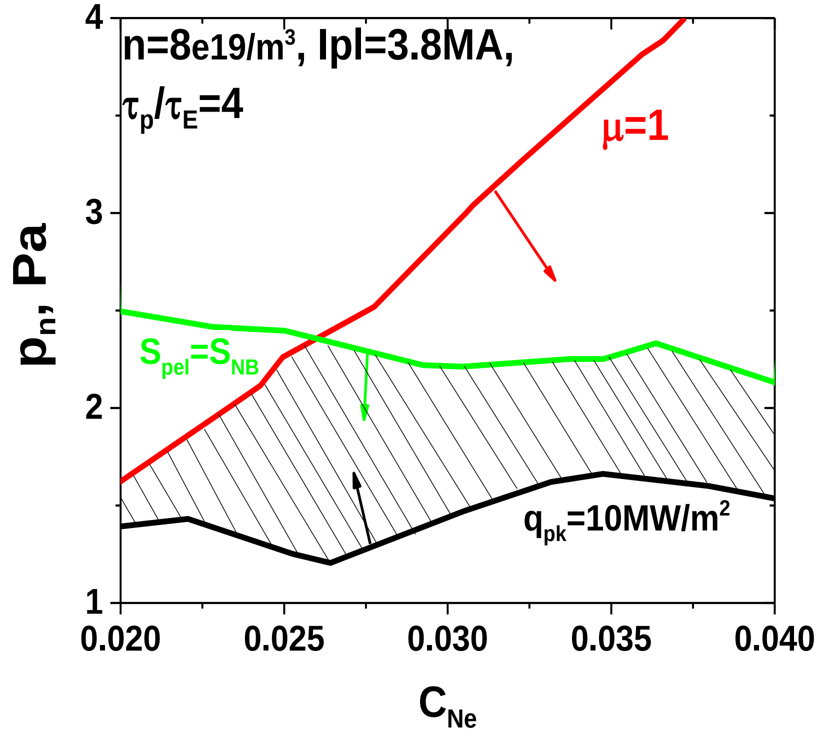


The particle confinement time τ_p goes up the pellet source decreases so that the condition on S_{pel} is violated at $\tau_{p/}\tau_E$ =4

Working window for divertor parameters

<n_e> increasing





The plasma density increasing opens the acceptable operating window, but this results in the reduction of the plasma current and neutron yield.

Modelling results

$\langle n_e \rangle$ $10^{19}/m^3$	τ_p/τ_E	$n_{He}(0)$ $10^{19}/m^3$	I_{pl} MA	q_{pk} MW/m^2	S_{Neut} $10^{19}s^{-1}$	P_{SOL} MW	P_{sh} MW	$\langle Z_{eff} \rangle$
6	2	0.16	5.2	9.6	1.34	37.4	0.30	2.9
7	2	0.15	4.5	9.0	1.17	35.9	0.15	2.7
7	3	0.18	4.5	8.6	1.13	35.2	0.16	2.7
7.5	2	0.14	4.2	9.1	1.04	36.1	0.11	2.6
7.5	3	0.16	4.2	8.3	1.05	34.4	0.10	2.6
8	2	0.12	3.8	8.4	0.976	34.7	0.093	2.4
8	3	0.14	3.8	9.3	0.835	36.6	0.076	2.5
8	4	0.18	3.8	8.7	0.795	35.3	0.068	2.6

Plasma current $\mathbf{I_{pl}}$ and Neutron yield $\mathbf{S_{neut}}$ go down with the density growth.

Conclusions

- Accumulation of the helium ash in the DEMO-FNS plasma does not look crucial. This is typical for devices with a low value of the fusion gain factor Q_{Fus}~1.
- Since the recycling fraction in the He density in the core is dominant, a significant reduction of the pumping speed may become limited by the helium removal conditions.
- An increase of the seeded Ne concentration shifts the operational boundary related to the up-down asymmetry towards higher values of neutral pressure p_n.
- However, the required value of neon density $n_{Ne}/n_e \sim 0.02 \div 0.03$ results in rather high values of $Z_{eff} \sim 2.5 \div 3$ in the core plasma