HELIUM ASH REMOVAL IN DEMO-FNS

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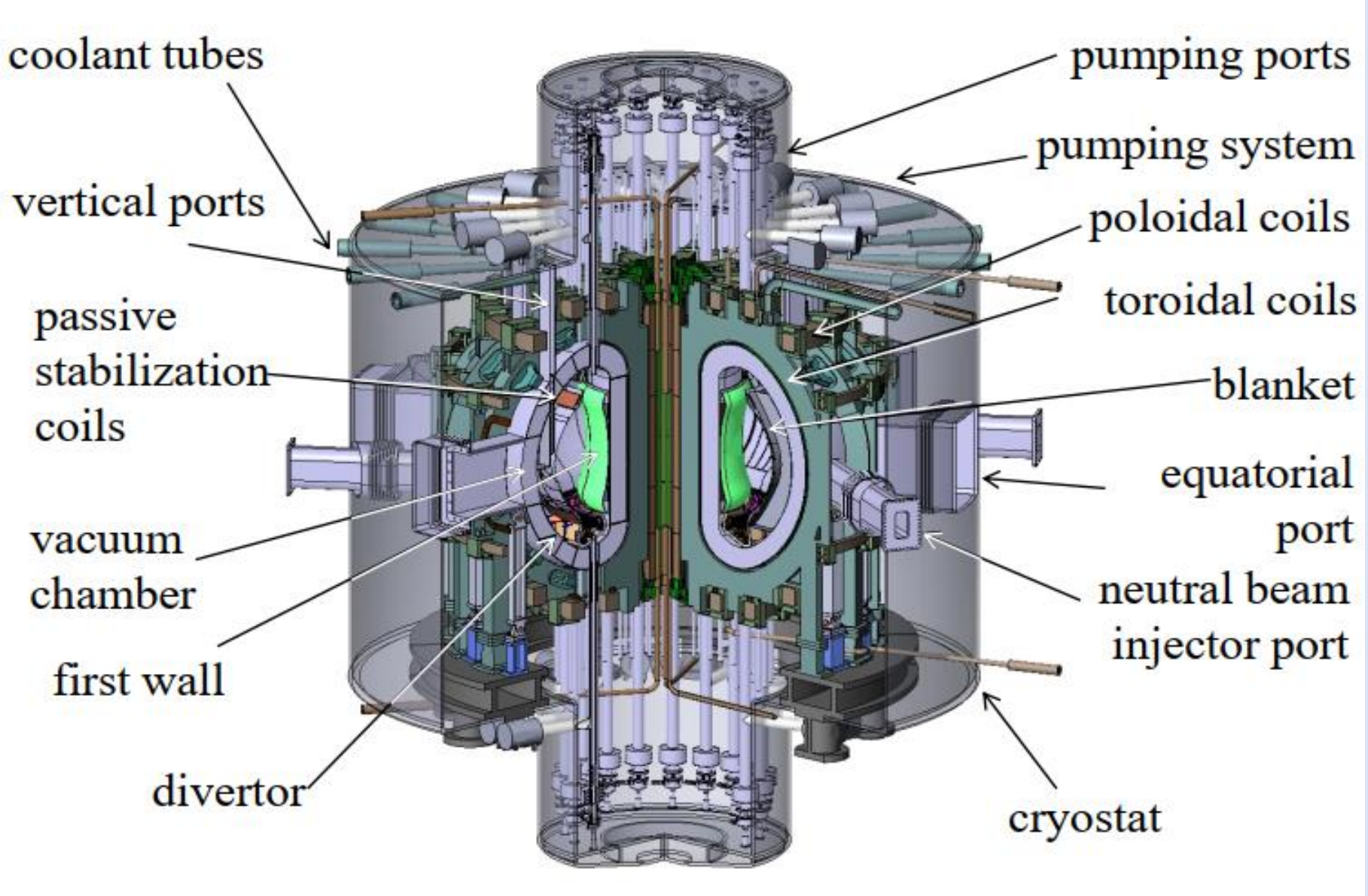
DEMO-FNS project



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**

- The steady-state regime for a tokamak-based DEMO Fusion Neutron Source is studied using the consistent simulations of the core and divertor plasma [A.Y. DNESTROVSKIY et al., Nucl. Fus. **59** (2019) 096053]
- Helium ash in divertor plasma
- Variation of the particle confinement time τ_p/τ_E = 2-4
- Variation of the plasma density

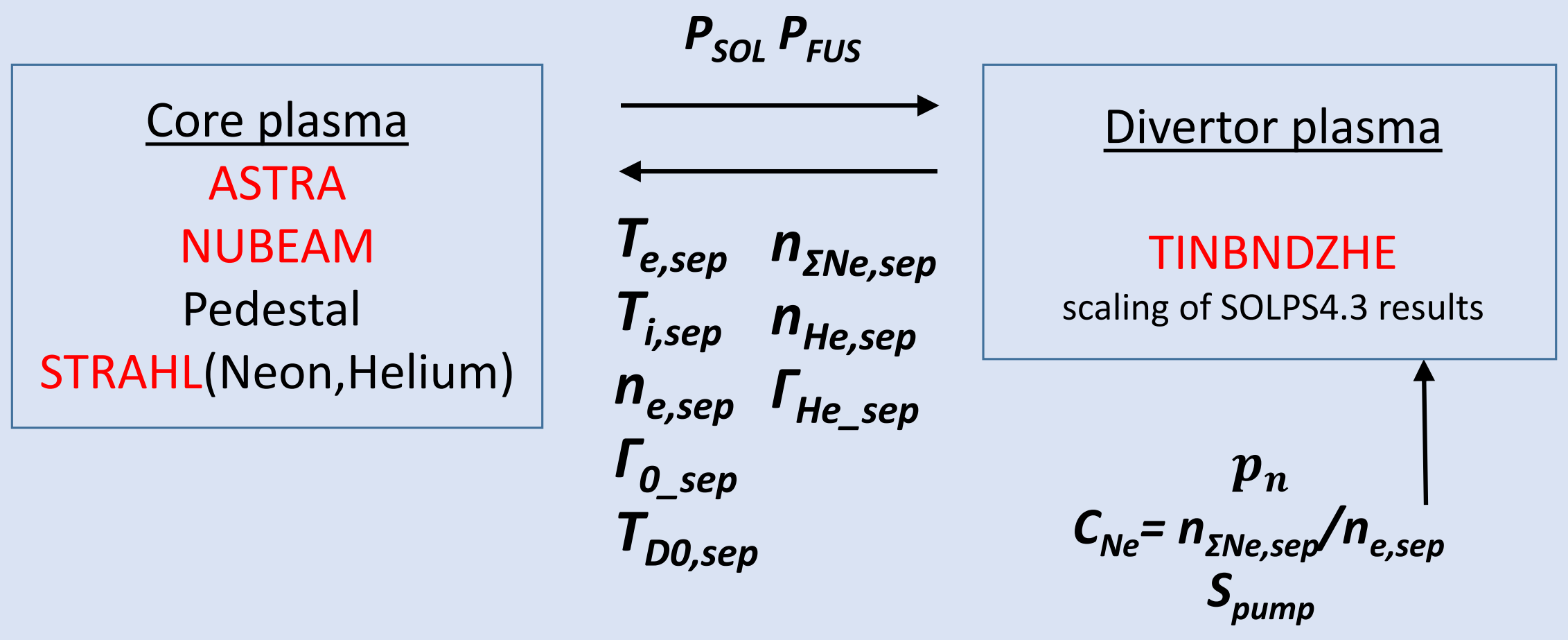
MODEL

✓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



Core plasma
ASTRA
NUBEAM
Pedestal
STRAHL(Neon,Helium)

P_{SOL} P_{FUS}

$T_{e,sep}$ $n_{\Sigma Ne,sep}$
$T_{i,sep}$ $n_{He,sep}$
$n_{e,sep}$ Γ_{He_sep}
Γ_{0_sep}
$T_{D0,sep}$

Divertor plasma
TINBNDZHE
scaling of SOLPS4.3 results

p_n
$C_{Ne} = n_{\Sigma Ne,sep}/n_{e,sep}$
S_{pump}

SOLPS4.3 result scaling laws

For boundary conditions

$$n_{e,sep} = 3.20\cdot10^{-2}\times\mu^{0.122}\times P_{SOL}^{0.537}\times C_{Ne}^{-0.204}$$

$$T_{e,sep} = 6.98\cdot10^{+1}\times\mu^{-0.048}\times P_{SOL}^{0.350}\times C_{Ne}^{0.094}$$

$$T_{i,sep} = 2.33\cdot10^{+2}\times\mu^{-0.075}\times P_{SOL}^{0.335}\times C_{Ne}^{0.200}$$

$$\Gamma_{D,sep} = 9.33\cdot10^{+2}\times\mu^{0.550}\times P_{SOL}^{-0.082}\times C_{Ne}^{0.912}$$

For divertor condition

$$\mu = 3.93\cdot10^{-3}\times p_n\times P_{SOL}^{-0.242}\times C_{Ne}^{-1.513}$$

For power peak load to divertor targets

$$q_{pk} = 5.47\cdot10^{-3}\times\mu^{-0.401}\times P_{SOL}^{1.674}\times C_{Ne}^{-0.367}$$

For helium balance boundary conditions

$$n_{He,sep} = 7.72\cdot10^{-7}\times\mu^{-0.686}\times P_{SOL}^{0.182}\times C_{Ne}^{-2.266}\times P_{Fus}/C_{pump}$$

$$\Gamma_{He,sep} = 1.66\cdot10^{-4}\times\mu^{-0.756}\times P_{SOL}^{-0.269}\times C_{Ne}^{-2.349}\times P_{Fus}/C_{pump}$$

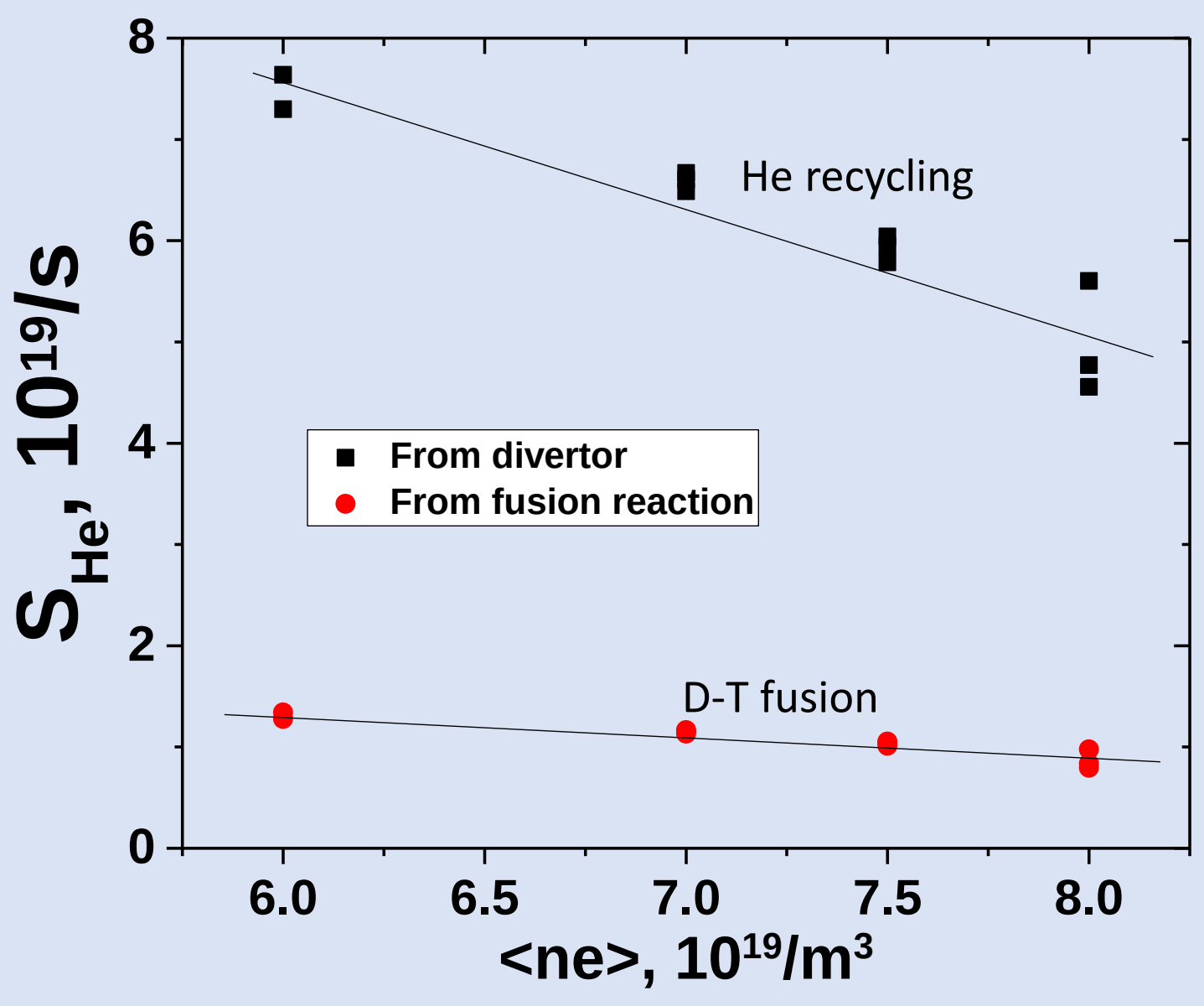
TABLE 1 SET OF CORE PLASMA PARAMETERS

τ_p/τ_E, τ_{He}/τ_E	2-4
H-factor	1.3
f_T	0.5
I_{pl}, MA	3.8-5.2
$n_{ped}/\langle n_e\rangle$	0.7
$\langle n_e\rangle$, 10^{19}/м^3	6-8

TABLE 2 SET OF DIVERTOR CONTROL PARAMETERS

P_{SOL}, MW	34 – 37.5
p_n, Pa	1-4
C_{pump}, m^3/s	20
$C_{Ne}=\Sigma N_{Ne}/n_e$	0.02-0.04
q_{pk}, MW/m^2	8.7-9.7
μ	0.8-0.9

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 conditions, although we did not vary C_{pump} in the present study



Diffusion coefficient for core to be taken from experiment

ν^* values are within the range of the experimental data from DIII-D, JET and MAST

D/χ_e = 0.2÷0.5 ratio selected for DEMO-FNS modelling is consistent with data from this devices

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

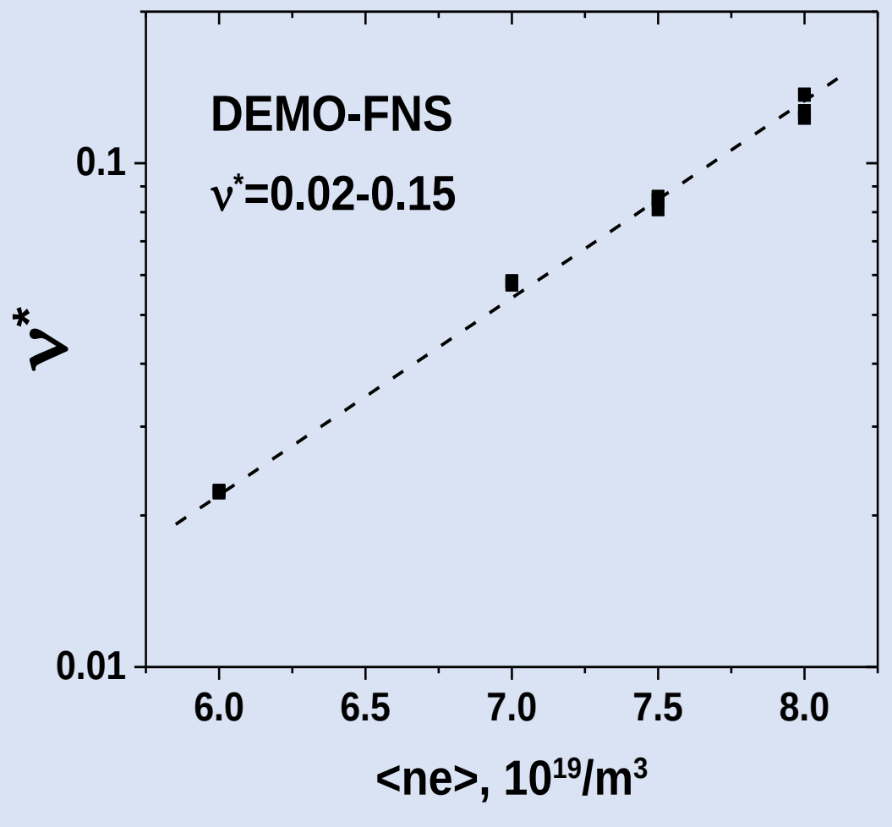


Figure 2. Normalized ion collisionality for DEMO-FNS vs averaged electron density.

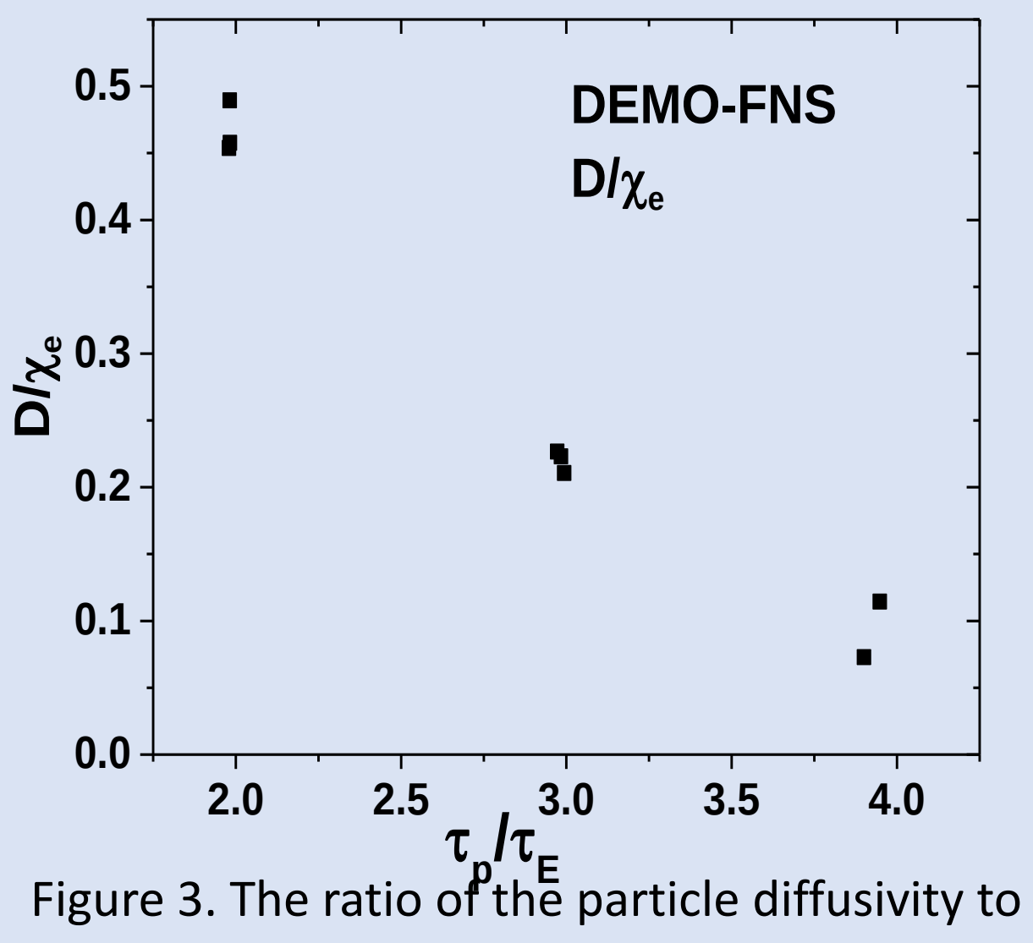


Figure 3. The ratio of the particle diffusivity to the electron heat conductivity vs the ratio of the particle confinement time to the energy confinement time.

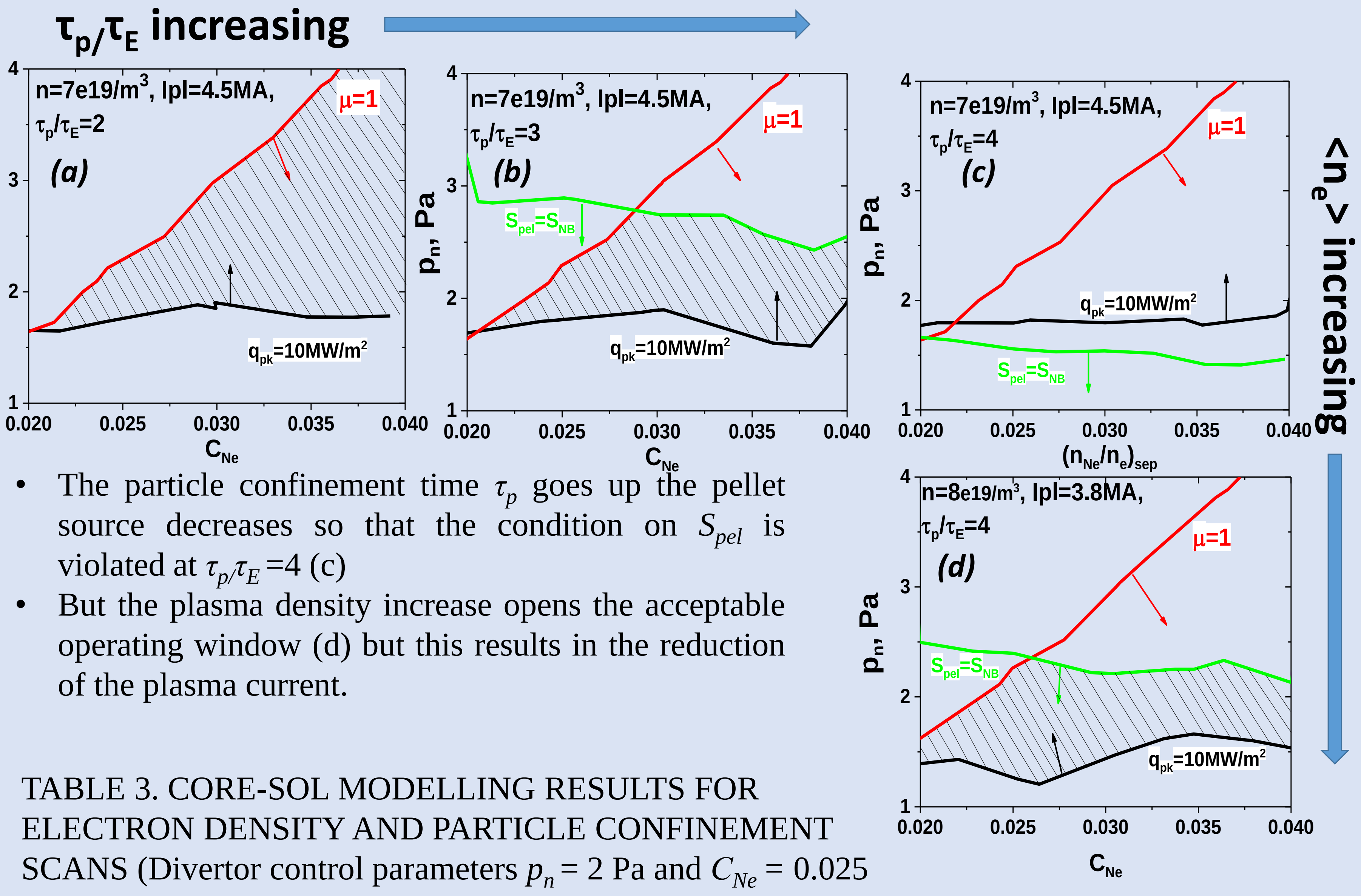
Modelling results

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

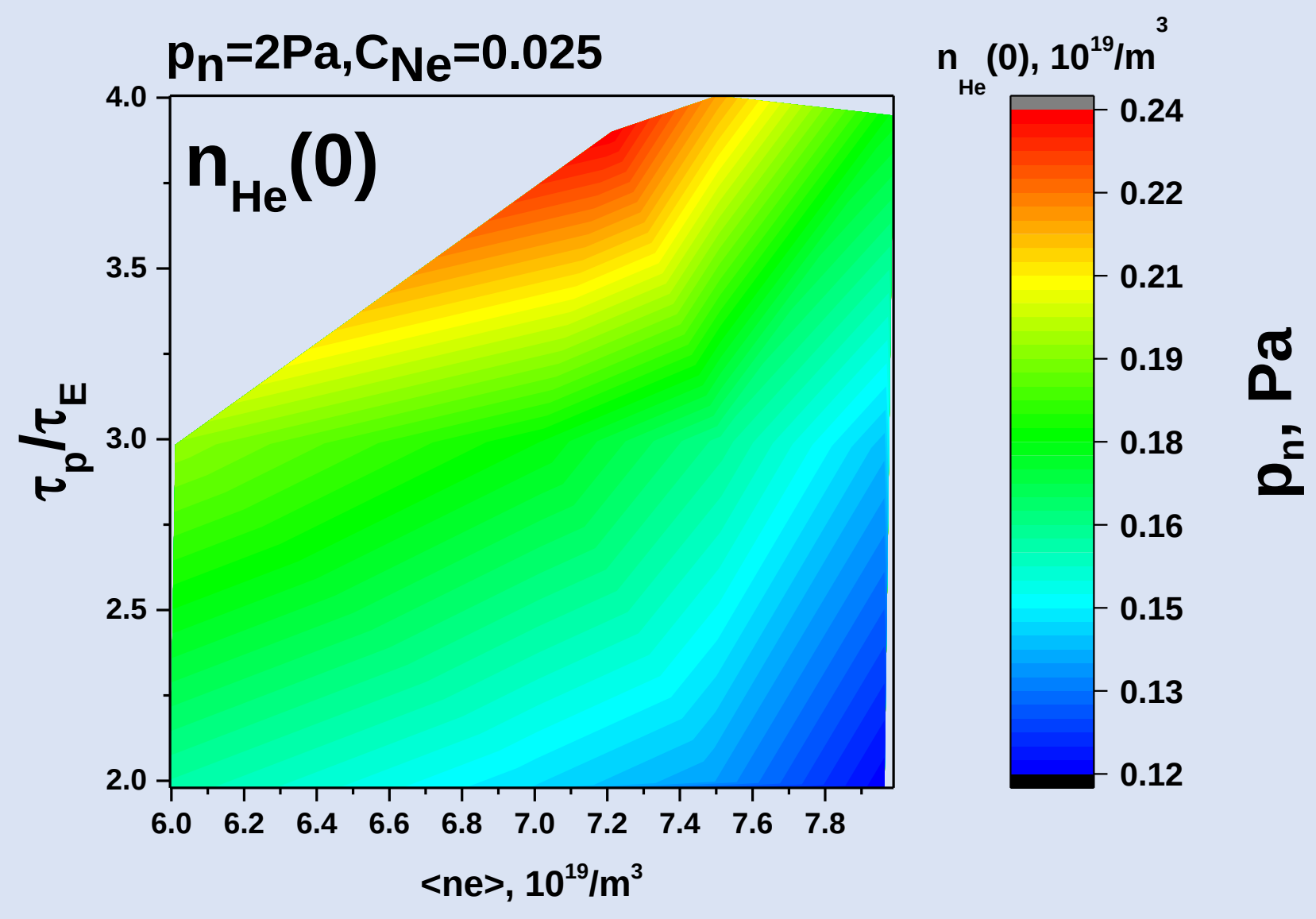


- The particle confinement time τ_p goes up the pellet source decreases so that the condition on S_{pel} is violated at τ_p/τ_E =4 (c)
- But the plasma density increase opens the acceptable operating window (d) but this results in the reduction of the plasma current.

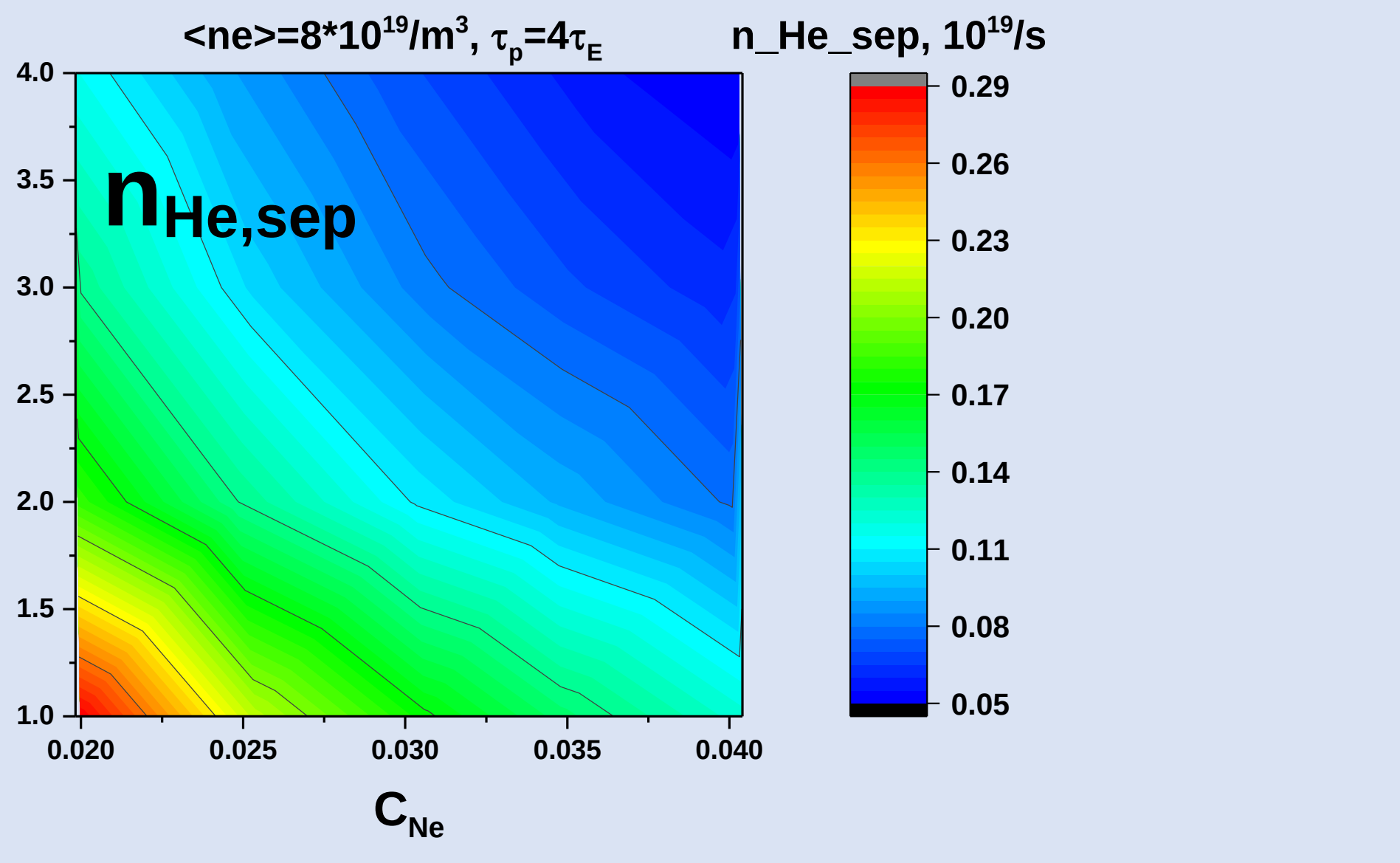
TABLE 3. CORE-SOL MODELLING RESULTS FOR ELECTRON DENSITY AND PARTICLE CONFINEMENT SCANS (Divertor control parameters p_n = 2 Pa and C_{Ne} = 0.025 are fixed)

$\langle n_e\rangle$ 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

Helium density at the plasma centre



Helium density at the separatrix



- Helium dilution turns out to be not important in DEMO-FNS as its density is a few per cent of the electron.
- Helium density at the plasma centre dependence on $\langle n_e\rangle$ and τ_p/τ_E is determined by the D-T fusion source.
- Helium density outside the separatrix adjusts itself to ensure the He particle flux to the pumping port maintaining the He removal rate equal to the He production rate in the core.
- Helium density at separatrix is determined by the transparency of the divertor plasma for the He atoms recycling off the target. Lower temperature – lower recycling on the divertor plates because of the lower ionization rate for He atoms. Both p_n and C_{Ne} are the factors, increasing of which cools the plasma near the targets and so reduces the He density at the separatrix.

CONCLUSION

- Accumulation of the helium ash in the DEMO-FNS plasma does not look crucial. The He density is within a few per cent of the electron density and depends but weakly on the particle confinement. This is typical for devices with a low value of the fusion gain factor Q_{Fus}~1. However, since the recycling fraction is dominant in the He density in the core, a significant reduction of the pumping speed may become limited by the helium removal conditions.
- The working window of the divertor control parameters expands when τ_P decreases or the plasma density increases. The main constraining feature is the necessity for the tritium source sufficient to maintain the tritium fraction f_T~ 0.5 in the core plasma.
- The lower plasma density is preferable from the point of view of the neutron yield. However, the increase of the density relaxes the uncertainty in the particle confinement but results in a decrease of the achievable plasma current.
- An increase of the seeded Ne concentration shifts the operational boundary related to the up-down asymmetry towards higher values of p_n. This opens the operational window in the control parameter space. However, the required value of C_{Ne} ~ 0.02÷0.03 results in rather high values of Z_{eff} ~ 2.5÷3 in the core plasma.

ACKNOWLEDGEMENTS

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