KURCHATOV INSTITUTE
NATIONAL RESEARCH CENTRE

PROGRESS IN MODELING THE D/T COMPONENT FLOWS IN FUELING SYSTEM OF CONTROLLED FUSION REACTOR BY SOLPS+ASTRA+FC-FNS CODES

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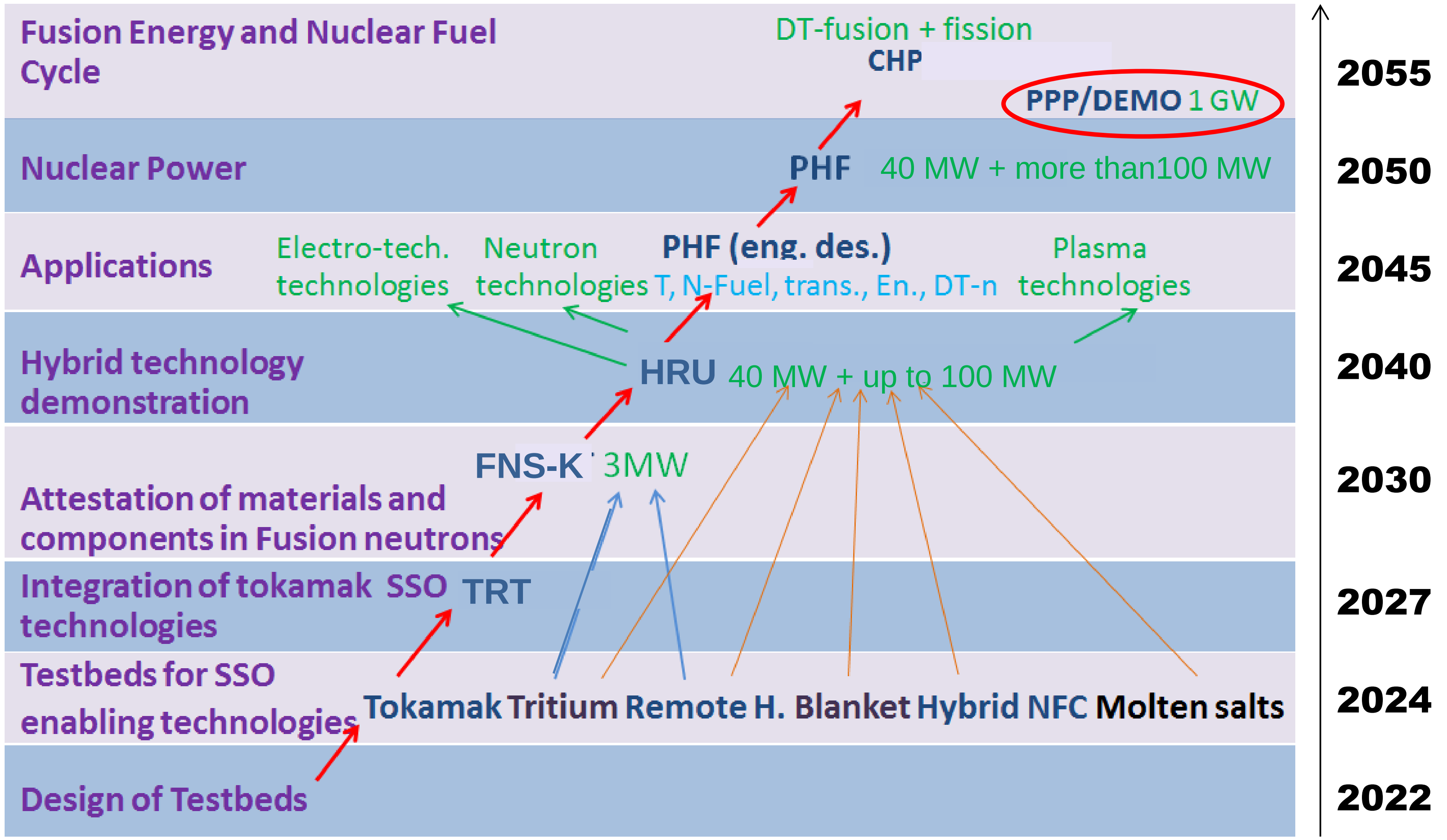
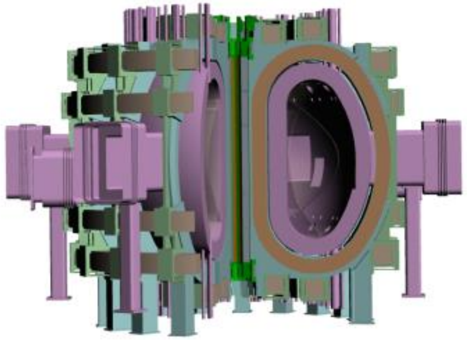
8th DEMO workshop
30 August 2022 to 2 September 2022 Vienna, Austria

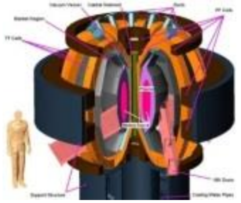
IAEA

Russian Federation FNS/FFHS roadmap

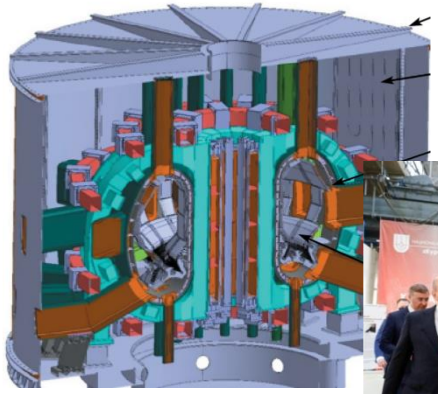




Superconducting magnetic system
40 MW additional heating
40 MW fusion
Integration of nuclear and fusion technologies



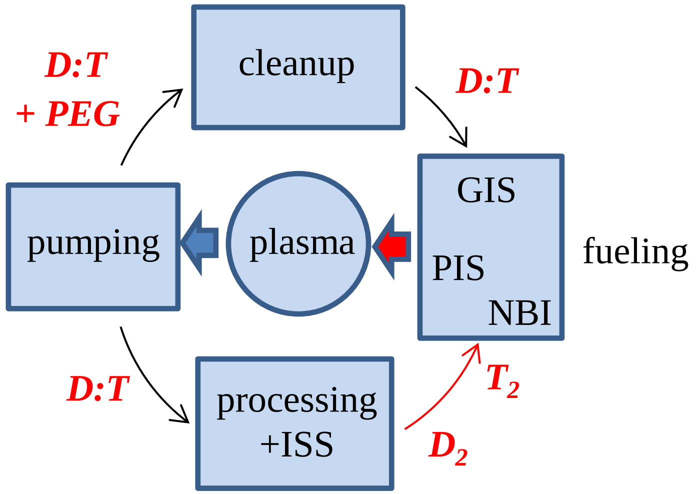
“Warm” magnetic system
10 MW additional heating
3 MW fusion
Stationary tokamak technologies



Tokamak with Reactor Technologies

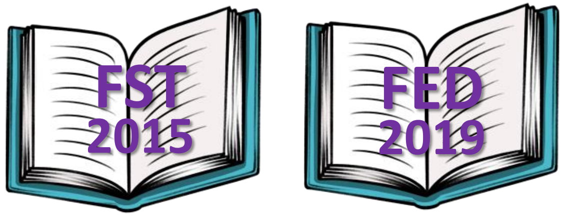
Quasi-steady-state tokamak T-15MD

Deuterium-Tritium Fuel Cycle for Fusion (Hybride) Reactor



FC-FNS code
(Fuel Cycle for Fusion Neutron Source)

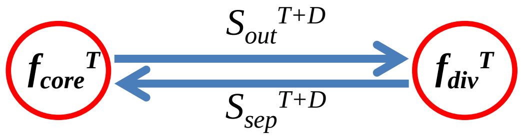
2014-2022



Particle balance in the core plasma

$$N_{core} = N_{sep} + S_{NB}\cdot\tau_{NB} + S_{pel}\cdot\tau_{pel} + S_{sep}\,\tau_{sep} - S_{fus}\cdot\tau_{tot}$$

τ_{NB}, τ_{pel}, τ_{sep}, τ_{tot} – ion confinement times



Loss of particles from plasma:

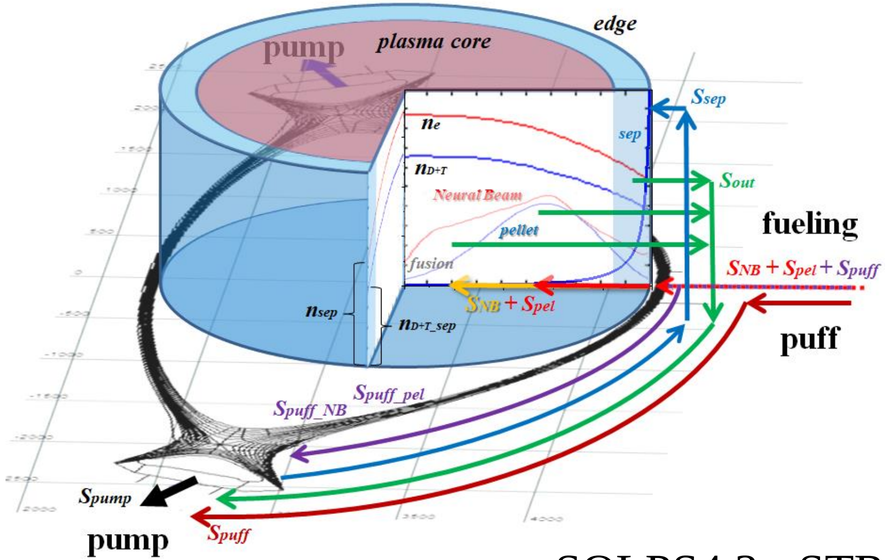
$$S_{NB}^{T+D} + S_{pel}^{T+D} + S_{sep}^{T+D} - S_{fus}^{T+D} = S_{out}^{T+D}$$

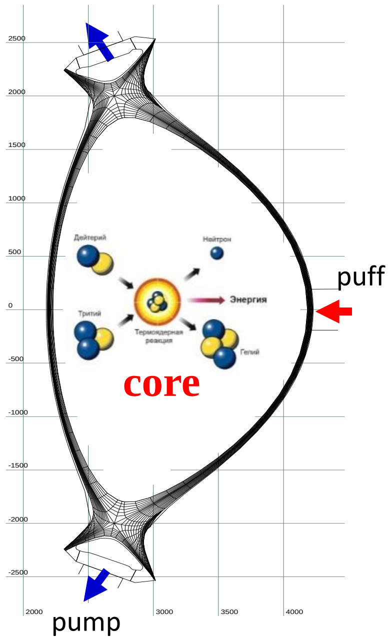
fueling — neutral flux from divertor — fusion

pump $p_n c_p = S_{puff}^{T+D} - S_{sep}^{T+D} + S_{out}^{T+D}$

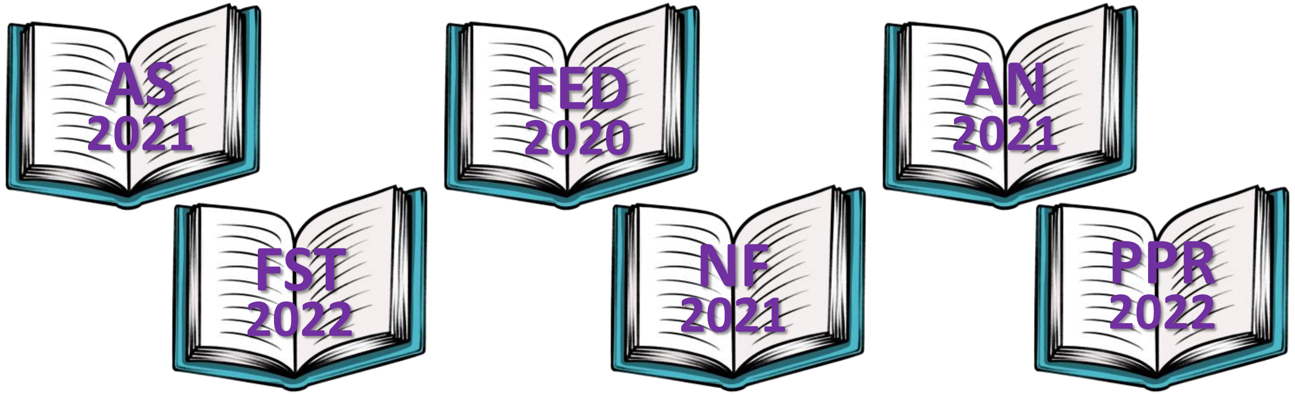
puff $S_{puff}^{T+D} = S_{GIS}^{T+D} + S_{puff(NB/pel)}^{T+D}$

ASTRA+NUBEAM codes





SOLPS4.3.+STRAHL+ASTRA codes



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Power system structure with Fission and Fusion Reactors

$$D^+:\begin{cases} n_{D^+}^{fast}: \text{ FP-solver by NUBEAM} \\ \frac{\partial}{\partial t} n_{D^+}^{beam} + div\left(-D\nabla n_{D^+}^{beam} + V n_{D^+}^{beam}\right) = S_{D^+}^{beam} - R_{D^+}^{beam} \\ \frac{\partial}{\partial t} n_{D^+}^{pel} + div\left(-D\nabla n_{D^+}^{pel} + V n_{D^+}^{pel}\right) = S_{D^+}^{pel} - R_{D^+}^{pel} \\ \frac{\partial}{\partial t} n_{D^+}^{sep} + div\left(-D\nabla n_{D^+}^{sep} + V n_{D^+}^{sep}\right) = S_{D^+}^{sep} - R_{D^+}^{sep} \end{cases}$$

$$T^+:\begin{cases} n_{T^+}^{fast}: \text{ FP-solver by NUBEAM} \\ \frac{\partial}{\partial t} n_{T^+}^{beam} + div\left(-D\nabla n_{T^+}^{beam} + V n_{T^+}^{beam}\right) = S_{T^+}^{beam} - R_{T^+}^{beam} \\ \frac{\partial}{\partial t} n_{T^+}^{pel} + div\left(-D\nabla n_{T^+}^{pel} + V n_{T^+}^{pel}\right) = S_{T^+}^{pel} - R_{T^+}^{pel} \\ \frac{\partial}{\partial t} n_{T^+}^{sep} + div\left(-D\nabla n_{T^+}^{sep} + V n_{T^+}^{sep}\right) = S_{T^+}^{sep} - R_{T^+}^{sep} \end{cases}$$

Boundary conditions

$$D^+:\begin{cases} n_{D^+}^{beam}(a) = 0 \\ n_{D^+}^{pel}(a) = 0 \\ n_{D^+}^{wall}(a) = \left(1 - f_T^{sep}\right)\cdot n_{D^+}^{SOLPS} \end{cases}$$

$$T^+:\begin{cases} n_{T^+}^{beam}(a) = 0 \\ n_{T^+}^{pel}(a) = 0 \\ n_{T^+}^{wall}(a) = f_T^{sep}\cdot n_{D^+}^{SOLPS} \end{cases}$$

Ion and energy confinement times

$$\tau_{D^+/T^+}^{beam} = \frac{\int_V \left(n_{D^+/T^+}^{beam} + n_{D^+/T^+}^{fast}\right) dV}{\int S_{D^+/T^+}^{beam} dV},$$

$$\tau_{D^+/T^+}^{pel} = \frac{\int_V n_{D^+/T^+}^{pel} dV}{\int S_{D^+/T^+}^{pel} dV},$$

$$\tau_{D^+/T^+}^{sep} = \frac{\int_V \left(n_{D^+/T^+}^{sep} - n_{D^+/T^+}^{sep}(a)\right) dV}{\int S_{D^+/T^+}^{sep} dV}.$$

$$\tau_E = \frac{\frac{3}{2}\int_V \left(n_e T_e + n_i T_i\right) dV}{\int P_{tot} dV},$$

$$\tau_p = \frac{\int_V n_i dV}{\int S_i^{tot} dV},$$

$$\tau_{tot} = \frac{\int_V \left(n_i - n_i(a)\right) dV}{\int S_i^{tot} dV},$$

Transfer coefficients

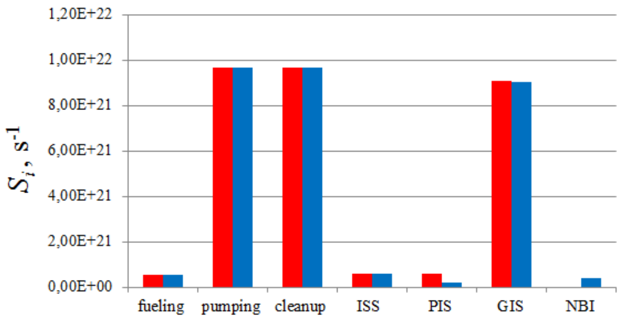
$$\begin{cases} D = k\cdot\chi_e, \\ V = 0 \end{cases}$$

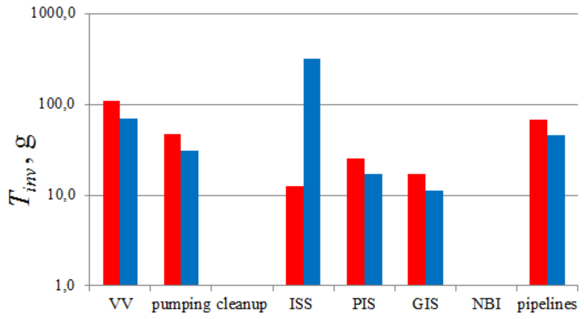
$$n_i = n_{D^+}^{beam} + n_{D^+}^{pel} + n_{D^+}^{wall} + n_{T^+}^{beam} + n_{T^+}^{pel} + n_{T^+}^{wall}$$

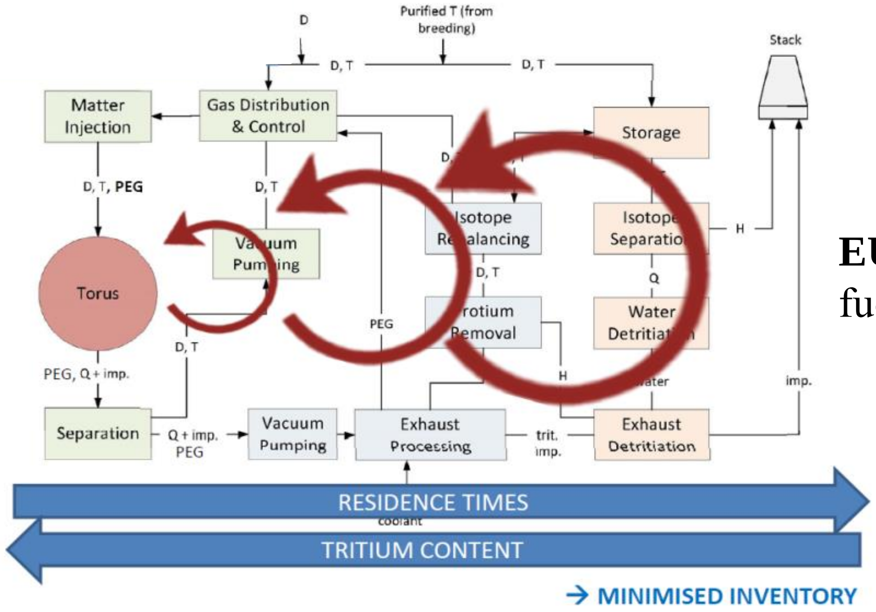
$$n_e = n_i + n_{D^+}^{fast} + n_{T^+}^{fast} + \sum_{Z=\text{He,Be,Ne}} Z\cdot n_Z$$

Deuterium-Tritium Fuel Cycle for Fusion (Hybride) Reaktor

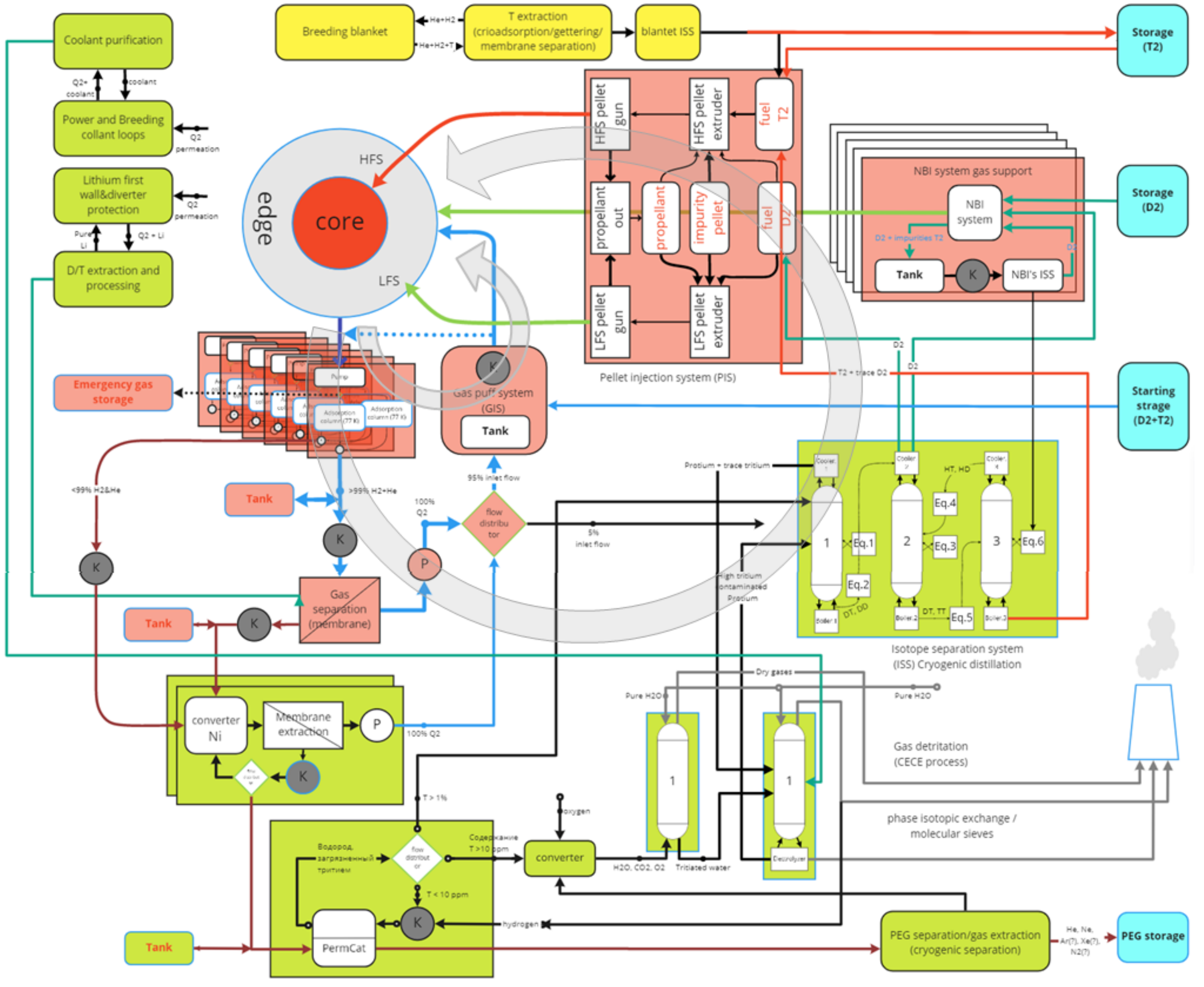
T/D particle fluxes through FC systems and T inventory in them







EU DEMO
fuel "smart" cycle

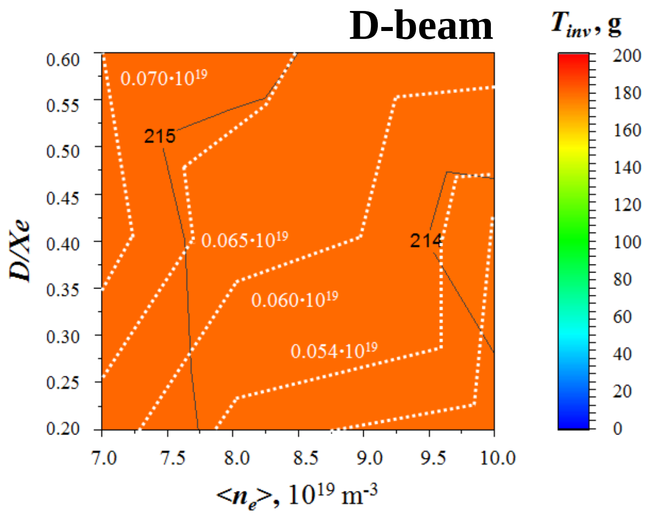


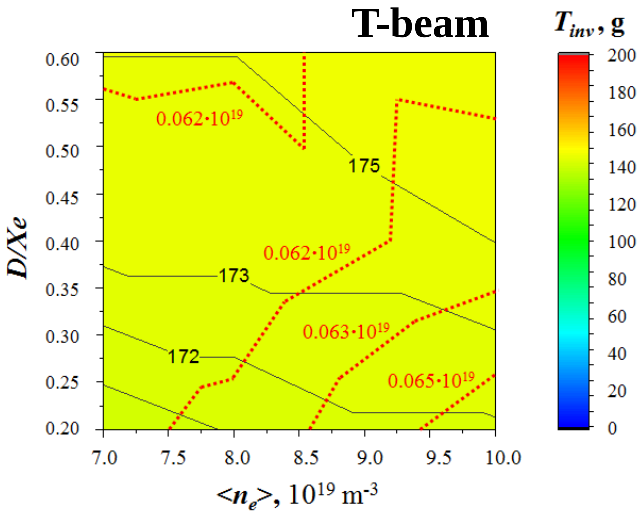
3 contours (highlighted in different colors):

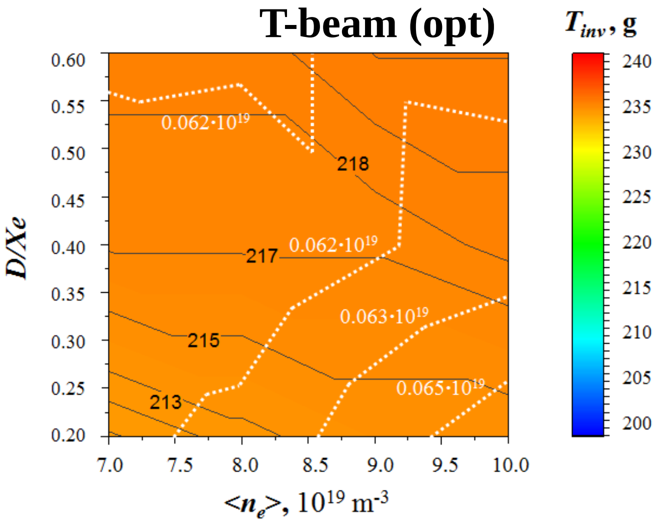
- fast processing of the "exhaust" of the tokamak,
- extraction of T from the blanket,
- processing of T-containing waste

Simulation of a compact fusion neutron source FNS-ST

T inventory at the facility site + neutron flux

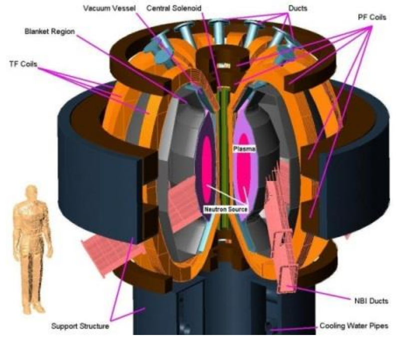






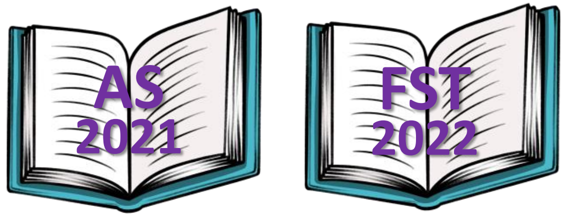
Compact tokamak - features:

- Synthesis proceeds predominantly on beams
- Influence of beam particles on plasma fueling
- Effect of divertor neutrals on plasma fueling

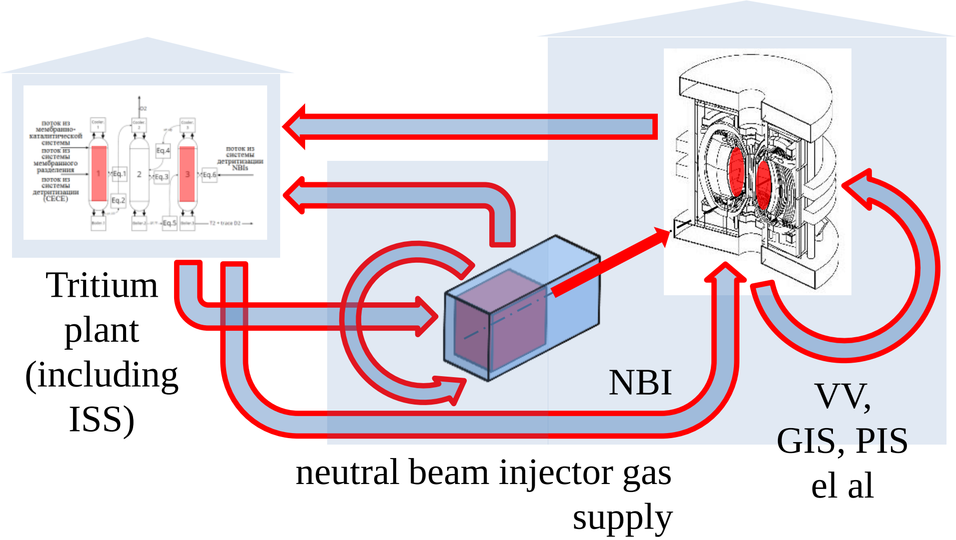


3-4 injectors 3-3.5 MW each

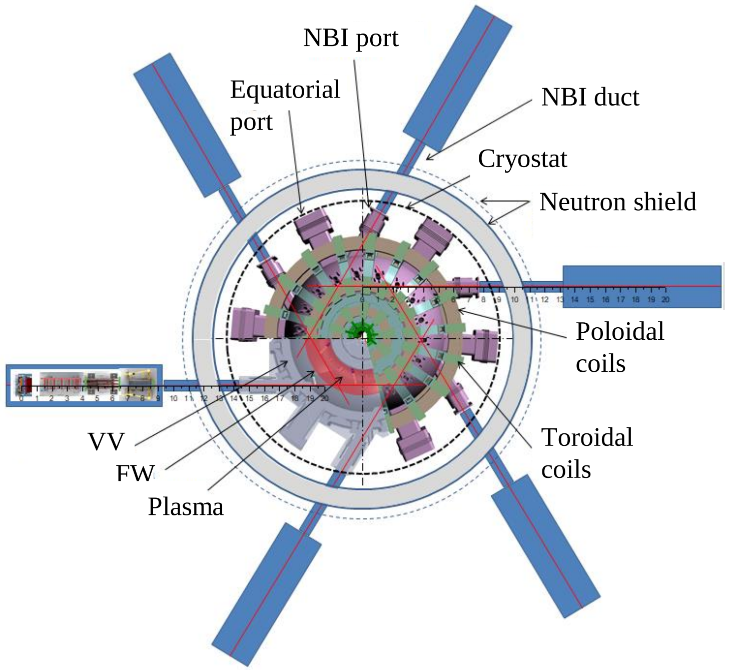
Injection in the equatorial plane

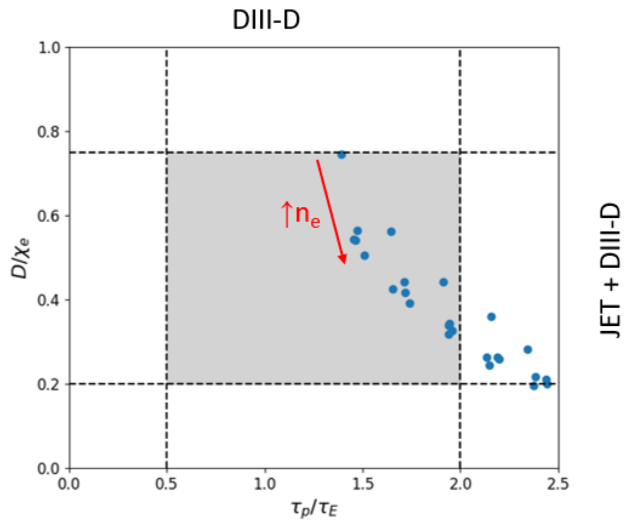


NBI gas support isotopic composition:	T-plant ISS et al	NBIs	VV, GIS, PIS et al	Total
D+T – beam	25	20	180	180-220
D – beam (partial separation)	10-25	0	75-160	90-190
D – beam (full separation)	25	0	180	210
T – beam (partial separation)	15	40	60-120	115-175
T – beam (full separation)	15	40	30	90
T – beam (NBI gas support optimization)	60	15	30	110



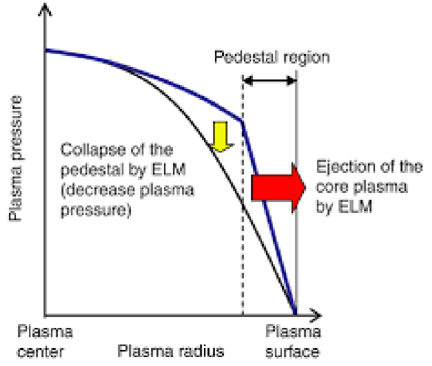
Simulation of a fusion neutron source DEMO-FNS

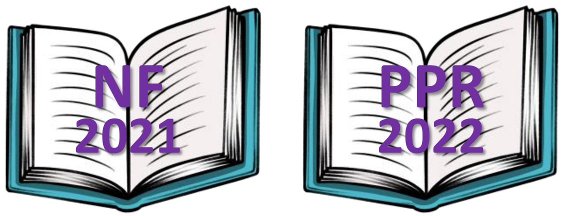




Modes with "natural" and convective ELMs

...influence to diffusion losses and fueling flows



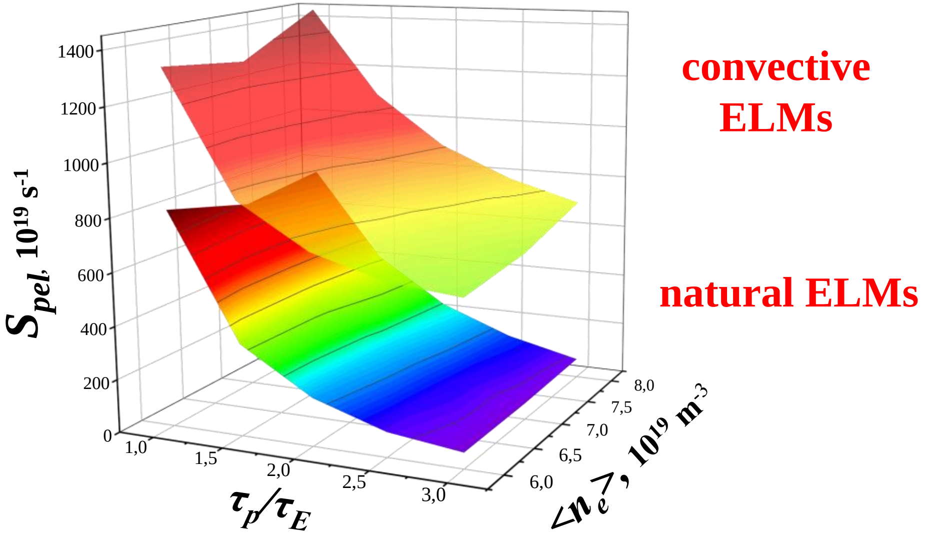


Equation for N_{core}:

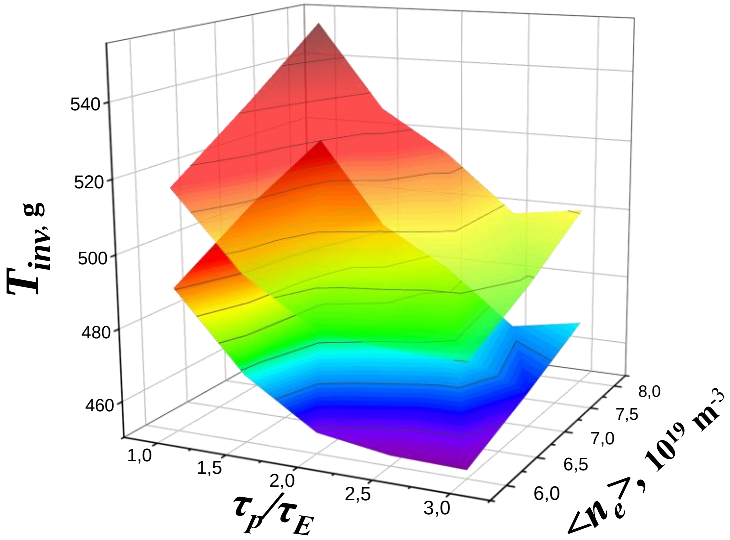
$$N_{core} = N_{sep} + S_{NB}\cdot\tau_{NB} + (S_{pel(LFS)} + S_{pel(HFS)} - \alpha_{ELM}\cdot(1-\gamma)\cdot P_{SOL}/3T_{ped})\cdot\tau_{pel} + S_{sep}\cdot\tau_{sep} - S_{fus}\cdot\tau_{tot}$$

From this equation, one can estimate the $(S_{pel(LFS)} + S_{pel(HFS)})$, needed to maintain N_{core} density...

Particle flows from pellet injection and natural/convective ELMs



T inventories in facility FC for natural/convective ELMs



Computer code

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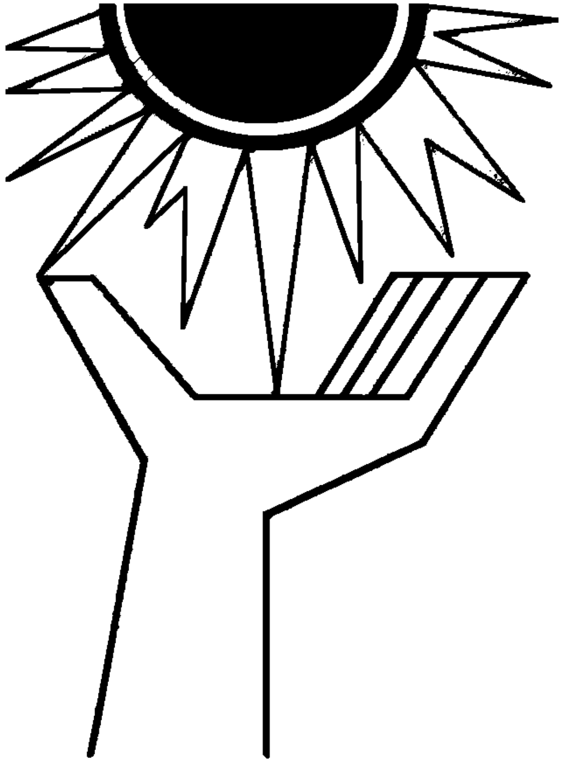

Thank you for your attention!