Feasibility Study of Tokamak, Helical and Laser Reactors as Affordable Fusion Volumetric Neutron Sources

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ABSTRACT

- Applicability of tokamak, helical and laser fusion reactors as a volumetric neutron source (VNS) has been examined.
- The performance of reactor-based VNS that can be designed based on the current physics and engineering basis with a reasonable running cost has been analysed using the systems codes that have been utilised for the conceptual design of fusion power plants.
- The characteristics and issues of the each reactor type has been compared.

BACKGROUND

- To realise a D-T fusion power plant, an irradiation test of the reactor materials and components by 14 MeV fusion fast neutrons are necessary.
- Accelerator driven neutron sources (e.g., A-FNS, IFMIF-DONES) has a high cost performance in terms of the maximum available neutron flux, but the high irradiation volume is quite limited (~0.5 L).
- Reactor-based VNS can provide a larger irradiation volume with a monoenergetic and a homogenous neutron field.
- Reactor-based VNS can also serve as an integration test bed of the entire reactor system.
- Tokamak, helical and laser systems are selected in this study because sophisticated design activities and related R&Ds towards a commercial power plant have been conducted and the systems codes that have been developed or modified by the authors are available.

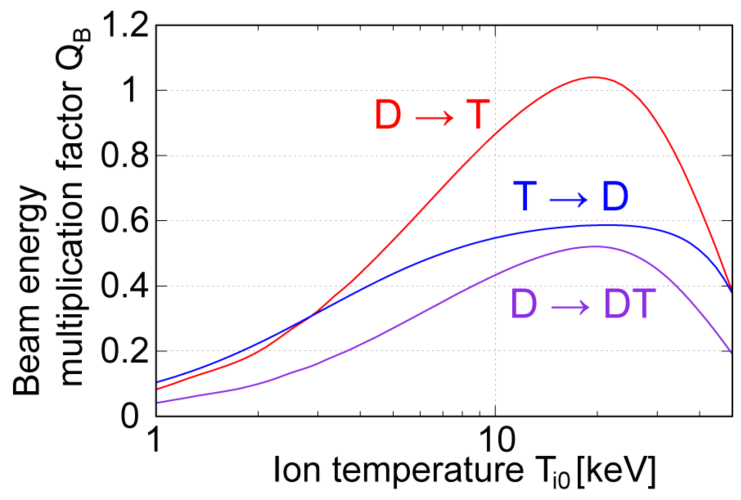
DESIGN PREREQUISITES

- Engineering and physics parameters achieved/expected in the device in operation/under construction
  - Tokamak: JT-60SA, ITER
  - Helical: LHD
  - Laser: GEKKO-XII
- Steady-state operation capability
  - Superconducting coils, NBI with the injection energy of ~100 keV (possibility of the use of positive ion-based NBI), neutron shielding with 25 cm thickness for tokamak and helical reactor-based VNS
  - 10 kJ/100Hz laser system for laser reactor-based VNS (can be realised by arraying 10 J/100 Hz system that has recently been developed)
- Annual electricity charge up to 5B JPY ($50M)
  - Acceptable electric power consumption is up to 10 MW considering the electricity charge for a large consumer (~2,000 JPY/month + ~15 JPY/kWh)
  - NBI power and laser power is limited to be ~5 MW and ~1 MW considering the system efficiency.

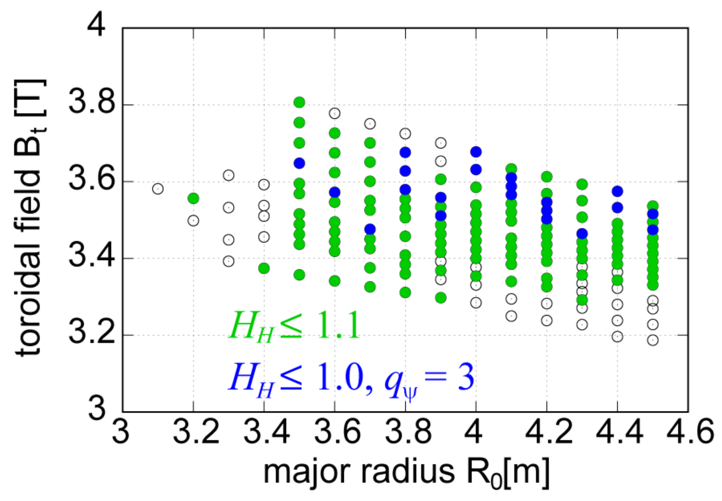
DESIGN WINDOW ANALYSIS

Tokamak

- Beam energy multiplication factor $Q_B \sim 1$ is expected by 100 keV D beam injection into T plasma of 20 keV.



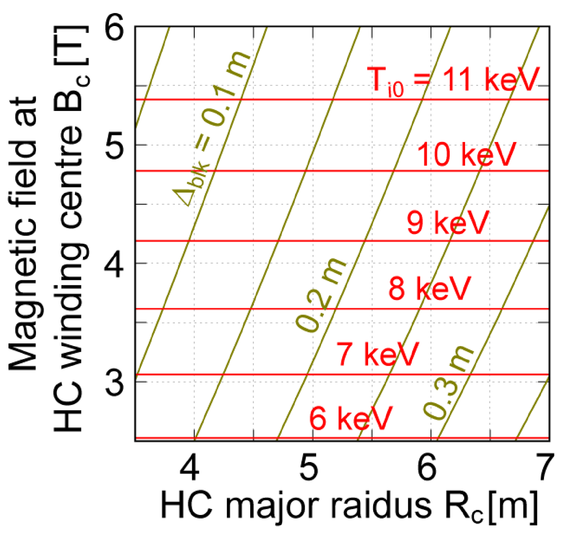
- P_{fus}~5 MW can be achieved at $R_0 = 3.5$ m and $B_t = 3.65$ T with the TF and CS coil design based on JT-60SA and the physics parameters assumed in ITER inductive operation: $n/n_{GW} \leq 1$, $\beta_N \leq 1.8$, $q_\psi = 3$ and $H_H \leq 1$.
- R_0 is mainly determined by the CS/TF coil design, not by the confinement property.

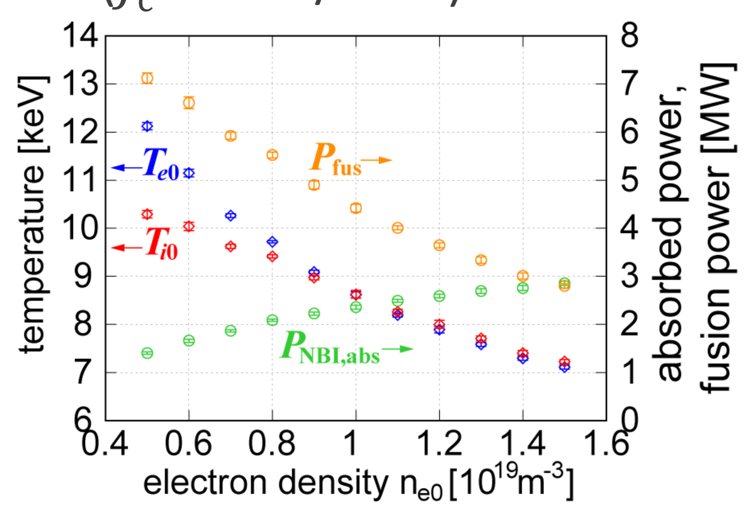


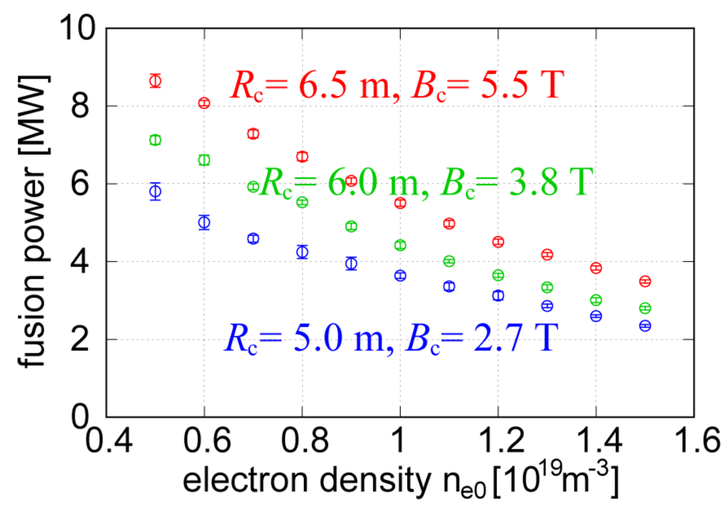
- If the increase of the NBI power or the running cost is permitted, P_{fus} can be increased without a large increase in R_0 and the construction cost.
- Availability is one of a big issues.

Helical

- Achievable R_c and B_c are determined by the shielding thickness.
- P_{fus}~5 MW can be achieved at $R_c = 6.0$ m and $B_c = 3.8$ T with the plasma performance and the helical coil current density confirmed in the LHD (j_c =35 A/mm²).







- Steady-state operation is expected.
- R_c can be reduced and/or P_{fus} can be increased if j_c increases.

Laser

- Neutron yield of Y_n~10^{13} has already been achieved by 100 kJ laser injection and it can be increased by increasing laser energy: $Y_n \propto E_L^{4/3}$.
- Considering the target injection capability of 10 Hz, 10^{14} n/s is expected and the neutron flux can be varied by changing the chamber radius.
- Large space for the blanket module exists and net TBR > 1 is expected.
- Multiple chamber operation is possible by steering the laser beams.

SUMMARY

- Characteristics of the reactor-based VNS has been examined.
  - Tokamak: Highest neutron flux
  - Helical: Highest annual neutron production and largest irradiation area
  - Laser: Flexible neutron flux and the possibility of tritium breeding
- Reactor-based VNS can be designed based on the present physics and engineering basis with much smaller device size than that for the electric power generation.
- Reactor-based VNS can be a test bed of the entire reactor system and also provide an environment for the burning plasma experiment and the demonstration of advanced concepts.

	Tokamak	Helical	Laser	A-FNS
Device size [m]	3.5 (major radius)	6.5 (major radius)	> 0.05 (chamber)	–
Required power [MW]	10	10	1	10
Neutron generation rate [n/s]	1.8×10^{18}	1.8×10^{18}	1×10^{14}	6.8×10^{16}
Neutron flux [n/m²/s]	9.0×10^{15}	4.5×10^{15}	< 8.0×10^{14}	> 10^{18} (high) ~10^{17} (low)
Irradiation area [m²]	~200	~400	> 0.125	~0.5 (high) ~4 (low)
Annual neutron production	~4.5×10^{25}	~6.0×10^{25}	~3×10^{21}	~2×10^{24}
Issues towards the increase of the neutron generation rate	Increase of the availability	Increase of the coil current and current density	Increase of the laser energy and the repetition rate	–