§2. A Conceptual Design of Heliotron DEMO Plant

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One or more demonstration plants for electricity production (DEMOs) will be constructed after ITER. They are expected to be the first fusion power plants with generating electric power at a level of several hundreds MWs. The DEMO plants should prove the capability of reliable operation of fusion power plants. As far as they are deuterium-tritium (D-T) fusion reactors, sufficient tritium breeding is indispensable. In order to contribute actually to reduction of CO_2 and the energy crisis, commercial use of fusion energy should be realized in the second half of this century, and the first DEMO reactor should start operation in 2030s, as shown in Fig. 1 [1].

Heliotron reactors have several features suitable for a fusion power plant, such as no need for current drive, no plasma current disruptions, suitability for steady state operation, and a wide space between helical coils useful for maintenance of in-vessel components. According to recent reactor studies based on the experimental results in LHD, the plasma major radius of a heliotron reactor is set to 14 to 18 m in order to install shielding and breeding blankets with total thickness of about 1.1 m [2]. The central toroidal field is 5 to 6 T, and the stored magnetic energy is estimated to be 120 to 150 GJ under the assumption of the confinement enhancement factor, H_H, of 1.4 to LHD.

The major radius of heliotron power plants is determined mainly by the minimum thickness of the blanket and the plasma minor radius required from the energy confinement time. The blanket thickness of the H-DEMO can be reduced by adopting excellent shield material such as WC and raising the upper limit of neutron flux in the superconducting magnets because their lifetime can be shortened than those of the power plants. In addition, it is not indispensable for the DEMO to satisfy the self ignition condition. The Q-value more than 20 is considered to be sufficient to prove the capability of reliable operation. Figure 2 shows required magnetic fields and magnetic energy to attain the self ignition condition for a typical LHD type reactor with H_H of 1.4 and 1.75 to LHD, the pitch parameter of 1.20, average beta of 4% to the central field, helical coil current density of 25 A/mm^2, helium ash ratio of 3%, oxygen impurities ratio of 0.5%, alpha particle heating ratio of 90%, and parabolic distribution of density and temperature. The self ignition with H_H of 1.75 corresponds approximately to Q of 25 with H_H of 1.4. The blanket space in Fig. 2 includes the ergodic layer of the plasma, and its thickness of 0.05 to 0.1 m should be considered. In order to attain Q-value more than 20 with H_H of 1.4 to LHD and the blanket thickness more than 0.8 m, the necessary major plasma radius and magnetic energy of the H-DEMO can be reduced to 13 m and 70–80 GJ, respectively, as shown in Fig. 2 and Table 1. The average neutron wall load to the blanket is less than 2 MW/m^2, which should be beneficial to the heat removal from the blanket. Since the amount of its magnet system is comparable to ITER, it can be realized with small extension of the ITER technology.

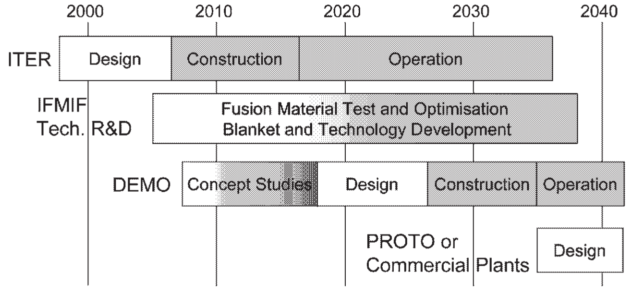

Fig. 1. A roadmap to fusion electricity in the IEA report [1].

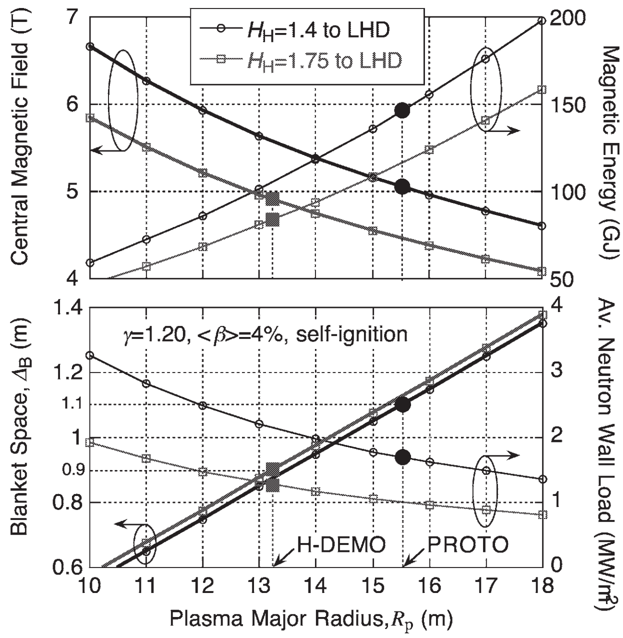

Fig. 2. Required magnetic field, magnetic energy, blanket space, and average neutron wall load of LHD-type reactor with H_H of 1.4 and 1.75 to LHD. The blanket space includes the ergodic layer of the plasma.

Table 1. Design studies on heliotron power plants.

	FFHR2m1	FFHR2m2	H-DEMO
H-factor of τ_E, H_H	1.4 to LHD	←	←
Energy gain, Q	∞	∞	> 20 (*1)
Tritium breeding ratio	> 1.0	←	←
Operation	Steady state	←	←
Thickness of blanket [m]	1.1	1.15	> 0.8
Fusion power [GWth]	1.9	3.0	~ 2
Pitch parameter, γ	1.15	1.25	1.20
Major radius of plasma [m]	14.0	16.0	13.2
Minor radius of plasma [m]	1.73	2.8	1.9
Major radius of coil [m]	14.0	17.3	14.3
Central toroidal field [T]	6.18	4.43	4.8
Maximum field [T]	13.3	13.0	10.6
Coil current density [A/mm^2]	26.6	32.8	25
Stored magnetic energy [GJ]	133	140	70–80
Neutron wall load [MW/m^2]	1.5	1.3	< 2
Weight of magnets [tons]	~16,000	~16,000	~10,000

(*1) Q=∞ (self ignition) is attained by H_H of 1.75 to LHD.

1) IEA/GB/RD(2006)4/2, From ITER to Power Plants - The Roadmap to Fusion Power, available from <www.iea.org/textbase/techno/technologies/fusion/FUSION.PDF>.

2) Sagara A. et al., *Fusion Eng. Des.* **83** (2008) 1690-1695.