§14. Comparative Design Analysis between Helical and Tokamak Reactors

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System analysis of typical three 1 GW-electric power fusion reactors (tokamak (TR), spherical tokamak (ST) and helical (HR) reactors) are carried out using PEC (Physics-Engineering-Cost) system code, and 1.5-D or 2.0-D burning plasma transport simulations are performed using TOTAL (Toroidal Transport Analysis Linkage) code to check steady-state operation with Internal Transport Barrier (ITB) [1, 2].

According to the present burning simulation done by TOTAL code using Bohm / Gyro-Bohm mixed model with ion temperature gradient (ITG) mode and ExB shear flow stabilization, the deep penetration of pellet fueling is required in TR-1 to realize steady-state advanced burning tokamak operation with ITB. In the helical reactor HR, ripple-induced ambipolar electric field is formed in the core, and ITB is realized even in the case of shallow pellet penetration.

Based on the above burning plasma simulation, we defined reference reactor models for TR-1, ST-1 and HR-1 (Table 1). According to the system assessment carried out by the PEC system code, the advantage of high-beta tokamak reactors in COE and the advantage of the compact spherical tokamaks in life-cycle CO_2 emission reduction are clarified in the economical and environmental analyses (Fig.1). In comparison with other electric power plants, life-cycle CO_2 emission reduction can be achieved in fusion reactors to the level of fission reactors. The EPR of fusion reactors is same as or higher than those of other power systems including fission reactors.

1) Yamazaki, K., Uemura, U., Oishi, T., Garcia, J., Arimoto, H., Shoji, T., 22nd IAEA Fusion Energy Conference (Geneva, Switzerland 2008/10/13-18)
2) Oishi, T., Yamazaki, K., Arimoto, H., Shoji, T., *"Analysis of Fueling in Torus Plasmas for Fusion Power Plant Using Integrated Equilibrium-Transport Simulation Code TOTAL"* Plasma Science Symposium PSS-2009 (Nagoya Univ., Nagoya, Feb. 2-4, 2009)
3) Uemura, U., Yamazaki, K., Arimoto, H., T., Shoji, T., Transactions of the Atomic Energy Society of Japan. **8** (2009) 34 [in Japanese].
4) Uemura, U., Yamazaki, K., Arimoto, H., Oishi, T., Shoji, T., *"Environmental and economical assessment of various fusion reactors by the calculation of CO2 emission amount"* The 18th International Toki Conference (ITC18) on Development of Physics and Technology of Stellarator/Heliotrons en route to DEMO (Toki, 9-12 December, 2008) P1-40

Table 1. Typical reference reactor design parameters (asterisk (*) denotes input parameters of PEC code)

Parameters	Tokamak	ST	Helical
	TR-1	**ST-1**	**HR-1**
R_p / a_p*	**3.06**	**1.62**	**5.7**
R_p /< a_p>*	**2.50**	**0.87**	**(7.8)**
T_0 [keV] *	**30**	**30**	**20**
<β>[%] *	**(5.3)**	**(22.6)**	**5**
β_N*	**4**	**6**	**-**
ellipticity κ*	**2.0**	**3.5**	**2.0**
triangurality δ*	**0.5**	**0.5**	**-**
B_{max} [T] *	**13 (SC)**	**7.4 (NC)**	**13 (SC)**
Electric Power[GW] *	**1.0**		
F_{wall} [MWYr/m^2] *	**20**		
Thermal Efficiency (%)	**50**		
Plant Availability (%)*	**75**		
Operation Period (Yr) *	**30**		
R_p [m]	**5.97**	**4.00**	**14.0**
a_p [m]	**1.69**	**2.46**	**-**
<a_p> [m]	**2.39**	**4.62**	**2.1**
<n_e> [10^{20}m^{-3}]	**1.43**	**1.02**	**0.97**
$n_{e,crit}$	**1.50**	**1.20**	**1.17**
B [T]	**6.03**	**2.46**	**4.16**
I_p [MA]	**13.4**	**22.9**	**-**
f_{BS} [%]	**49**	**95**	**-**
τ_E [s]	**1.63**	**2.26**	**3.8**
H_H-factor	**1.31**	**1.67**	**-**
ISS improvement factor	**-**	**-**	**5.01**
P_{fusion} [GW]	**2.62**	**3.21**	**1.87**
P_α [GW]	**0.52**	**0.64**	**0.38**
P_{CD}[GW]	**0.12**	**0.01**	**-**
$L_{neutron}$ [MW/m^2]	**3.11**	**3.87**	**0.89**
Blanket Thickness [m]	**0.85**	**0.90**	**0.69**
Shield Thickness [m]	**0.36**	**0.39**	**0.30**
Wall Lifetime (Yr)	**4.6**	**3.7**	**16.0**

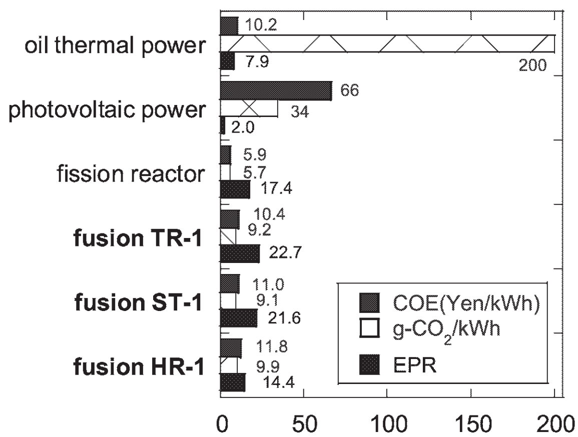

Fig. 1. Comparisons among fusion reactors and other electric power plants with respect to cost of electricity (COE) , CO_2 emission and energy payback ratio (EPR).