§5. Evaluation of Energy Payback Ratio (EPR) of Tokamak Reactors

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For the development of economic and environment-friendly fusion power plants, plasma simulation and system assessment have been performed[1)-3)]. Especially Spherical Tokamak (ST) reactor is expected to be a high-beta compact and economic system in comparison with conventional Tokamak Reactor (TR) designs.

Up to now, a lot of literatures on steady-stare tokamak reactors were published starting from STARFIRE design and leading to a series of ARIES designs in US and SSTR design in Japan. Especially, ARIES-ST as a normal conducting ST design, and VECTOR and Slim-CS as LART (Low Aspect Ratio Tokamak) designs were proposed. The COE, CO2 and EPR assessments have been carried out by several authors on standard tokamak reactors using general reactor system design codes not by detailed specified design analyses. Especially we included spherical tokamak reactor, helical reactor and inertial confinement reactor models in addition to tokamak designs, and COE, CO2 and EPR were evaluated totally. Here, the analyses are focused on ST designs.

Aspect-ratio and ellipticity dependences of COE are shown in Fig.4 for low-aspect-ratio ST with NC coil system and standard TR with SC coil system. The strong aspect-ratio dependence on COE in ST-NC reactors is shown here different from that of TR-SC design.

Related to global warming, green-house gas emissions relevant to energy productions are serious problems. The life-cycle CO_2 emission amount per output electric power from fusion reactor is evaluated in Fig.1. In the previous analysis, the ST high-beta reactor is supposed favorable in CO_2 emission reduction because rather compact and simple normal conducting coil system is adopted. In the present analysis, the life-cycle CO_2 emission for ST is larger than the TR design, since the assumed beta value is more stringent than the previous work.

The energy efficiency has been evaluated using Energy Payback Ratio, or Energy Profit Ratio (EPR) defined by the ratio of net energy output to energy input including energy related to material production, machine construction, operation, fuel, and decommissioning. Typical energy intensity used here is from input-output table[(9)]. The Fusion Island (F.I.) energy investment of ST-1A,B is smaller than that of TR-1, as shown in Table 2. However, Balance of Power (BOP) energy investment of ST-1A,B is larger than that of TR-1, due to large thermal output power in ST-1A,B. The EPR of TR-1 is slightly higher than that of ST-1A depending on the assumption of normalized beta scaling laws.

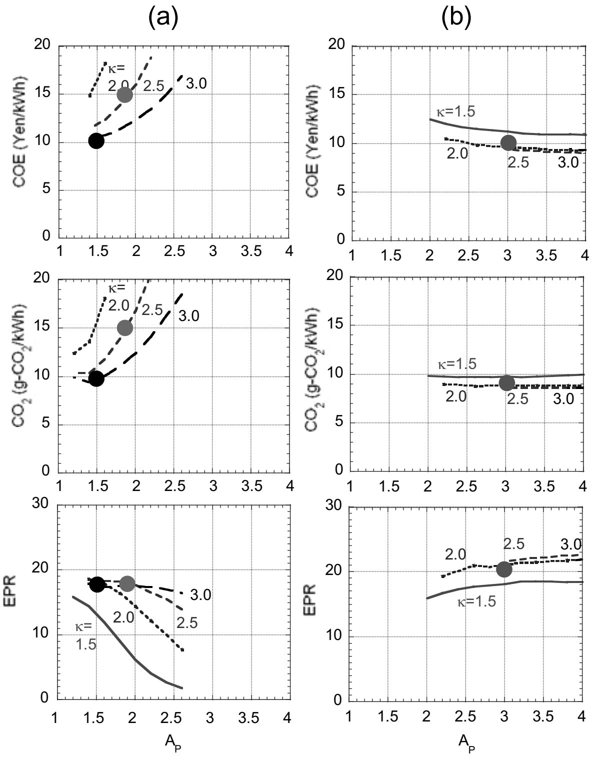

Fig.1. Cost of electricity (COE), CO_2 emission rate and energy payback ratio (EPR) for (a) ST and (b) TR designs as functions of plasma aspect ratio A_p and ellipticity κ. Solid circles denote three reference designs; ST-1A(black), ST-1B(green) and TR-1(red).

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2) K. Yamazaki, T. Oishi and K. Mori, Nucl. Fusion **51** (2011) 103004 (6pp)
3) K. Mori, K. Yamazaki, T. Oishi, H. Arimoto and T. Shoji, Plasma and Fusion Research **6** (2011) 2405126