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Economic Analysis of Tokamak and Spherical Tokamak Advanced Fuel Fusion Reactors
トカマク型及び球状トカマク型先進燃料核融合炉の経済性評価

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D-^{3}He fusion reactor has very low neutron wall load and D-D fusion reactor has abundant fuel resources, compared with D-T reactor. Not only engineering issues but also economic assessments are important in order to achieve these advanced fuel fusion reactors as commercial plants. We calculated and compared COEs of D-T, D-^{3}He and catalyzed D-D fusion reactors. The assessment results show that D-^{3}He and D-D reactors require high beta confinement system and high plasma temperature, in order to obtain COE of these reactors as low as that of D-T reactor.

1. Introduction

D-T fusion reactor would be the first commercial reactor, because D-T reaction has relatively high reaction rate at low plasma temperature. However, about 80 percents of the power of the D-T reactor is from 14.1MeV neutrons. These neutrons activate the reactor wall, and the D-T reactor needs replacement of wall and other components every few years. In addition, the D-T reactor needs radioactive substance (tritium) breeding and storage system. Then, D-^{3}He and D-D reactions are expected as next-generation advanced fusion reactions; because D-^{3}He reaction generates no neutron and D-D reaction has abundant fuel resource. To achieve a commercial fusion reactor,, it is important to check economics of these reactors as well as technical issues to be resolved. In this study, we estimate the costs of D-T and advanced fuel fusion plants and compared with each other.

2. Analysis Procedures

We calculate cost of electricity (COE) of fusion reactors using PEC (Physics-Engineering-Cost) system code [1]. PEC code calculates plasma parameters and engineering designs of fusion reactors to satisfy target output electric power and ignition margin.

3. Reactor model

We estimate three types of fuel cycle, D-T, D-^{3}He and catalyzed D-D, and two types of confinement system; Tokamak Reactor (TR) and Spherical Tokamak reactor (ST). Combining them, we estimate five types of reactor system, TR D-T, TR D-^{3}He, TR cat D-D, ST D-T and ST D-^{3}He. The cat D-D reactor system recycles T and ^{3}He produced by D-D reaction, and extracts energy of D-T and D-^{3}He reaction.

Blanket model is Flibe/FS like FFHR [2] and D-^{3}He is assumed no blanket system like ARIES-3

Table I. Reference cases of reactors

Confinement system	TR			ST	
Fuel cycle	D-T	D-^{3}He	cat D-D	D-T	D-^{3}He
Net electric power P_{enet} (GW)	1.00	1.00	1.00	1.00	1.00
Normalized beta β_N [a]	4	8	8	8	8
Aspect ratio A [a]	3.53	3.53	3.53	1.62	1.62
Maximum field B_{max} (T) [a]	13	13	13	8.75	13
Central ion temperature T_i (0) (KeV) [a]	30	70	70	30	70
Plasma major radius R_p (m)	6.40	8.57	9.05	4.00	6.63
Toroidal field B_t (T)	6.15	7.81	7.60	2.34	3.30
Fusion power (GW)	3.49	2.74	2.83	4.71	2.67
Neutron power (GW)	2.79	0.07	1.33	3.76	0.06
Power density (MW/m^3)	4.66	1.52	1.34	3.22	0.40
Neutron wall load (MW/m^2)	3.62	0.05	0.88	5.08	0.03

[a] Input parameters

[3]. Features of ST are low aspect ratio and no inner blanket. The coil of ST D-T reactor is assumed normal conducting for central post coil, but the coil of ST D-^{3}He is assumed super-conducting.

We fixed the following input parameters; target net electric power is 1000MW, plant availability is 75%, operating period is 30 year and target ignition margin is 1.01. Reference cases of reactors are shown Table.I.

4. Results

Dependence of COE on normalized beta value (β_N) is shown in Fig.1. High β_N improves plasma confinement performance; as a result, required plasma volume decreases. Therefore, the size of a reactor becomes small and COE falls. D-^{3}He and cat D-D have a lower output power density, and require larger plasma volume, compared with D-T plasma volume.

D-^{3}He and cat D-D reactors need high β_N and high ion temperature (=70keV) in order to obtain almost same COE of TR D-T (at β_N=4~5). However, conventional Tokamak system seems to be difficult to achieve high β_N value (>5). Because ST can have high β_N, ST is expected to be a confinement system suitable for D-^{3}He and cat D-D reactors.

Figure 2 shows COE breakdown of reference cases. Since D-^{3}He and cat D-D requires large plasma major radius R_p, the cost concerning construction becomes large and, the capital cost becomes large. Because of neutron damage to the first walls, D-T reactor requires frequent replacement of blanket within plant lifetime. In contrast, D-^{3}He reactor has very low neutron wall load, and no need to replace blanket. Thereby, D-^{3}He reactor has almost no replacement cost. Cat D-D has relatively low neutron wall load; therefore,

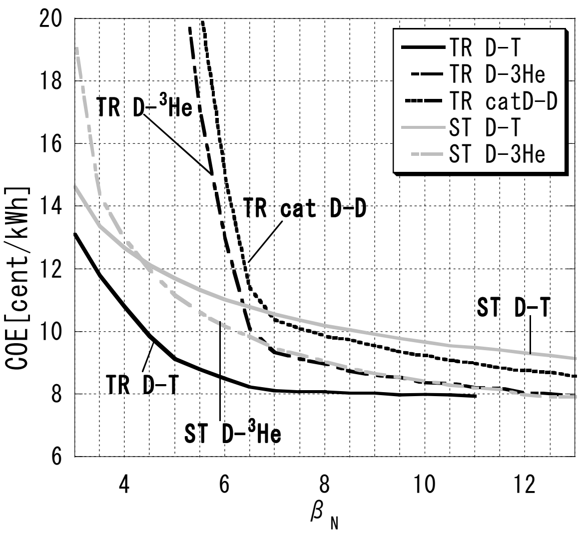

Fig.1 Dependence of COE on β_N

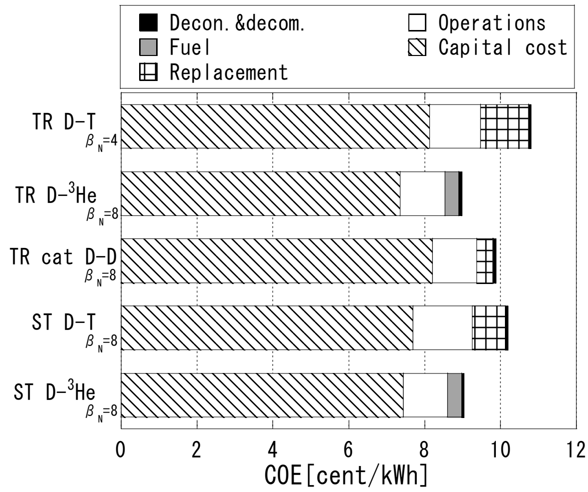

Fig.2 COE breakdown of reference cases

replacement cost is assumed as 1/3 of the replacement costs of D-T. In addition, D-^{3}He and cat D-D reactor can omit tritium breeding system. However, ^{3}He gas is very precious resource on the earth. In this study, we assumed that the scenario taken out ^{3}He from the moon's surface [4], and it was calculated by 200$/g.

Assuming high ion temperature (=70keV) and high β_N (>7), COE of advanced fuel fusion reactors are expected to be similar to that of D-T reactor.

References

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