Assessment of Spherical Tokamak Reactors Comparing with Other Fusion Power Plants

Kozo YAMAZAKI[1], Tetsutarou OISHI[1], Kanae BAN[1],
Takuya KONDOH[1], Hideki ARIMOTO[1], Yoshio NAGAYAMA[2]

[1]Nagoya Univ., Chikusa-ku, Nagoya 464-8603, Japan
[2] National Institute for Fusion Science, Toki, Gifu 509-5292, Japan

OUTLINE

1. **Introduction**
2. **Burning Simulation using "TOTAL"**
   (Toroidal Transport Analysis Linkage)
3. **Life-Cycle Assessment using "PEC"**
   (Plasma, Engineering and Cost)
   Cost, CO2, Energy Payback etc.
4. **Summary**

1. Introduction

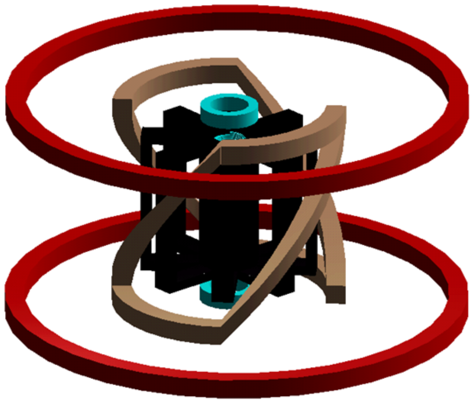
ST-Relevant Research (1/3)

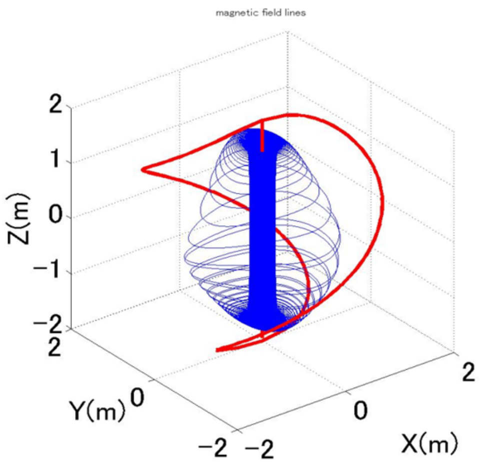
TOKASTAR (miniature hybrid experiment)

29-3-2 (Oral) M. Hasegawa et al.,
"Low aspect ratio plasma in tokamak-helical hybrid device TOKASTAR-2".

28-3P-5 H. Ozeki et al.,
"Confinement Analysis of Spherical Tokamak-Stellarator Hybrid Configurations".

TOKASTAR





ST-Relevant Research (2/3)

TOTAL code (burning plasma simulation)

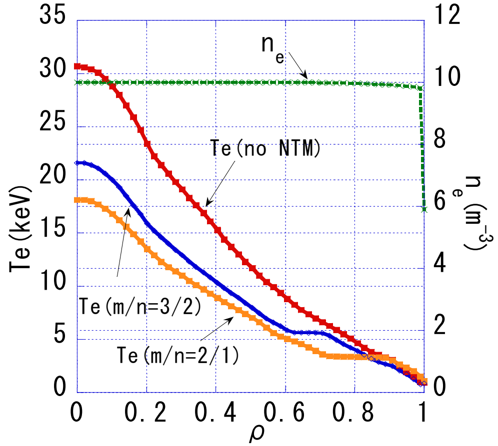
28-3P-18 D. Kurita et al.,

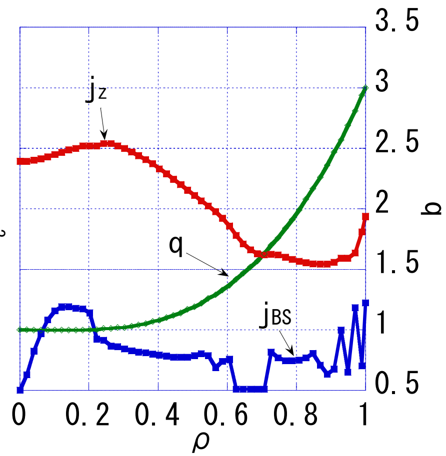
"Neoclassical Tearing Mode Analysis in Spherical Tokamak Burning Plasmas".

28-3P-20 T. Oishi et al.,

"Integrated Analysis on the Current Profile and the Operational Scenario of D-^{3}He Spherical Tokamak Reactors".

Toroidal Transport Analysis Linkage





ST-Relevant Research (3/3)

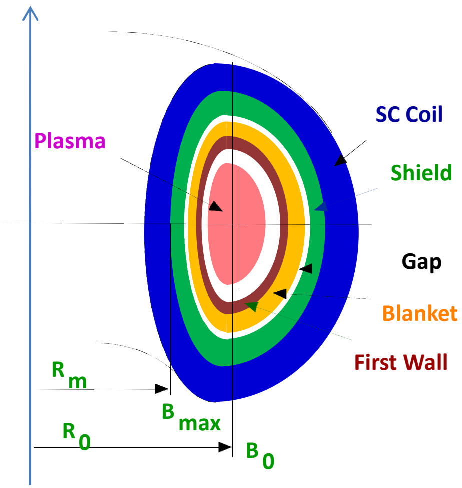
PEC (reactor system analysis)

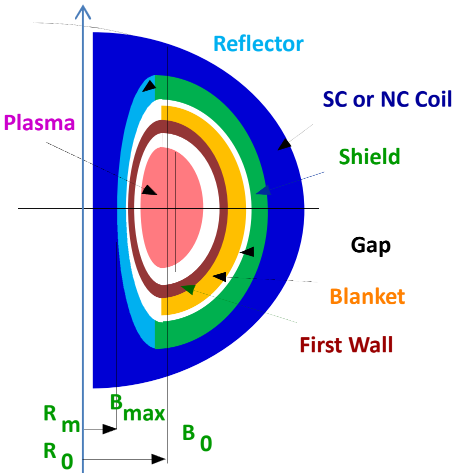
30-2-1 (Oral) K. Yamazaki et al.,
"Assessment of Spherical Tokamak Reactors Comparing with Other Fusion Power Plants".

30-2-2 (Oral) K. Ban et al.,
"Life Cycle Assessment for Energy Payback of Spherical Tokamak Reactors".

PEC

Physics, Engineering, Cost





2. Burning Plasma Simulation: Using “TOTAL” Code

History

Start (~1980)

Tokamak (2^{nd} stability)

Nuclear Fusion Vol.25 (1985) 1543.

Helical Analysis

Nuclear Fusion Vol.32 (1992) 633.

Burning Simulation (Tokamak & Helical)

Nuclear Fusion Vol.49 (2009) 055017.

Based on JT-60U ITB operation and LHD e-ITB data.

Main Feature of "TOTAL" is to perform both Tokamak and Helical Analyses

Core Plasma

Equilibrium Tokamak: :2D APOLLO
Helical: 3D VMEC, DESCUR, NEWBOZ

Transport Tokamak : TRANS、GLF23、NCLASS
Helical : HTRANS, GIOTA

Stability NTM, Sawtooth, Ballooning mode

Edge transport H-mode edge transport

Impurity IMPDYN (rate equation) Tungsten
ADPAC （various cross-section）

Fueling NGS (neutral gas shielding) model
mass relocation model
NBI HFREYA, FIFPC
Puffing AURORA

Divertor density control, two-point divertor

TOTAL

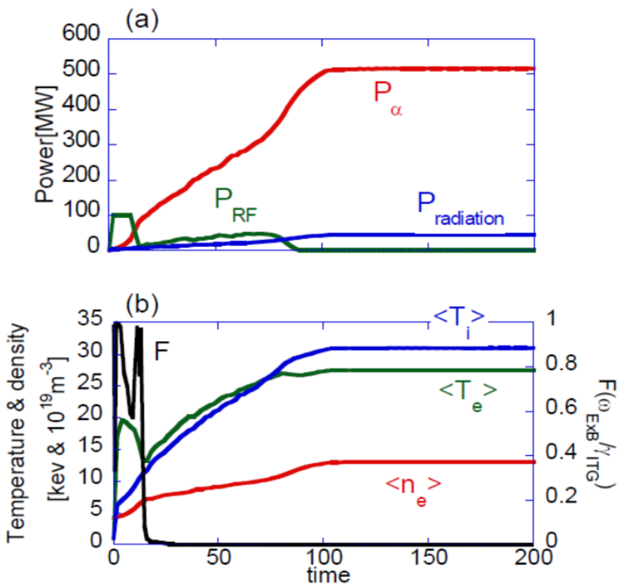
Toroidal Transport Analysis Linkage

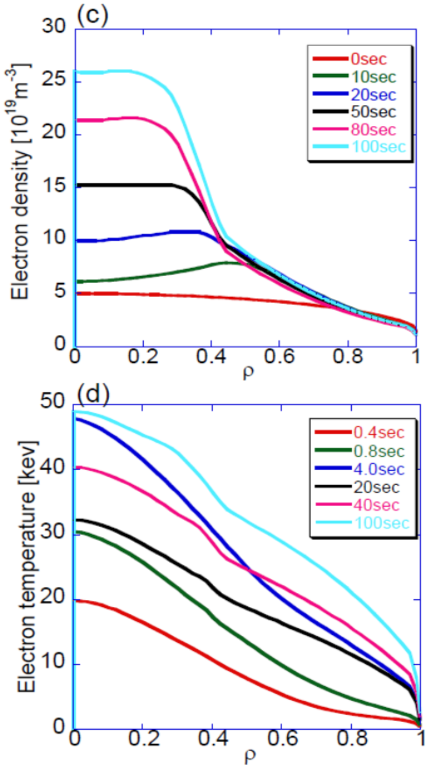
World Integrated Modeling

TOTAL-T,-H(J)
TOPICS(J)
TASK(J)
CRONOS(EU)
TRANSP(US)
ASTRA(RU)

Time evolution of reversed-shear-mode operation with continuous HFS pellet injection

1GWe Tokamak Reactor TR-1





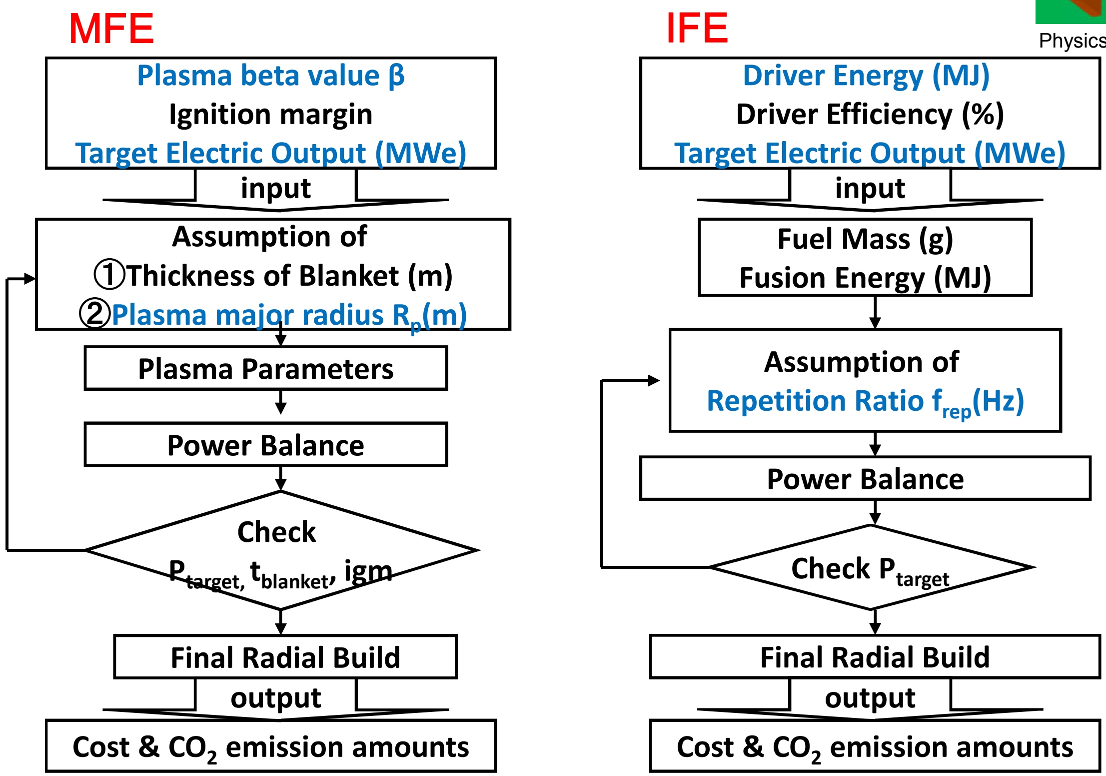
3. System Code Assessment: using "PEC" Code

History

Tokamak Ignition Design (~1980)
Helical Design Assessment
IAEA-Montreal (1996)
Helical & Tokamak Assessment
IAEA-Lyon (2002)
Cost/CO_2/EPR Analysis in MFE reactors
IAEA-Geneva (2008)
Cost/CO_2/EPR Analysis in MFE & IFE reactors
IAEA-Daejeon (2010)

Main Feature is Comparative Assessment of Various Reactors

Physics, Engineering, Cost

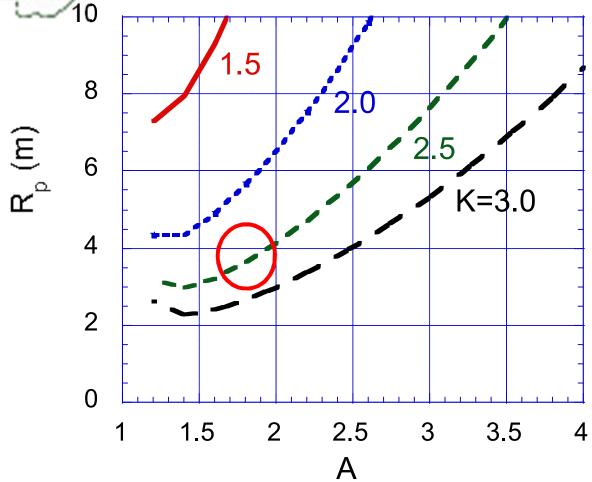


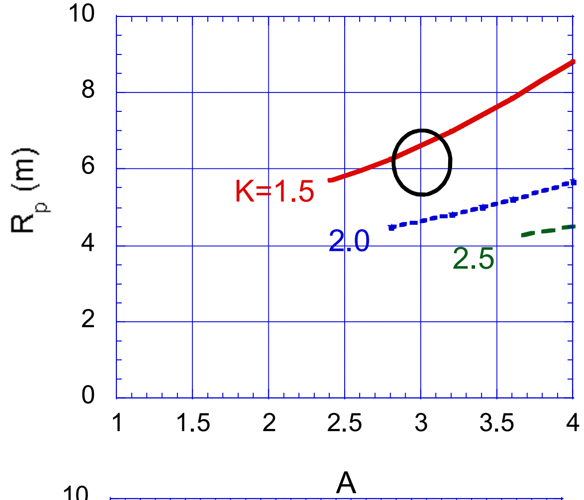
Reference Designs

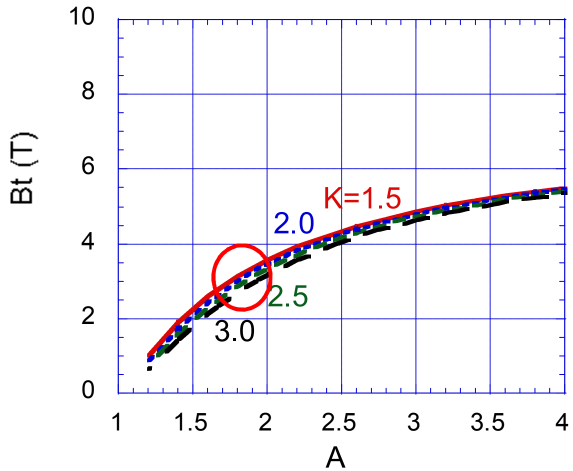
Type of Reactors *input	Tokamak TR (DT)	ST ST (DT)	Helical HR (DT)	Tokamak TR (F-F)	Tokamak TR (D^3He)
R_p / a_p*	3.06	1.62	5.7	3.06	3.06
R_p / $\langle a_p \rangle$*	2.50	0.87	(7.8)	2.50	2.50
T_0 [keV] *	30	30	20	30	80
$\langle\beta\rangle$[%] *	(5.3)	(22.6)	5	(5.3)	(7.9)
β_N*	4	6	-	4	10
ellipticity κ*	2.0	3.5	2.0	2.0	2.0
triangularity δ*	0.5	0.5	-	0.5	0.5
B_{max} [T] *	13 (SC)	7.4 (NC)	13 (SC)	13 (SC)	20 (SC)
R_p [m]	5.97	4.00	14.0	5.06	7.85
a_p [m]	1.69	2.46	-	1.43	2.56
$\langle a_p \rangle$ [m]	2.39	4.62	2.1	2.02	3.14
$\langle n_e \rangle$ [$10^{20}m^{-3}$]	1.43	1.02	0.97	0.87	2.63
$n_{e,crit}$	1.50	1.20	1.17	1.38	1.34
B [T]	6.03	2.46	4.16	4.71	10.92
I_p [MA]	13.4	22.9	-	8.89	27.7
f_{BS} [%]	49	95	-	49	95
τ_E [s]	1.63	2.26	3.8	2.72	8.27
H_H-factor	1.31	1.67	-	2.32	4.25
ISS H-factor	-	-	5.01	-	-
P_{fusion} [GW]	2.62	3.21	1.87	0.59	2.74
P_α [GW]	0.52	0.64	0.38	0.12	-
P_{CD}[GW]	0.12	0.01	-	0.13	0.19
$L_{neutron}$ [MW/m^2]	3.11	3.87	0.89	0.97	0.97
Blanket thickness [m]	0.85	0.90	0.69	0.90	0
Shield Thickness [m]	0.36	0.39	0.30	0.39	0.6
Wall Lifetime (Yr)	4.6	3.7	16.0	11.0	13.3

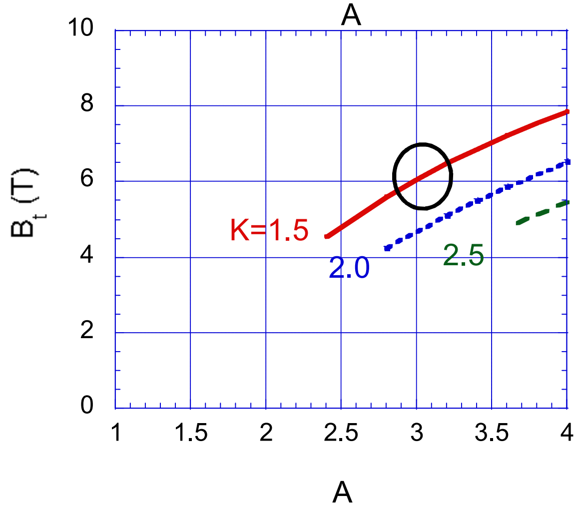
ST(NC coil)

TR(SC coil)

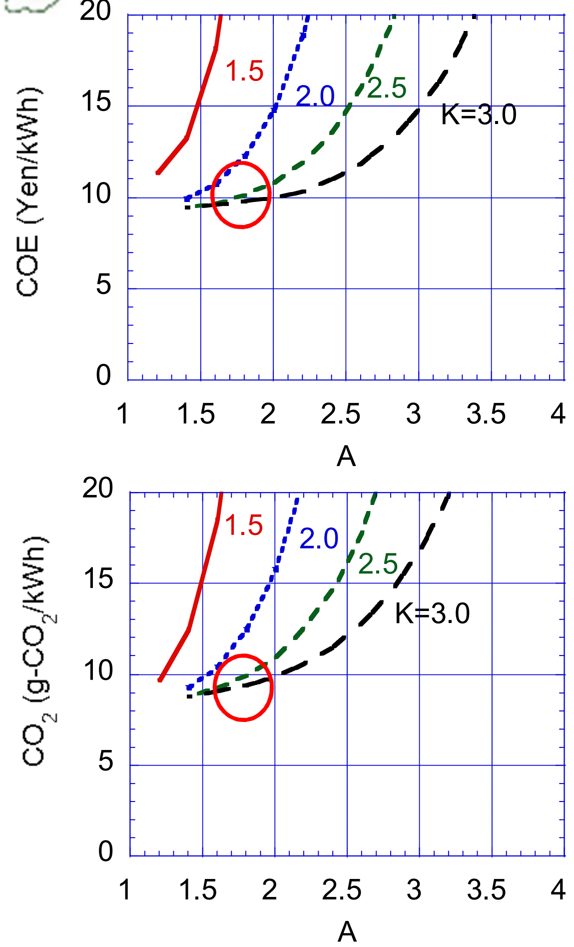




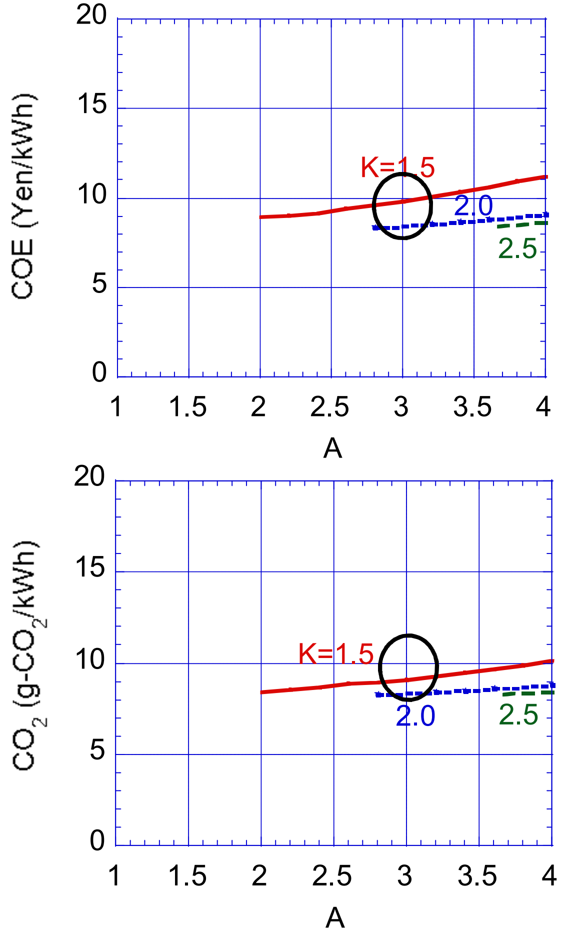


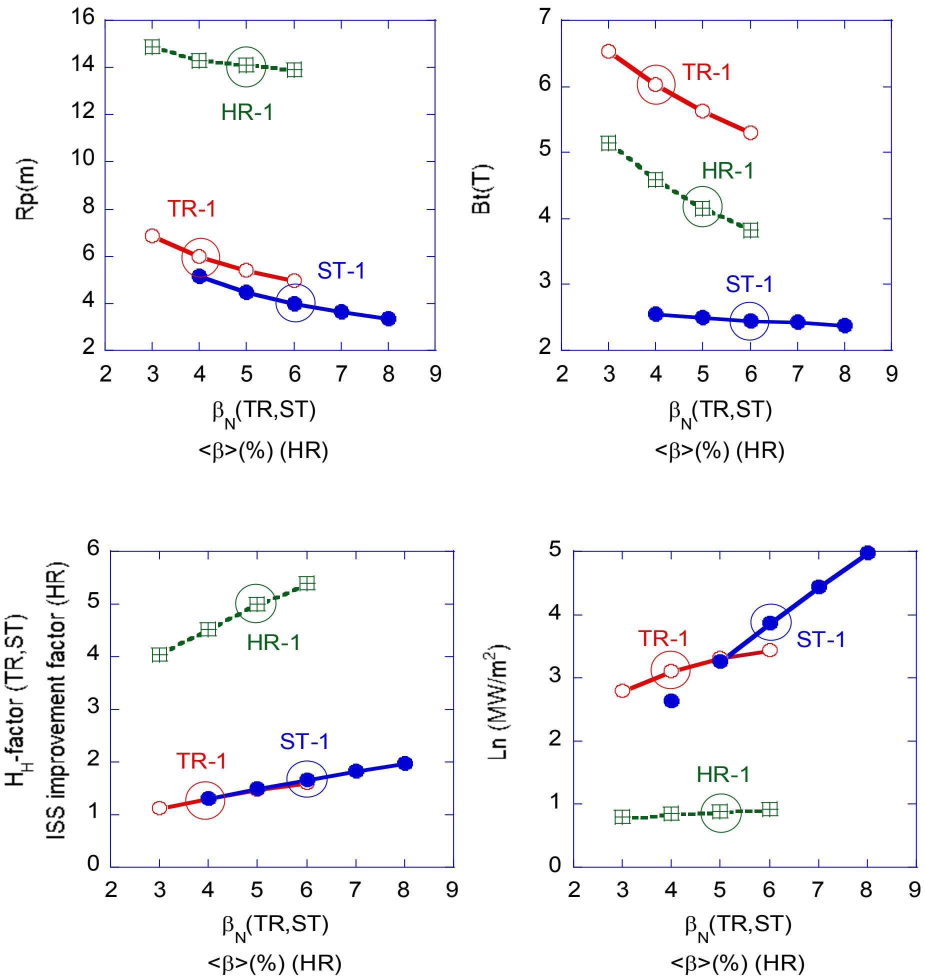


ST(NC coil)



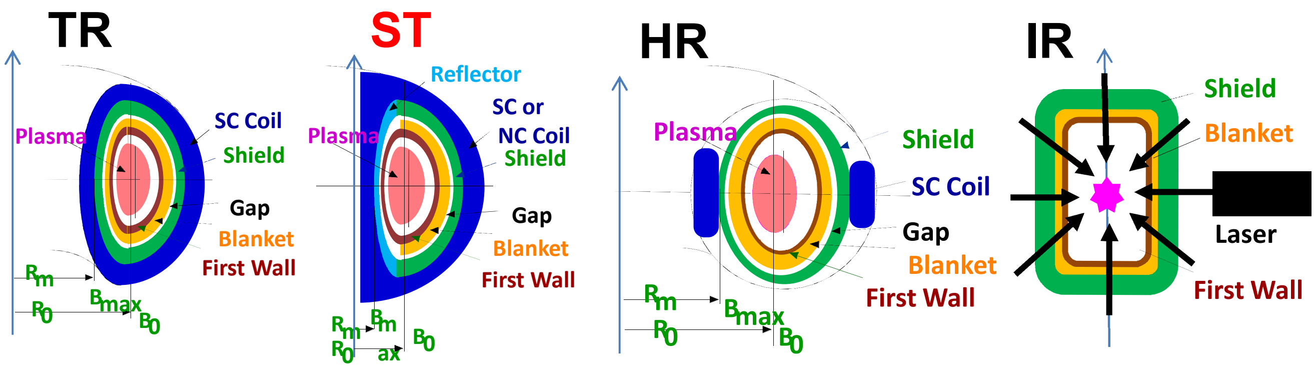
TR(SC coil)





Rp(m)
HR-1
TR-1
ST-1
β_N(TR,ST)
<β>(%) (HR)
Bt(T)
TR-1
HR-1
ST-1
β_N(TR,ST)
<β>(%) (HR)
H_H-factor (TR,ST)
ISS improvement factor (HR)
HR-1
TR-1
ST-1
β_N(TR,ST)
<β>(%) (HR)
Ln (MW/m^2)
TR-1
ST-1
HR-1
β_N(TR,ST)
<β>(%) (HR)

Multiple Approaches Have Similar COE,CO2, EPR



Tokamak Reactor
9.8 ¢/kWh
9.2 g-CO_2/kWh
EPR ~ 19.3

Spherical Torus
10.4 ¢/kWh
9.1 g-CO_2/kWh
EPR ~ 18.1

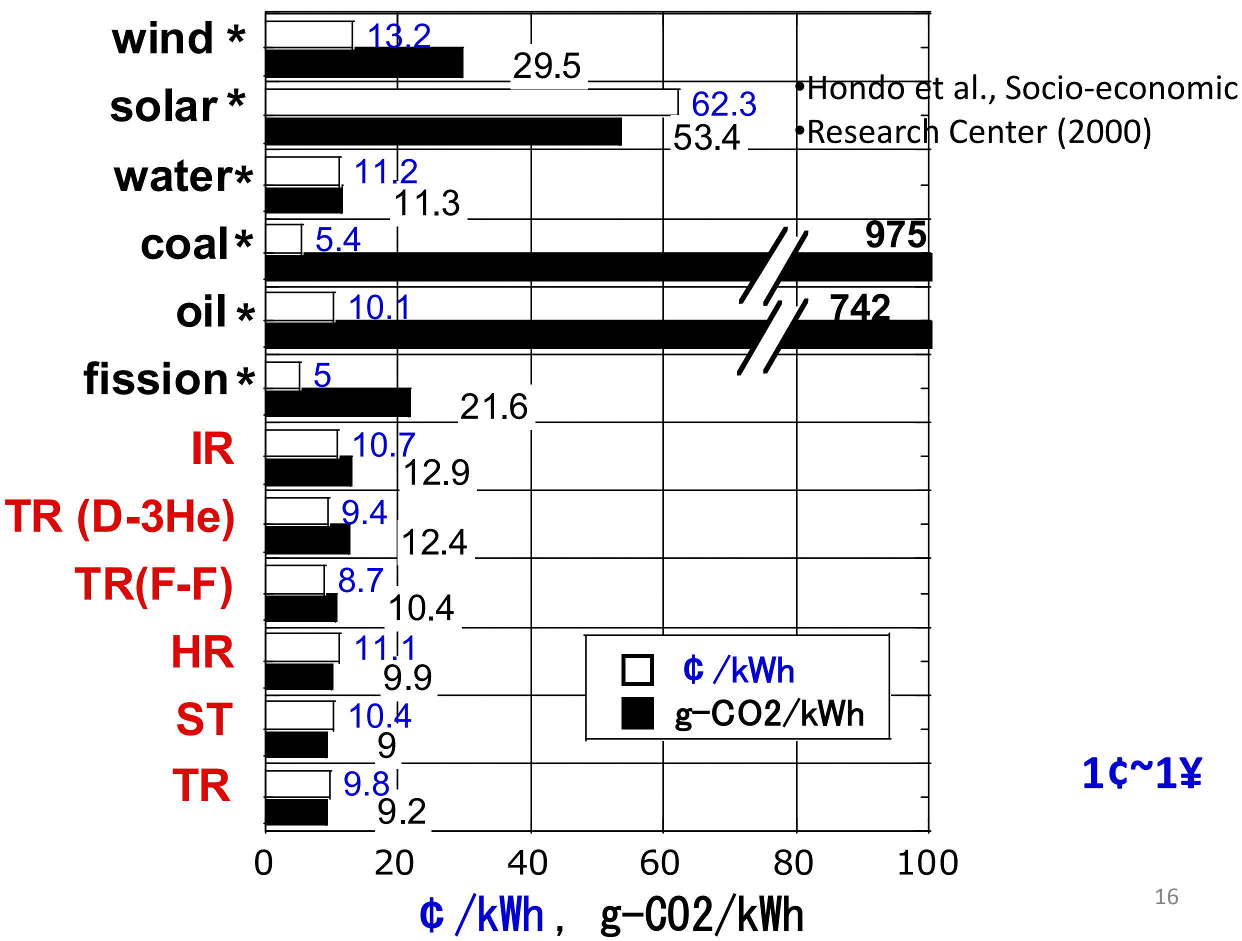
Helical Reactor
11.1 ¢/kWh
9.9 g-CO_2/kWh
EPR ~ 12.1

Inertial Reactor
10.7 ¢/kWh
12.9 g-CO_2/kWh
EPR ~ 26.6

1GWe Plant

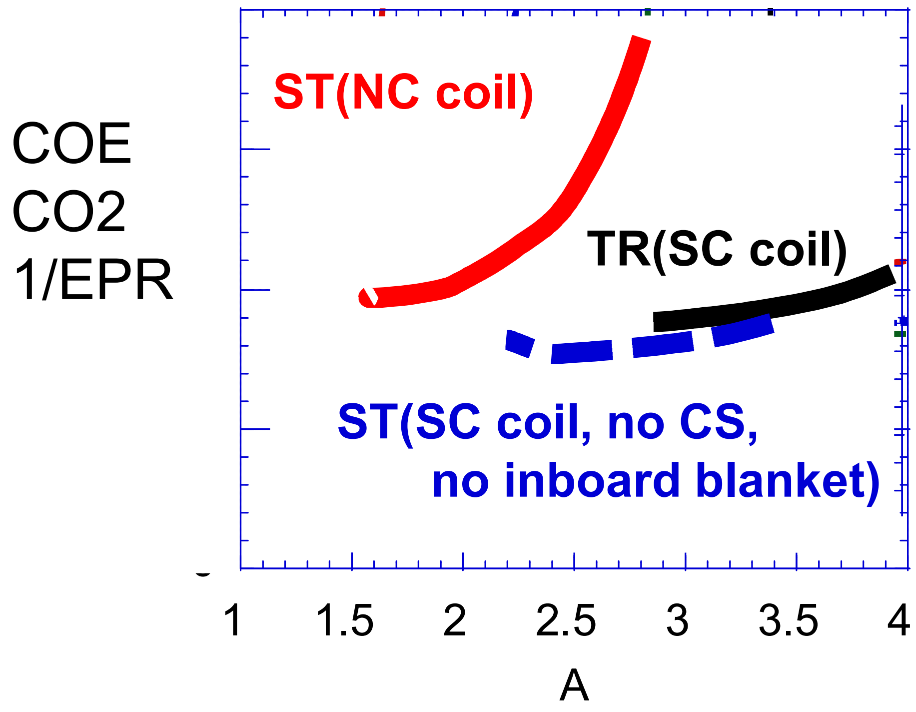
1¢~1¥

Comparisons with Other Power Plants



1¢~1¥

ST (with SC coil) is better than ST(NC coil) and TR (SC coil).



4. Summary

- Comparative system studies have been done for several magnetic fusion energy reactors (TR, ST, HR) and inertial fusion energy reactor (IR) .
- The advantages of TR in COE and of ST in lifetime CO_2 emission reduction are clarified.
- The optimized ST system with SC coils and without inboard blanket is suggested.
- Comparing fusion reactors with other electric power generation systems, we confirmed that fusion reactor, especially ST, does not emits large CO_2 amount.