Fusion power control considering plant operation

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Motivation

- What kind of plant operation is required for a future tokamak fusion power plant considering the future grid system？
- How does each component (reactor core, blanket system, turbine system) contribute for the plant operation？
- How can be the fusion power controlled in the plant operation？

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Introduction

- Tokamak Fusion Power Plant is supposed to play a role as a base supply power plant .
- Accordingly, fusion power is basically controlled to be constant, but is there no need to change the fusion power during an operation indeed?

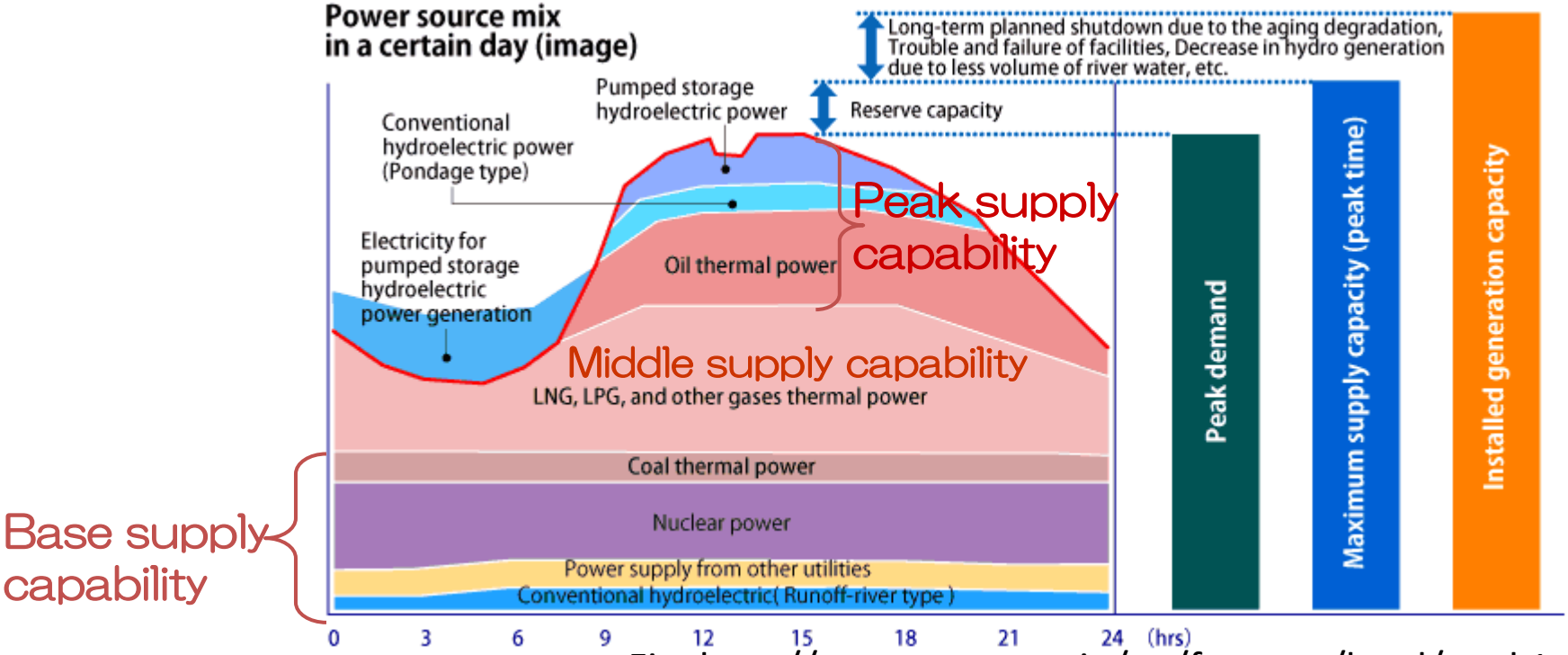

Fig: http://www.tepco.co.jp/en/forecast/html/peak1-e.html

Background: Plant operation mode

- There are several operation modes for a power station.
- It is preferable to handle as many operation modes as possible for the grid system control.

Operation mode	Role
Rating operation	• To keep the rating electric power output
Load following operation	• To match the electric demand curve
Load frequency control	• To keep the rating frequency 50Hz or 60Hz
Standalone (house load operation)	• Stand by operation during a grid accident
Ramp up and down operation	• To start and finish the plant operation
Commissioning operation	• To verify all of the components for the power plant

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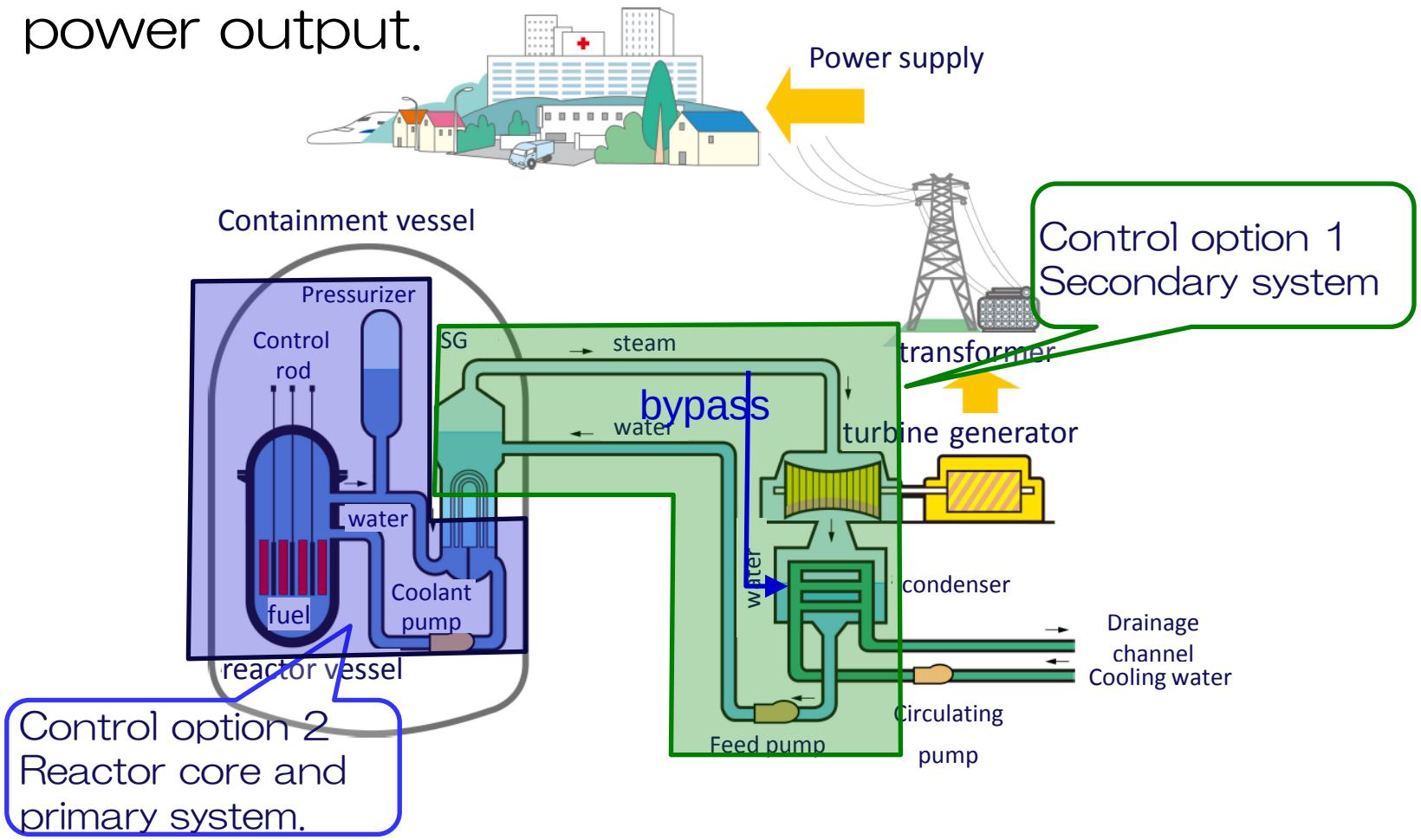
Background : Emerging issue on the grid

- Renewable power (solar and wind) is increasing , and this power source can not be precisely foreseen and controlled by the electric power company (Loss of controllability for the grid system).
- For example, a minimum demand in a year is usually in the early morning on January 2nd, but in this year that unexpectedly moved to afternoon on the same day, probably because of solar power generation at home.
- In future, a large stiff power station like a nuclear power will be less welcome in the grid system.
- Fusion power plant has to be developed under the consideration for the future grid system. Of course, more flexible control capability, more valuable for the grid system.
- At least, controllability of the fusion power plant in the grid system has to be understood carefully.

Control option of power plant system

- There are two options for control of the electric power output.



Essential operation mode for power plant

Operation mode	Role	Priority for power plant
Rating operation	• To keep the rating power output • Fusion power is kept to be constant.	Necessary
Load following operation	• To match the electric demand	Preferable
Load frequency control	• To keep the rating frequency 50Hz or 60Hz	Preferable
Standalone (house load operation)	• Stand by operation during a grid accident	Preferable
Ramp up and down operation	• To start and finish the operation • Fusion power has to be changed	Necessary
Commissioning operation	• To verify all of the components for the power plant • Wide range of fusion power required to test the system	Necessary

Control parameters for fusion power

- Fusion power can be controlled by density, tritium ratio, impurity(helium) and plasma current.

$$P_f \approx n_D n_T \langle \sigma v \rangle_{DT} Q_{DT} V_{plasma}$$

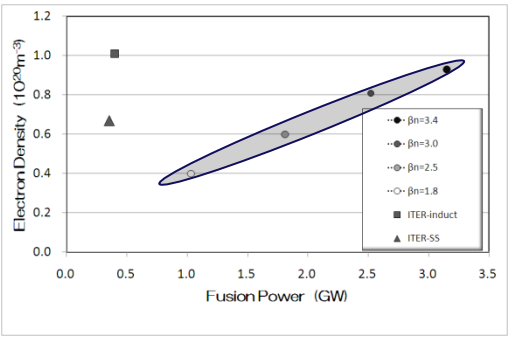
$$= \left[-\left(\frac{n_T}{n_{DT}} - \frac{1}{2} \right)^2 + \frac{1}{4} \right] \left(n_i - n_{imp} \right)^2 \langle \sigma v \rangle_{DT} Q_{DT} V_{plasma}$$

$$\propto \beta_N^2 \left(I_p / a \right)^2 B_t^2$$

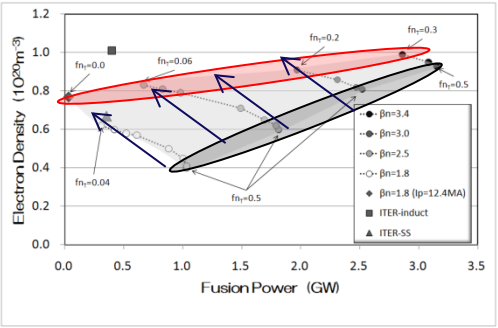
- To discuss the control method of the fusion power, an operational space as for the fusion power is preliminarily investigated under the consistent condition on MHD stability and current drive property.

Analysis step

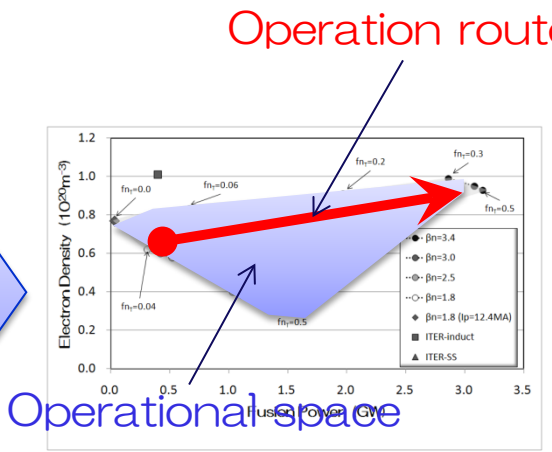
- Density control is considered as a reference control method.
- Step1: several operation points for each fusion power are analyzed based on the reference control method, considering MHD and current drive.
- Step 2: Expansion of operational space by other control method is investigated.
- Step 3: The control route has to be confirmed by the integrated transport code.(future issue)



①Reference operation points



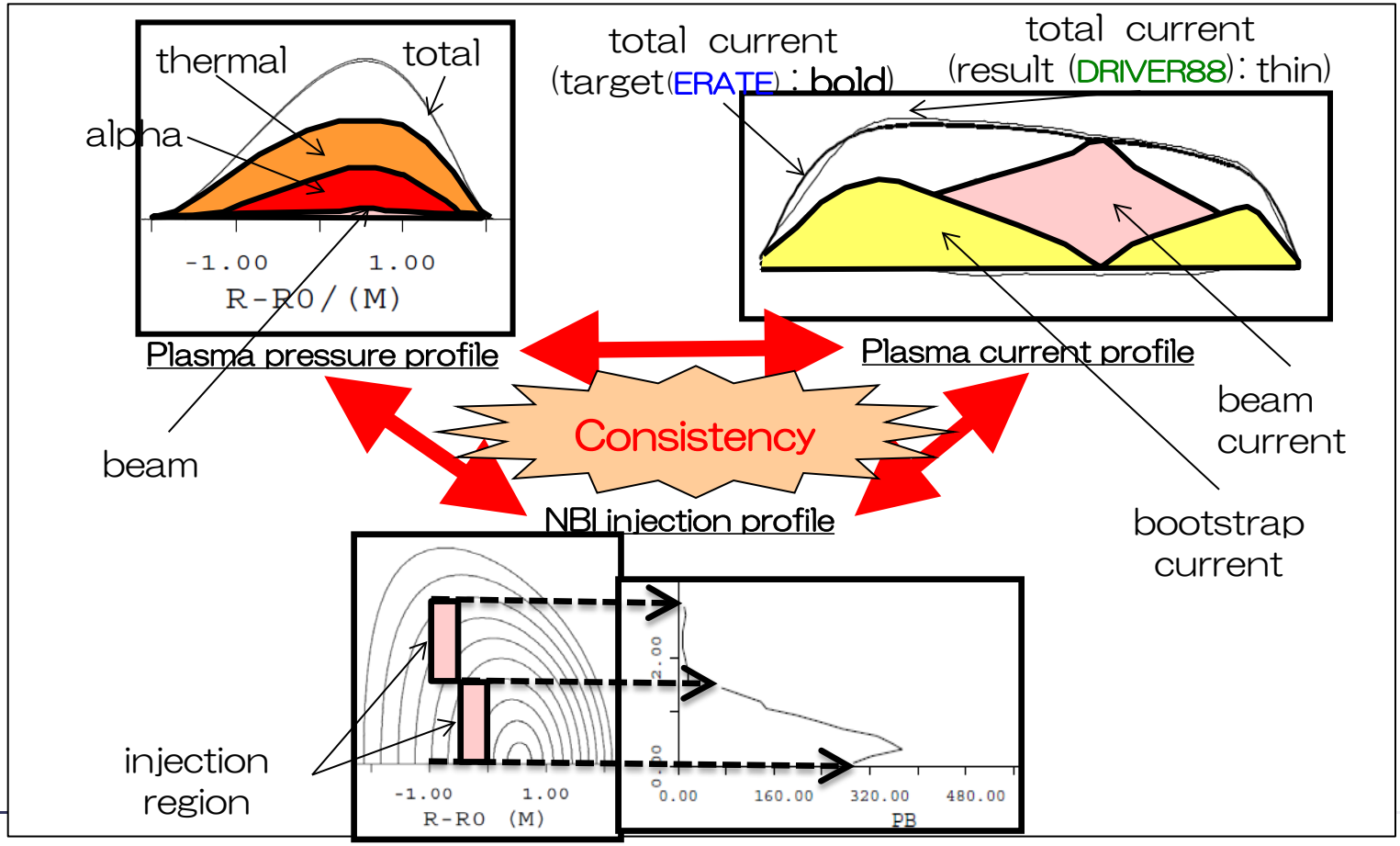
②Expansion operation space



③Confirmation of operation route

MHD & current drive analysis

- Consistency among profiles of pressure, plasma current, NBI deposition is analyzed by EQLAUS/ERATO and DRIVER88 from the view point of MHD stability(low n kink, high n ballooning, Mercia criterion), NBI current drive property



Operation points for Demo-CREST

- Reference operation points for β_N=1.8-3.3 by density control for Demo-CREST are shown.

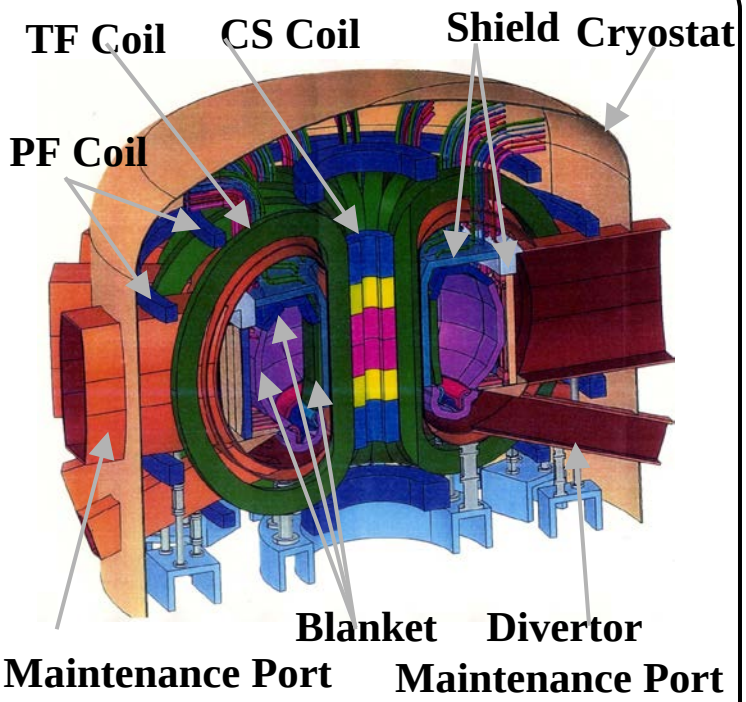


Figure :Bird's-eye of Demo-CREST

		OP1	OP2	OP3	OP4	OPRS
R (m) / A		7.25 / 3.4				
q_{min}/q_{95}		-/5.0			-/5.2	3.6 / 6.5
β_N		1.9	2.5	3.0	3.3	4.0
HH		0.96	1.1	1.2	1.2	1.4
fn_{GW}		0.56	0.73	0.80	1.02	1.31
P_b (MW)		188	190	185	191	106
P_f (MW)		1260	1940	2460	2840	2970
P_{enet} (MWe)	Basic Blanket (30%)	30	230	390	490	-
	Advanced Blanket(40%)	-	-	-	850	1090

Tritium ratio control

- The smaller tritium ratio enables the smaller fusion power. Considering the operation points of β_N=3.0, the fusion power can be reduced from 2.5 GW by f_T=0.5 to 1.3 GW by f_T=0.1.
- Fig.(b) shows the tritium ratio control requires the high confinement.
- This control method enables the wide operational space of the fusion power with keeping high plasma density. This property is preferable for the divertor plasma operation.

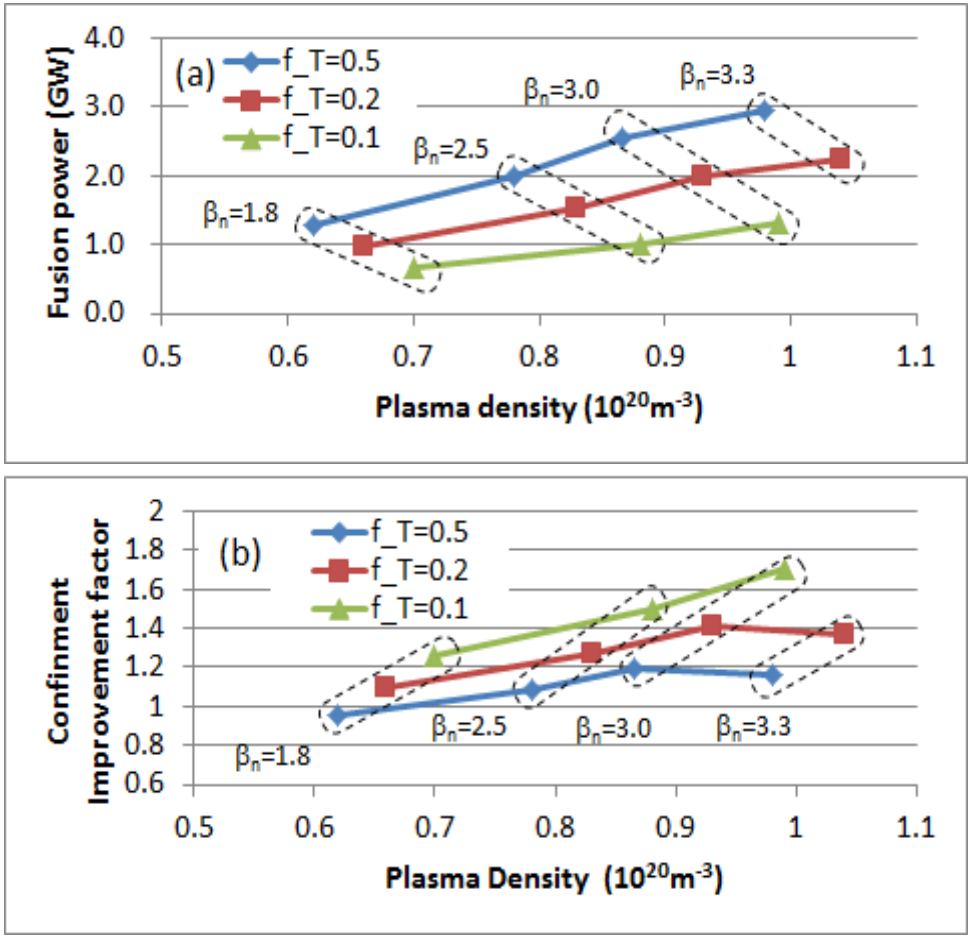


Fig. Operation space of fusion power by tritium ratio control and its HH actor

Helium ratio control

- Operational space is investigated under the conditions of the helium ratio f_{He}=0.04-f_{He}=0.3.
- In case of f_{He}=0.3, the high density operation point of β_N=3.3 cannot keep the profile consistency as for the MHD stability and the current tailoring.
- A engineering issue for this control method is increase of current drive power, due to the $\langle n_e \rangle$ increase.
- Of course, physical issue as for controllability is He transport property. If the smooth He exhaust would not be easy, recovery of the fusion power is the next issue.

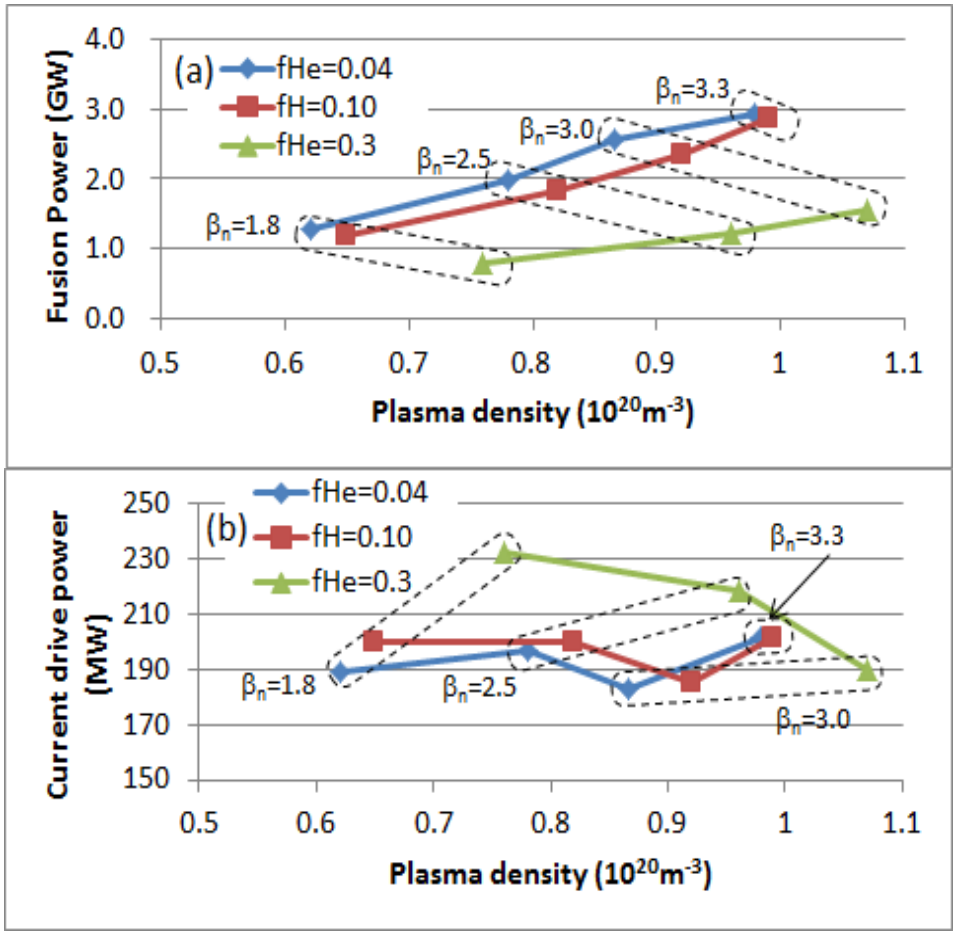


Fig. Operation space of fusion power by Helium ratio control and required Pcd

Plasma current control

- Under the same β_N and B_T condition, Ip decrease means the pressure drop.
- When we choose the operation point, we have roughly two options: a constant temperature and a constant density. Usually, the constant temperature is preferable, because that condition is thermally stable and a good efficiency for the current drive.
- Accordingly, a Ip decrease with a high temperature is initially examined. Figs. show the operational space for the Ip decrease (increase of surface q value from 5.0 to 6.0) and the required confinement improvement factor.
- Basically, a small Ip requires a high HH up to 1.4.

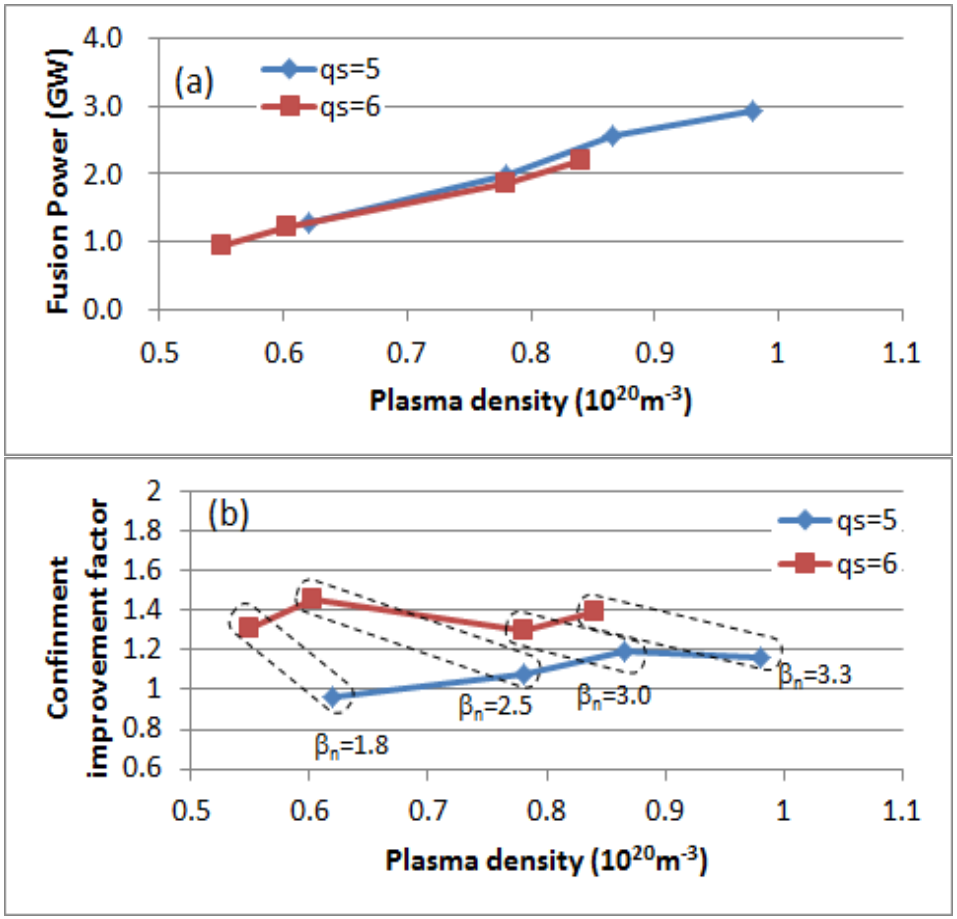


Fig. Operation space of fusion power by Ip control and its HH factor

Summary

- First, requirement of fusion power control is assessed considering plant operation mode.
- Among operation modes, the rating operation, the ramp-up/down one, and the commissioning one are essential for the plant operation. Especially, ramp-up/down operation and the commissioning operation require wide operation flexibility for the fusion power.
- Operation space as for the fusion power by several control methods (density control, tritium ratio control, He seeding control, plasma current control) is also analyzed, and its requirement of critical plasma parameter and engineering parameter is investigated using plasma parameters of a conceptual demonstration reactor concept Demo-CREST.
- It is found that tritium ratio control and plasma current control require high HH, He seeding control does large current drive power.
- The operation route to change the fusion power is remained to be confirmed by the integrated transport code.

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