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Inevitable Measurement Parameters for the Control of Fusion DEMO Reactors
原型炉の制御と必須な計測諸量

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The diagnostics in fusion reactors are quite important to control burning plasmas. However, due to the radiation environment and due to the limited access area, we should select the minimum and inevitable diagnostics. In this report, a list of such diagnostics is presented assuming a tokamak type and a helical type reactors. The number of diagnostics is reduced to a reasonable level (10 sets) considering the available access area in DEMO reactors.

1. Introduction

In order to operate fusion reactors safely and efficiently, the plasma should be controlled precisely. For that purpose, various diagnostics have been developed. However, due to technical difficulties, such as the radiation environment, we must select suitable diagnostics or we must develop them. In addition, not to degrade the tritium breeding performance, the available access area for diagnostics is very limited. Therefore, we should find out what are the inevitable diagnostics for fusion power plants, such as DEMO devices. It is expected that the operation scenario is fixed in DEMO devices and the behavior of the plasma is known. Therefore, the diagnostics will be used to identify and control the state of the plasma.

In this report, we list up inevitable diagnostics, assuming a tokamak type and a helical type DEMOs considering those situations mentioned above.

2. List of Diagnostics

Table I shows the list of inevitable diagnostics, which based on the discussion in Ref. [1] and the diagnostics in ITER. Some additional modifications have been made. In the table, parameters to be measured, purposes (i.e. control targets), methods, numbers of measurement points, required accuracies and time resolutions are shown. Hereafter, we describe each item briefly.

Position and shape control of magnetic flux surface is a principal control for tokamaks, while they are determined mainly by external coils in helical systems. Thus, various magnetic measurements are inevitable for tokamaks. Although loops and coils are simple instruments for these purposes, some problems must be solved. One such problem is the drift of time-integrated signals due to radiation induced offsets on the raw signals. The effect becomes unavoidable in the long discharge durations. Therefore, some DC field measurement method (e.g. Hall sensor) should be equipped and used for the calibration of the loops. On the other hand, the role of magnetic measurements in helical devices is not so significant as in tokamaks.

Once the position and the shape are controlled, the plasma should be fuelled and heated to sustain a burning state. The state can be represented by temperature and density, while their responses to the heating source (and the power loss) and the particle source (and the particle exhaust) can be represented by various transport rules such as 0-d energy confinement scalings. The resultant burning state must be monitored and controlled by measuring neutrons. We should also pay attention to various instabilities, such as beta limits, density limits.

In order to minimize the access area of the diagnostics, not only the number of the types of diagnostics, but also the numbers of channels should be minimized. If one can predict the profile, one can reduce the number of channels. In the case of tokamak, where H-mode and/or internal transport barriers are considered to be the inevitable core structures, at least a few spatial measurement points are required to identify the profile. On the other hand, in the helical reactor design FFHR-d1, profiles are a function of a base profile and fewer parameters are required to identify the profile. The resultant numbers of spatial points become much lower than those in ITER, assuming such predictability.

Since tokamak reactors rely on bootstrap current, pressure profile should be speculated from limited information. In helical systems, edge density is important to avoid radiation collapse, while in tokamaks, H-mode pedestal pressure is important to control ELMs and fast time-response diagnostics are require to monitor the ELMs.

Divertor plasmas should be measured from the following two points of view. The divertor plasma is a particle (D, T, He and impurities) exhaust and/or influx route to the core plasma. In addition, detachment and radiation should be controlled to reduce the heat flux to the divertor plates.

3. Discussion and Conclusion

Besides the radiation environment, available access area for diagnostics at the plasma facing surface is very limited to preserve the tritium breeding area. The available area is thought to be less than 10 m^2, while the area in ITER is about 50 m^2. Excluding the magnetic measurements, the number of diagnostics in Tab. I is 10 sets (marked with * in the table) for tokamak, while that in ITER is about 40. Therefore, the number in Tab. I is reasonable from the view point of the area. However, the number of spatial points for each diagnostics is reduced by one-two orders of magnitude. Thus, it is quite challenging to identify and control the plasma with such little information, and we need experiences and a predictable model for burning plasmas.

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References

[1] Program Committee of Technical Study on the Diagnostics for Control of the Fusion DEMO Reactors: NIFS-Memo-68 (2014).

Table I. List of diagnostics

Measured parameters	Purpose (Conrol/Measurement Target)	Diagnostics	No. (Units, Lines, Points)/Accuracy/Δt	
			Tokamak	Helical
Plasma current	Equilibrium	Rogowski	1/1%/1ms	1/10%/1s
Plasma current	VDE detection	Rogowski	1/30%/0.1ms	-
Poloidal flux	Position, Shape, Equilibrium,	Flux loop, Saddle loop	100P/ 0.7%/10ms	20/?/0.1ms
Local B	Instability dection (e.g. RWM)	Pickup coil	20/?/0.001-1ms	20/?/0.001-1ms
Zax	VDE detection	Flux loop	6P/30%/0.1ms	-
βp	Equilibrium	Diagmag. Loop	1P/0.3%/10ms	-
DC magnetic field	Calibration of magnetic measurements	Hall sensor	200P/0.5%/100s	-
Line averaged density*	Fuelling, Pressure profile (Bootstrap current)	Tangential or radial Interferometer (and/or polarimeter)	2L/1%/10ms	1L/0.1%/10ms
Electron density	Radiation collapse, Detachment	LIDAR Thomson and/or Reflectometer	-	10P/1%/100ms
Electron temperature*	Pressure profile (Bootstrap current)	Edge:Thomson, Center: VUV	2P/5%/100ms	-
Electron temperature	Radiation collapse, Detachment, Mag. Axis	LIDAR Thomson	-	10P+10P/10eV/100 ms
Ion temperature profile*	Pressure profile (Bootstrap current), Aux. heating	Edge:CXRS, Center:Crystal	2P/5%/1s	-
Edge and divortor line emiss. (D, T, W, He, Ar)*	ELM・H-mode trans., Edge D/T ratio, Detachment	Spectrometer	10L/10%/0.1 ms	5L/10%/10ms
Divertor Radiation*	Divertor, Detachment, Impurity	2D-Imag, bolometer	1U/?/1s	-
Divertor particle/heat flux*	Divertor, Detachment	Electrostatic probe? IR-camera?	20/10%/10ms	20/10%/10ms
Line av. Zeff*	Core impurity, Core He	Vis. Spectrometer	1L/20%/1s	1L/20%/1s
EUV radiation/Bremss.	Radiation Collapse	EUV spectrometer?		1/10%/100ms
DT neutron*	Burning state	Neutron (camera)	20L/5-10%/100ms	20L/5-10%/100ms
DD neutron*	Core nD/nT	Neutron spectometer or γ spectrometer?	1L/10%/1s	1L/10%/1s
Total neutron yield*	Plant, Calibration	Micro-fission Chamb./Activation Foil	5P/10%	5P/10%/100ms?