Maintenance method for blanket and final optics of dry wall fast ignition ICF power plant

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Outline

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   * Motivation : Why dry wall is selected?
   * Importance of maintenance
2. Objectives
3. Replacement procedure for Blanket system
   * Large cask type similar to Tokamak case
   * Blanket segmentation and beam line layout
4. Replacement procedure for final optics system
   * Cartridge style module built in the reactor room wall
5. Critical issue
   * Relationship with reactor physics
   * Maintenance period and plant availability
6. Summary

Dilemma of Wall Concept

Dry wall dilemma

- Dry wall enables higher laser repetition rate
- Heat load capacity of the solid wall is much less than that of the liquid metal wall

↓

Chamber size increases

↓

Construction cost increases

Wet wall dilemma

- Liquid metal wall allows a higher heat load pulse.
- Evaporation of liquid metal on the wall deteriorates a vacuum condition in the chamber.

↓

Lower repetition rate of laser pulse (< a few Hz).

↓

Lower fusion output and a higher cost of electricity.

How does Fast Ignition contribute to solve these dilemma ?

Motivation

Fast Ignition, which can decrease the pulse energy, may mitigate such dilemma on the design of ICF reactors

In our present study, we have considered to make the most merit of the fast ignition by

(1) minimizing the single fusion pulse

(2) minimizing the size of solid wall chamber

(3) maximizing the laser repetition rate

New challenging path against the above dilemma.

Key Issue on Dry Wall Concept

Smaller chamber size(5.6m <- first wall heat pulse condition:2J/cm^2)

⇒ Relatively, large neutron and heat wall load

⇒ Shorter life time of structure material and first wall material

*Structure material (Neutron fluence)

pulse energy:40MJ, repetition rate:30Hz,

wall load is about Pn~2.0MW/m^2, about 5 years of blanket life time

*First wall (Blistering and exfoliating effect)

Exfoliation condition:~10^{22}He/m^2. thickness:1.9μm/exfoliation,

W armor exfoliating thickness:

0.3mm/year(annealing effect#) – 5mm/year

#S.B.Gilliam et al., JNM347(2005)289

Final optics device is directly exposed to neutron flux from the reactor core

Blanket and final optics devices are required to replace every several years

Maintenance of blankets and final optics is essential to establish our new fast ignition ICF power plant

Objectives

To show a new possible path of fast ignition-ICF power plant, a Fast Ignition ICF reactor concept with a Dry Wall chamber and a High Repetition Laser (FI-DWHRL concept) is proposed.

In this study, maintenance approach for the FI-DWHRL concept is proposed and its critical issue is discussed.

Two Maintenance Methods

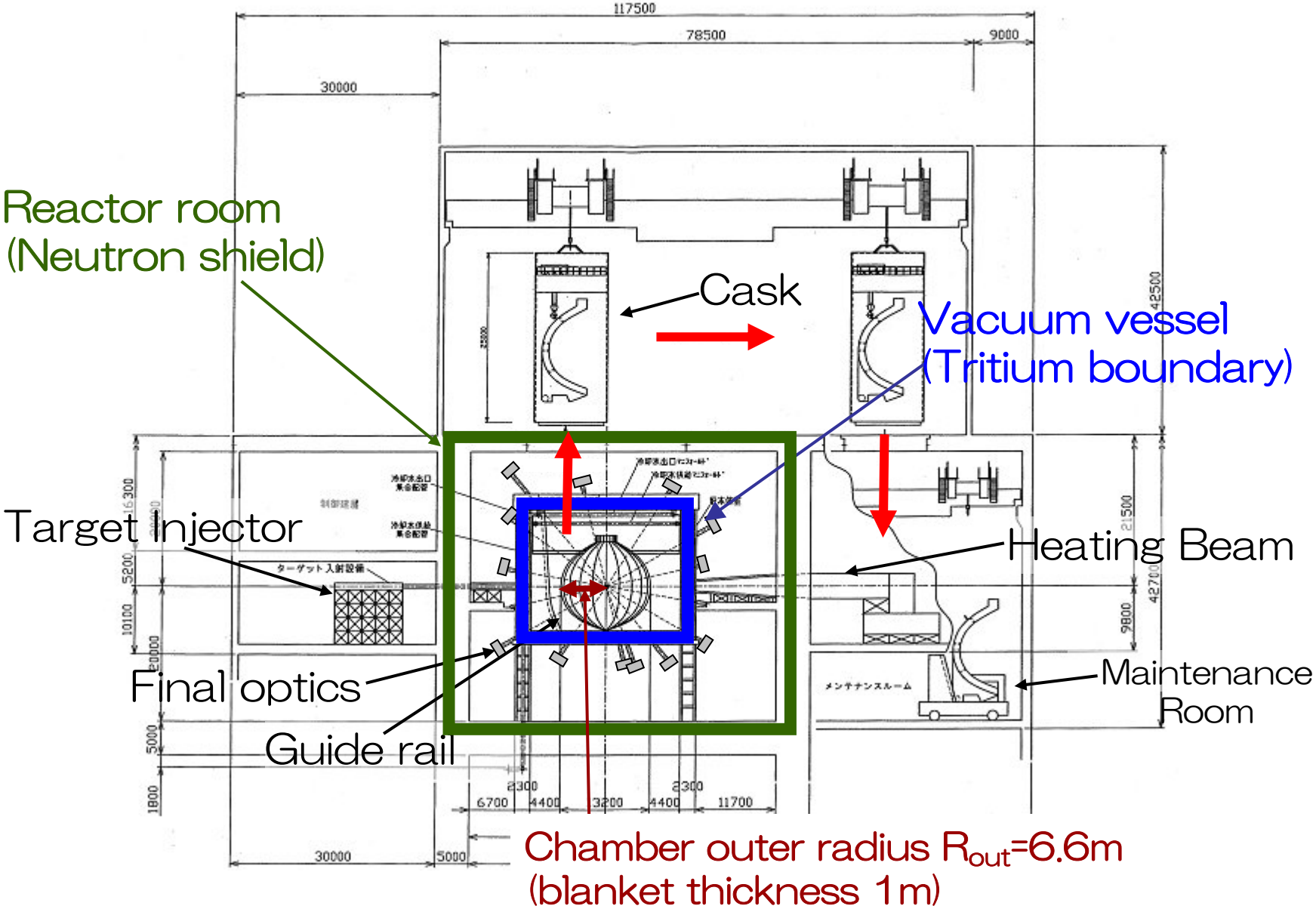
Generally, there are two methods as for the blanket replacement:

- One is to use a remote manipulator arm and a maintenance rail as applied to ITER(in-situ method),
- the other is to use a large cask and a large maintenance port for replacement (large cask method).

From the view point of the plant availability, the latter concept is effective to reduce the time to unfasten, fasten and check the joints of the structure component and the heat transfer system.

Large cask method is applied to this FI-DWHRL concept

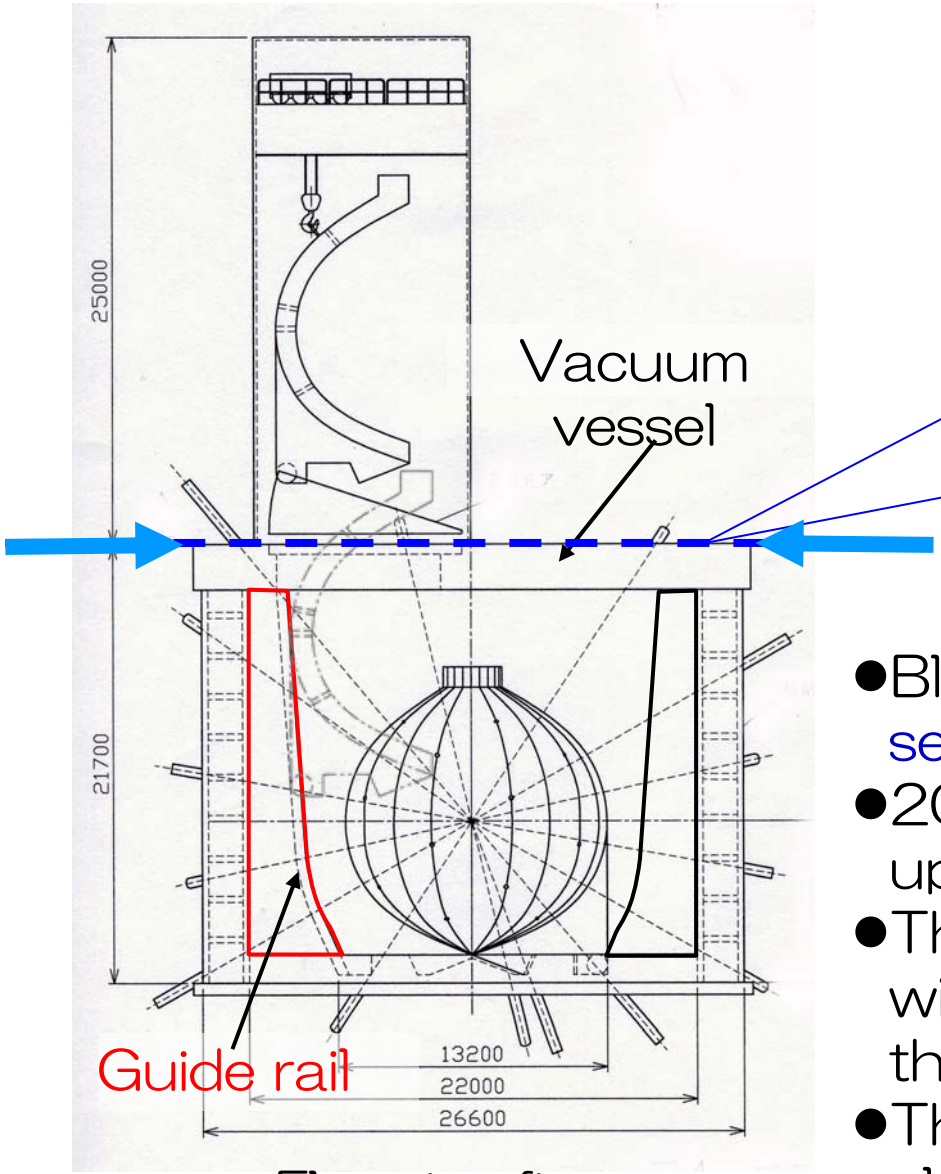
Maintenance schematic diagram



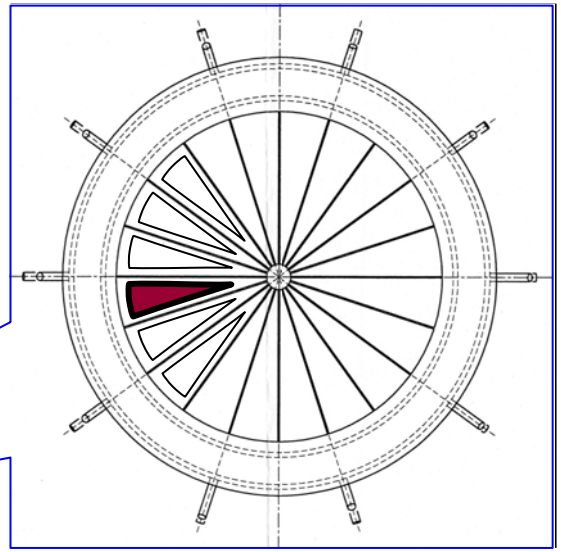
Layout of reactor components

1. The first wall and blanket system is divided into 20 sectors (about 90t/sector) .
2. All compression beam lines go through the division between blanket sectors.
3. Due to the beam injection port, the vacuum vessel is located outside the blanket system. This vacuum vessel also plays a role of the tritium boundary.
4. To keep vacuum state in the vacuum vessel, vacuum ducts for all beam lines are set up outside the vacuum vessel.
5. Those beam ducts are not thick enough to be the neutron shield. Therefore, almost all reactor core components except the final optical device for the heating beam are placed in the reactor room, which plays a role of neutron shield.

Blanket Replacement Method



Elevation figure



Plane figure of vacuum vessel

- Blanket is divided into 20 sectors(90t/sector)
- 20 maintenance ports on the upper side of the vacuum vessel
- The maintenance hatch together with the cask hatch is opened to the inside of the cask
- The blanket module is extracted along the guide rail.

Blanket Replacement Method

1. The Blanket sector is extracted and installed through the upper large port.
2. 20 maintenance ports exist on the upper side of the vacuum vessel.
3. The maintenance hatch together with the cask hatch is opened to the inside of the cask, after the cask door is attached to the port door.
4. Because of the vacuum vessel, 20 blanket sectors do not have to be completely sealed. Therefore each blanket sector is extracted after cutting connections for the heat transfer and tritium recovery system. To avoid the sector's shaking during extracting from the vacuum vessel to the cask, the guide rails are located.
5. Each blanket sector has a joint on its bottom side to stand by itself.

Beam Lines Layout

- Those beam lines correspond to the lines between the center and the vertex and the center of gravity in each surface of the regular icosahedron(20-polyhedron).
- The upper pole beam line is probably an obstacle to the maintenance.

- Laser beam lines more than about 30 were found to improve the laser uniformity for the target compression[1].
- The fast ignition method does not require the good uniformity.

Those facts may enable to remove the upper pole beam line.

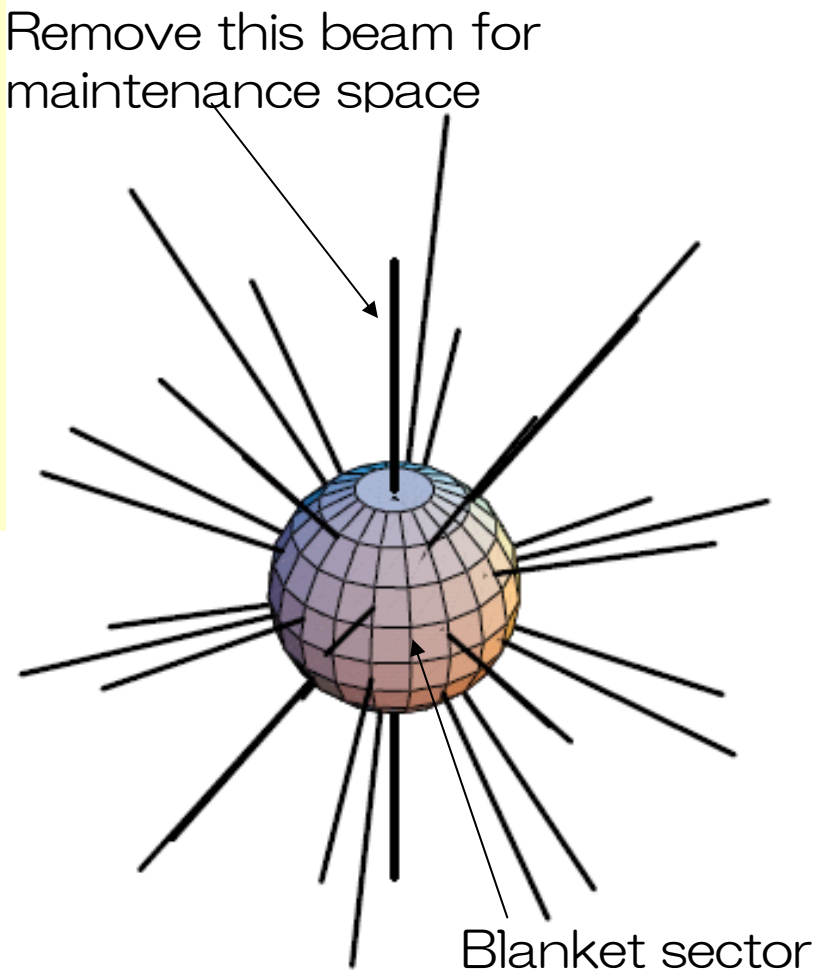


Fig. Schematic drawing of beam lines layout

[1]M.Murakami, et al., J. Appl. Phys. 74, 802(1993)

Location of final optical devices

- The location of final optical devices can be divided into 6 groups(red, blue, green).
- To access the final optical device, 6 access corridors are placed on the reactor room wall.
- All final optical devices for compression beam lines can be replaced through those corridors.

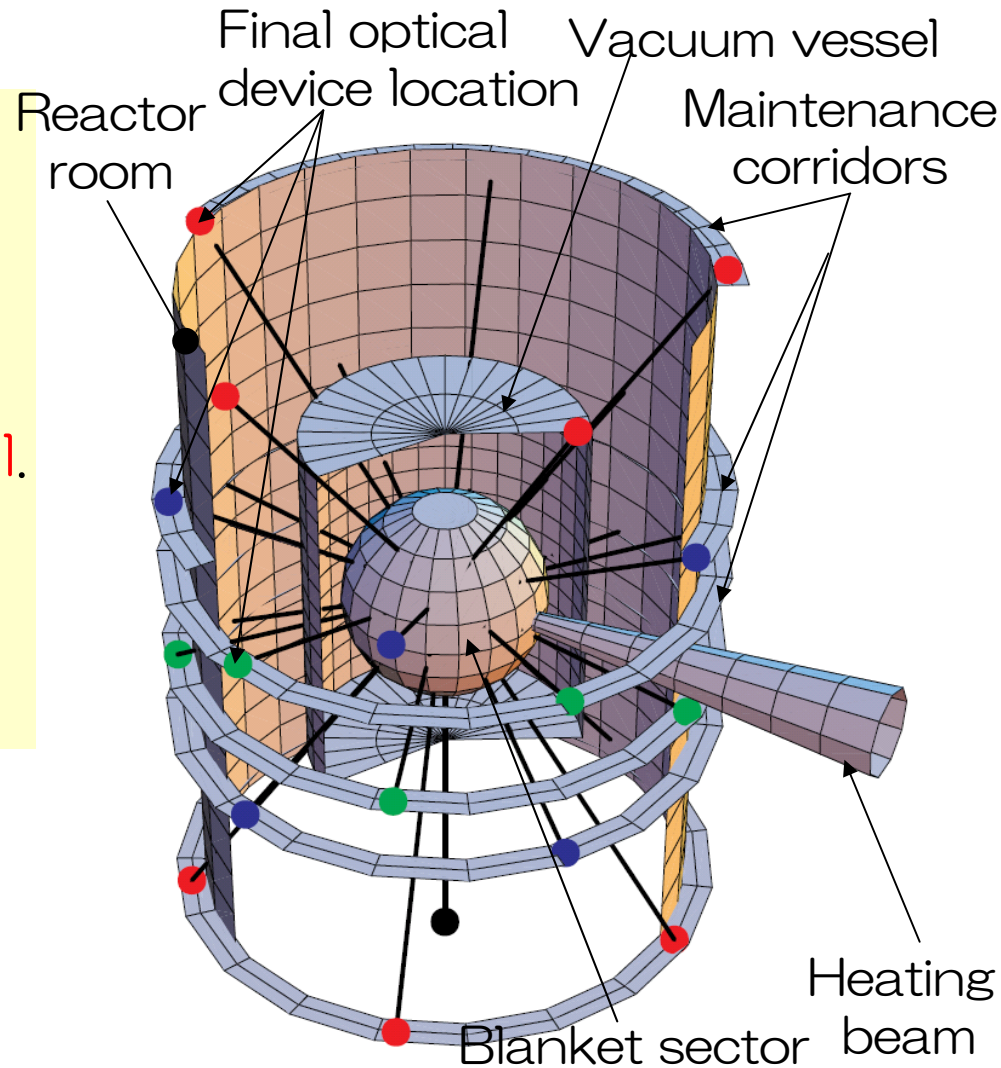
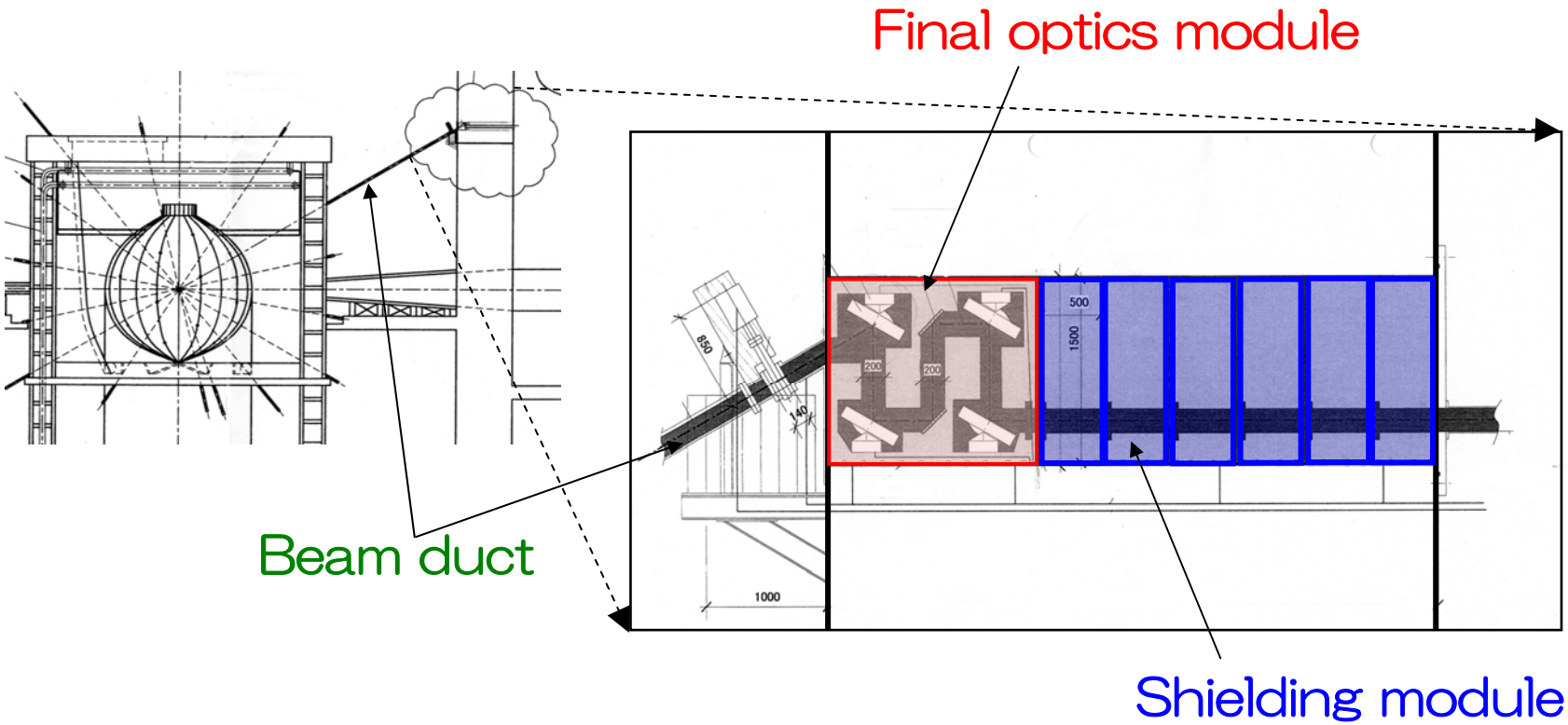


Fig. positions of the final optical position for the compression beams and those maintenance corridor

Preliminary concept of final optics system

Schematic view

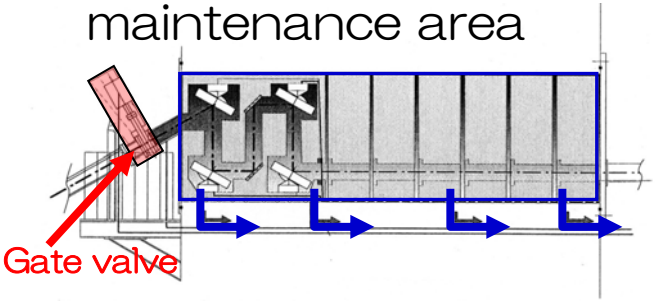


- ◆Build-in style in the wall of the reactor room
- ◆Final optics module and shielding modules
- ◆Several bending points of beam duct for reducing neutron shreaming

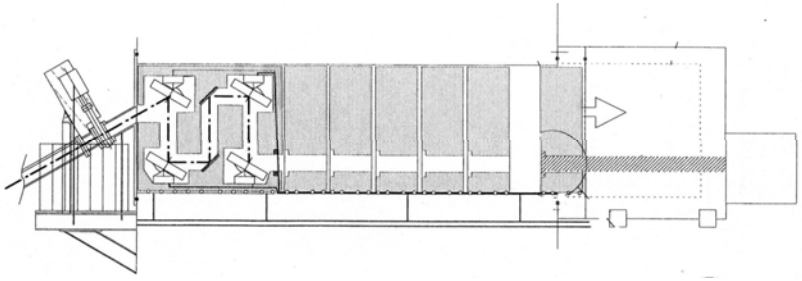
(Beam duct layout in the figure is tentative)

Preliminary replacement procedure

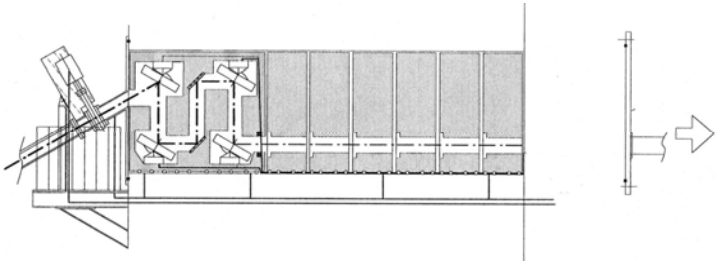
- Gate valve closes
- Exchange atmosphere in the maintenance area



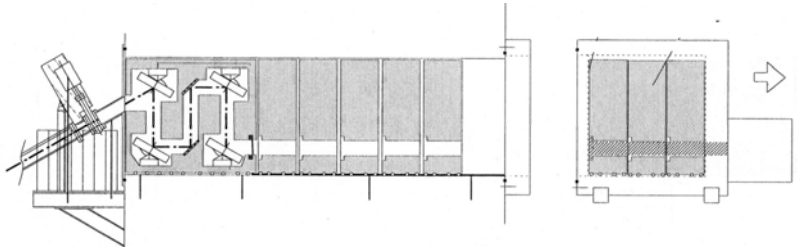
- Shielding module is extracted



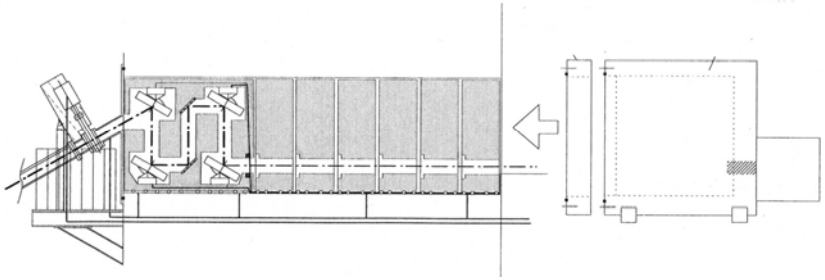
- Cut the beam duct
- Open the maintenance area



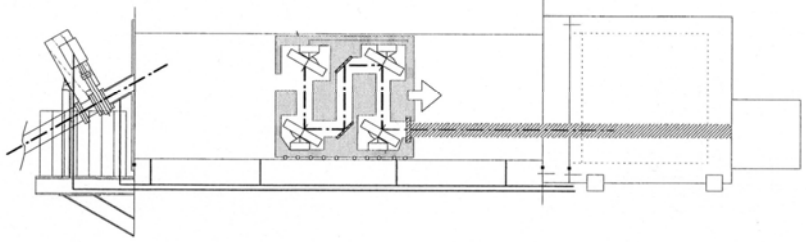
- Maintenance cask goes to maintenance room.



- Connection gate is placed
- Maintenance cask accesses



- Finally, the final optics module is extracted.



Critical Issues on Maintenance 1

The upper polar beam line should be removed in the present FI-DWHRL concept for the cask accessibility.

This removal effect on the FI process is not considered to be small, because the laser uniformity is a key to get the sufficient compression of target toward the large fusion gain(G～100).

the fast ignition method does not require the good laser uniformity, which is required for the central ignition

The system code analysis reveals that a convention compression ratio over 1400 has to be achieved.

Precise investigation is required to check whether the beam line removal is possible or not.

However, this possibility to remove one compression beam line for the maintenance may be considered as the merit of the FI method.

Critical Issues on Maintenance 2

The maintenance period and the resultant plant availability are not yet made clear.

- In contrast with the tokamak fusion power plant, there are two key devices required to replace in this FI-DWHRL concept, that is, the blanket sector and the final optical device.
- Each lifetime for the blanket system and the final optical device is required to determine the operation duration.
- Both operational durations should be as long as possible, and both replacements should be carried out at the same time.

Blanket

The lifetime is probably determined by the first wall condition, because of blistering and erosion on the surface of the first wall. Those effects have to be examined more carefully.

Final optical device

The lifetime is determined by the radiation damage by neutrons. The operational limits of the final optical device is required.

Summary

The maintenance approach for a new concept of Fast ignition power plant with dry wall and high repetition laser is proposed.

- The first wall and blanket system is divided into 20 sectors (90ton/sector) and all beam lines go through the division between blanket sectors.
- The large cask and the large maintenance port for replacing the blanket sectors are applied
- The maintenance cask accesses from the upper side of the vacuum vessel.
- The upper compression is should be and may be removed to keep a maintenance space.
- The built-in style system in the reactor room wall is applied to the final optics devices.
- The Maintenance corridor to access the final optics is placed along the reactor room wall.
- Maintenance period and resultant plant availability remain to be solved.

Additional Slide

Merit of Fast Ignition

Recent development of the fast ignition (FI) method

Laser power can be reduced to achieve the large energy gain

Small fusion pulse leads to allow the smaller chamber than the central ignition method.

This new FI-ICF concept has a potential of a moderate electric power and capital cost

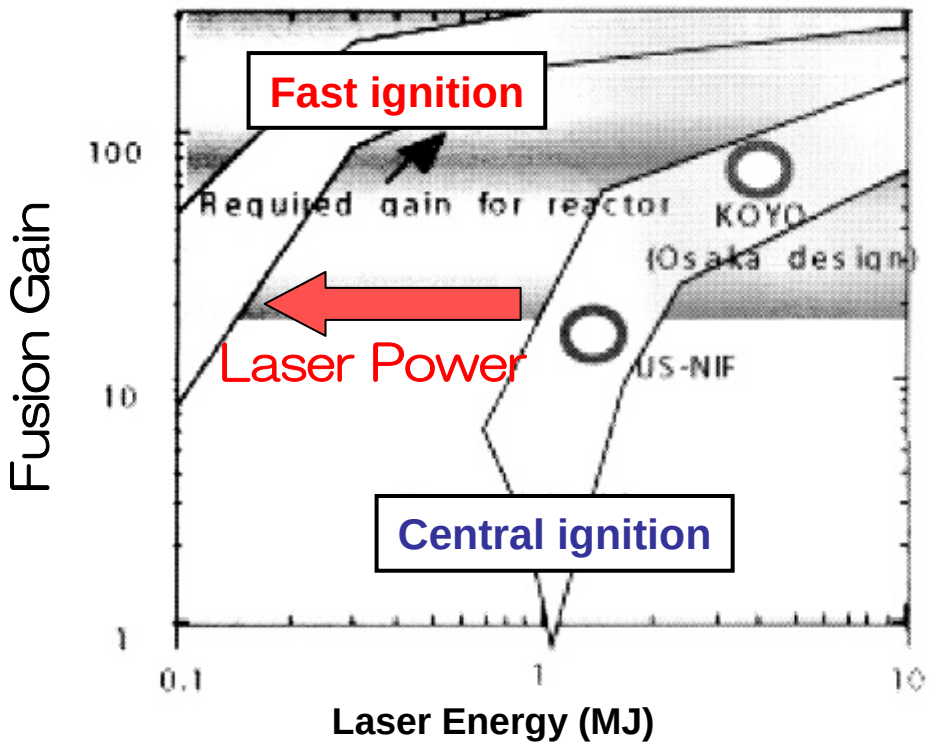


Fig. Laser energy dependents of fusion gains for fast ignition and central ignition.

Role in Electric Grid System

Load Curve and role of power source

Load Manager (Power source to manage the demand change in a day)

- Moderate output
- Low construction cost

LNG and Hydro. Power St.

Backbone power source

- Large output (Scale merit)
- Low COE

Fission Power Station

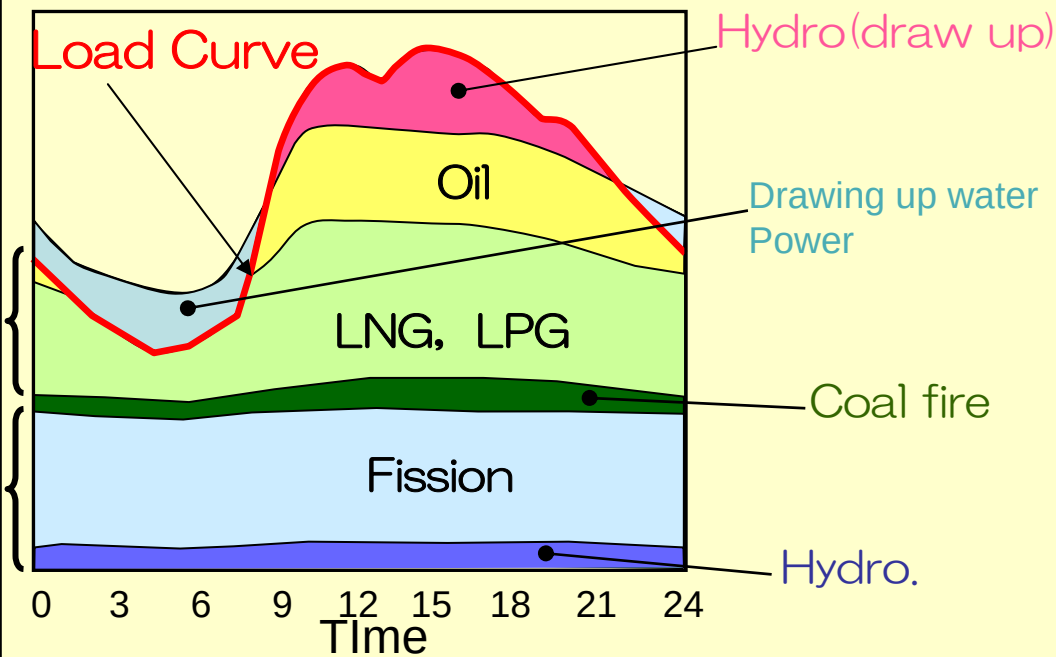


Fig. Typical Load Curve in a day for Japan

Tokamak fusion power plant → Backbone power source

Fast Ignition ICF power plant → Both Roles possible ?

FI-WDHRL Concept

- We can find that the design point of the target gain with the injection energy of 400kJ under a relatively conservative condition of α_c= 2, η_c=5%, η_h=20%
- If h_c=5% is allowed, G =135 can be achieved with the injection energy of 300kJ (implosion 250kJ, heating 50kJ).

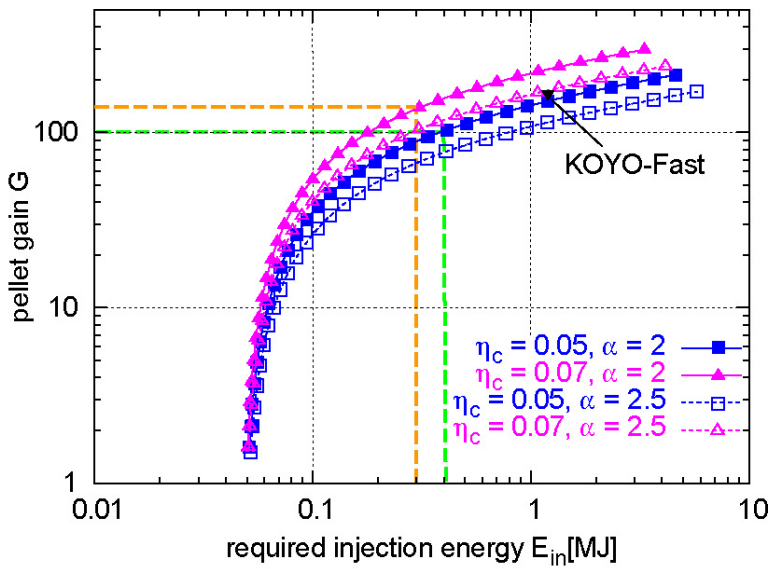


Fig. Gain curve for various implosion parameters Calculated with a simple point model

Further precise analysis is presented by T..Goto "Design Analysis of Fast Ignition Laser Fusion Reactor with Dry Wall Chanber" 01aC32P in the same poster session of 23th JSPF Annual Meeting.

- The minimum fusion pulse energy with acceptable target gain is about 40MJ.
- In this case, we can design the solid wall chamber with R =5.64 m, if pulse heat load limit of 2J/cm^2 is allowed.

Issues on FI-WDHRL Concept

(1) Dry wall design will not allow to use the so-called 'Cone target' with metal cone for ignition laser. This implies that direct heating without a conelike laser guide is required. Such heating technique by two beam injection (a channeling beam and a heating beam) or single beam has to be established.

(2) Feasibility of 30 Hz power laser, as well as 30 Hz injection of targets has to be developed.

(3) Even with 2 J/cm^2, the pulse power load on the first wall is still very severe for the first wall material. Some new materials, like tungsten carpet[1] or tungsten form[2] , may be required.

(4) Cost of Electricity of such moderate output reactor.

[1]A. R. Raffray, L. A. El-Guebaly, G. Federici, D. Haynes, F. Najmabadi, D. Petti, and the ARIES-IFE Team, Fusion Science & Technology 46 417-437, (2004).
[2]M Andersen, S. Sharafat and N. Ghoniem, 'Thermo-Mechanical Analysis of a Micro-Engineered Tungsten-Foam Armored IFE FW', in 7th Int. Symp. Fus. Nucl. Technol. (ISFNT-7) S2-05-O-02, Tokyo (2006)