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CONCEPTUAL DESIGN STUDIES OF IN-VESSEL VIEWING EQUIPMENT FOR ITER

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Kenjiro OBARA, Kiyoshi OKA, Hiroshi TAGUCHI, Akira ITOH
Eisuke TADA and Kiyoshi SHIBANUMA

日本原子力研究所
Japan Atomic Energy Research Institute

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Conceptual Design Studies of In-vessel Viewing Equipment for ITER

Kenjiro OBARA, Kiyoshi OKA, Hiroshi TAGUCHI, Akira ITOH
Eisuke TADA and Kiyoshi SHIBANUMA+

Department of Fusion Engineering Research
Naka Fusion Research Establishment
Japan Atomic Energy Research Institute
Naka-machi, Naka-gun, Ibaraki-ken

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In-vessel viewing systems are essential to inspect all surface of in-vessel components so as to detect and locate damages, and to assist in-vessel maintenance operations. The in-vessel viewing operations are categorized into the three cases, which are 1) rapid inspection just after off-normal events such as disruption, 2) scheduled inspection, and 3) supplementary inspection during maintenance operations. In case of the rapid inspection, the viewing systems have to be operated in vacuum (ca.10^{-5}Pa) and high temperature (ca. 300℃) under a gamma ray dose rate of 10^7 R/h. On the other hand, the latter two cases are anticipated to be under atmospheric inert gas, 150℃ and $3x10^6$ R/h [1], [2]. Accordingly, the in-vessel viewing systems are required to have sufficient durability under those conditions of all cases as well as precision of the vision to all of in-vessel surface.

Based on those requirements, scoping studies on various viewing concepts have been performed and the applicability to the ITER conditions have been assessed. As a result, two types of viewing systems have been chosen, which are a periscope type viewing system and a image fiber type viewing sysytem with a multi-joint manipulator. Both systems are based on radiation hard optical elements which are being developed [3]. In this report, the design features of both viewing systems are described, including technical issues for ITER application. Finally,

This activity is credited as a ITER Design Task and this report decribes the results of 1994 ITER Design Tesk (D59).

+ Department of ITER Project

a periscope type viewing system is recommended as a primary system and the following specifications/conditions are proposed for the further engineering design.

(1) Unified type periscope with a movable mirror at the tip
(2) Integrated lighting device into the periscope
(3) Accessed from top vertical ports located at 7.3m from the machine center
(4) Proposed configuration with a total length of around 27m and a diameter of 200mm.

Keywords : Fusion Experimental Reactor, ITER, In-vessl Viewing Equipment, Inspection Periscope, Image Fiber, Radiation Hardness, High Temperature, High Vacuum

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核融合実験炉（ＩＴＥＲ）用炉内観察装置の概念設計・検討

日本原子力研究所那珂研究所核融合工学部
小原建治郎・岡　　潔・田口　　浩
伊藤　　彰・多田　栄介・柴沼　　清＋

（1996年２月６日受理）

核融合実験炉（ＩＴＥＲ）の炉内構造物の損傷や，炉内保守作業の監視を主な目的とする炉内観察装置（以下，観察装置とする）は核融合実験炉にとって不可欠な装置である。観察装置は，１）プラズマデイスラプションが発生した直後や　２）定期点検　３）炉内保守作業時に使用される。使用時の炉内環境は１）の場合，概略，温度200℃以上，放射線強度１x10^7Ｒ／ｈ，雰囲気は高真空（10^{-5}Ｐａ）となる。これに対し２)と３)では温度が150～200℃，放射線強度３x10^6Ｒ／ｈ，雰囲気は真空あるいは不活性ガス雰囲気（１気圧）となる。従って観察装置には，炉内全面を観察できる機能の他，先の環境下での耐久性が求められる。

以上の観点から，ＩＴＥＲに適用可能な観察装置について検討をしてきたが，その結果，先端に反射鏡駆動機構をもつ光学式ペリスコープと多関節マニピュレータによって走査されるイメージファイバの２方式が，別に実施されている耐放射線性試験をはじめとするこれらの構成要素機器・部品の環境試験の結果からも適切と判断された。

本書では，それぞれの方式の概要とＩＴＥＲへ適用する際の問題点について述べると共に，照明装置を組み込んだ全長27ｍ，外径約200㎜，の耐放射線性光学式ペリスコープを上部ポートから炉内に挿入する方式を提案している。

本設計・検討は，ＩＴＥＲ工学設計タスクの一環として実施したものであり，報告内容はタスク番号Ｄ59に対する進捗状況を整理したものである。
那珂研究所：〒311－01　茨城県那珂郡那珂町向山801-1
＋　ＩＴＥＲ開発室

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(1) Investigate various methods for applicable to the ITER in-vessel viewing system
(2) Develop a design concept of the selected method as a primary viewing system
(3) Clarify the issues of the primary viewing system when applied to ITER

2. DESIGN REQUIREMENTS

According to the current ITER design , the design conditions of the viewing system are considered for various operation modes as described below. The detailed structural design of the viewing system is not included in this report bacause of insufficient information on loading conditions such as magnetic loads and structural constraints.

(1) Design conditions for scheduled inspection (one day after shut down)
- Temperature : over 150°C
- Atmosphere : vacuum/inert gas such as dry nitrogen
- Dose rate : $3x10^6$ R/h

(2) Design conditions for rapid inspection (just after abnormal events such as plasma disruption)
- Temperature : ca. 300°C
- Atmosphere : vacuum(ca. 10^{-5} Pa)
- Dose rate : ca. 10^7 R/h

(3) Design conditions for stand-by in a storage cask
- Temperature : Room Temp.
- Atmosphere : vacuum/inert gas
- Dose rate : ca. 10 mR/h(gamma ray), ca. 10^2 n/cm^2-s(neutron)

The viewing system for these operations is considered to be inserted from the upper vertical port or the horizontal port into the vacuum vessel. In case of the upper vertical port insertion, the position of the viewing system location is assumed to be around 9m from the machine center.

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3. VIEWING METHODS

3.1 Comparative studies on various viewing methods

The comparative studies on various viewing methods have been performed mainly for a periscope type and a image fiber type viewing systems since CCD camera and laser type viewing systems will be less radiation hard capability due to their principle and component composition, comparing with the periscope and image fiber type viewing systems[4],[5]. Figures 3.1.1 to 3.1.4 show the ITER tokamak layout, the upper vertical port configuration and the plan view of the ITER in-vessel area, which are the geometrical requirements to the comparative studies on the viewing systems.
Table 3.1.1 shows the possible schemes of the periscope type and the image fiber type viewing systems, and gives the general assessment results in terms of visualization, technical difficulty, reliability, rescue, maintenability, controllability and mobility for the in-vessel viewing and the vacuum leak detection. As a result, Plan-B and Plan-D in Table 3.1.1 are selected through this preliminary assessment as candidate methods for the selection of a primary method with the further extensive investigation. The key features of both concepts(Plan-B and Plan-D) are summarized below.

Item	Plan-B	Plan-D
Viewing method	Periscope	Image fiber
Access port	Upper port	Upper port
No. of port	6	6
Advantages	Fine visualization, Simple rescue	High accessibility & flexibility

3.2 Periscope type viewing system (Plan-B)

3.2.1 Outline of the system

Figures 3.2.1 and 3.2.2 present the overall structure and the cross-sectional view of the periscope type viewing system located inside and ouside the ITER tokamak. In this configuration, the required height and installation area for the external support structure are 15m and 3x3 m^2, respectively. A total length of the periscope is about 18m and the available stroke for insertion and removal is around 11m. Since the periscope position is located at 9m distance from the machine center, the insertion depth is limited to be 2450mm from the machine horizontal center due to interference with the out-board blanket surface.

In order to enable viewing of all in-vessel walls, the periscope type viewing system is designed to have 3 degrees of freedom, which are the sliding for insertion/removal along the periscope axis, the rotation of the periscope body, and the tilting of a front-end mirror. Figure 3.2.3 shows a typical structure of the periscope tip to rotate the periscope body and to tilt the mirror. These rotating and tilting mechanisms have been qualified through experiences in the JT-60 in-vessel viewing system[6] but the reliability under the ITER in-vessel environmental conditions should be assessed and demonstrated, including the radiation hardness of the mechanisms.

Figures 3.2.4 and 3.2.5 represent the relation between the visual range and the tilting angle of the front-end mirror, and the poloidal visual range of the in-vessel walls depending on the vertical location of the viewing system inserted at the 9m distance from the machine center, respectively. In Fig. 3.2.4, a wide viewing range of more than 120 degree can be attained by tilting the mirror up to 105 degree which is a maximum angle. From Fig. 3.2.5, it is found that all in-vessel walls can be viewed using the sliding, rotating and tilting mechanisms, excepting the divertor target plate in the out-board region as shown in (3) of Fig. 3.2.5. For viewing of this specific area, there are two possibilities, which are to insert an additional image fiber type viewing system or to change the periscope insertion position at 7m distance from the machine center instead of 9m distance.

Figure 3.2.6 represents typical viewing picture taken by the periscope type viewing system at the vertical position (2) in Fig. 3.2.5. In this figure, one picture divided corresponds to a picture taken at a fixed mirror position. Figure 3.2.7 represents the visible range in the toroidal direction using the periscope type viewing system. From this figure, it is clear that a periscope can view more than 1 sector(18°) of the in-vessel walls. The number of the viewing system to cover all in-vessel walls in the toroidal direction can be determined according to this result but more detailed specifications such as a minimum resolution capability are needed for selecting the final system arrangement.

As a whole, the key features and remaining issues of the periscope type viewing system are summarized below.
(1) Advantages:
- Possible to get a wide viewing range with a high quality picture
- Easy operation and rescue due to simple structure
(2) Disadvantages:
- Difficult to view a narrow area such as divertor target plate
- Relatively long length(ca. 20m) for insertion/removal
(3) Remaining issues:
- Radiation hardness of optical elements and rotating/tilting mechanisms
- Compactness of the system and storaging cask

3.2.2 Optical design and illuminance

Optical axis of the periscope type viewing system is basically composed of a front-end mirror, an objective lens, a number of relay lens pairs, and an eye piece. If the minimum resolution is assumed to be 1mm from the 5m distance, a focal value(F) on CCD camera externally located at a periscope end is to be 3.83 with a magnifying index of 1. The optical transmittance estimated is to be 35.3% in the case of 16 relay lenses for the periscope with a total length of 18m.

In this typical configuration of the periscope type viewing system, a minimum illuminance(E) on a subject can be estimated to be 3823 lx using the following relation.

$$E = E_1 \times 1/T \times [F_2/F_1]^2 \times 1/\eta \times 1/f(\alpha) \quad (1)$$

where, E_1 : minimum illuminance of lens F_1 (ca. 5 lx)
T : transmittance of the periscope (0.353)
F_1 : F value of the lens (1.4)
F_2 : F value of periscope (11.5)
η : reflectance (0.5)
$f(\alpha)$: illuminance rate depending on a light angle(α) (0.5)

The required luminous flux(F_l) based on the minimum illuminance can be calculated using the equation of $F_l = E \cdot R^2 \cdot \omega$ where, R is the distance from a light source to a subject, and ω is the angle. When R is 6m, the maximum luminous flux is estimated to be 1.8×10^6 lm, which corresponds to 17 halogen lamps with a 1kW capacity. However, the luminous flux can be reduced by limiting the visible range and by adopting a reflector. If the visible range of 30 degree and the reflector angle of 45 degree are assumed, the required luminous flux is reduced to be 1.6×10^5 lm, which corresponds to 6 of 1kW halogen lamp.

3.2.3 Investigation on thermal and electromagnetic loads

The viewing capability is strongly influenced by the operating conditions such as dose rate, atmosphere, thermal loads and electromagnetic loads. In case of the dose rate and atmosphere, the durability of the components under the given conditions is the most important characteristics and the viewing capability should be assumed by the radiation hard component development. On the other hand, thermal and electromagnetic loads raise a possibility of misalignment of the optical axis due to thermal and mechanical loads applied to the periscope type viewing system have been estimated as described below.

(1) Thermal loads
The thermal loads to be considered are the radiation heat in the ITER in-vessel area and the heat input due to a lighting equipment of the viewing system. The radiation heat(Q_1) can be calculated from the equation (2) and the total heat is estimated to be around 6070 kcal/h with assumptions of the emissivity, temperature and surface area corresponding to the ITER environments and the viewing system design.

$$Q_1 = \sigma \cdot (T_2^4 - T_1^4) \cdot A_1 / \{ 1/\varepsilon_1 + (A_1/A_2) \cdot (1/\varepsilon_2 - 1)\} \cong 6070 \text{ kcal/h} \quad (2)$$

where, σ : Stefan-Boltzman constant (4.88×10^{-8}kcal/m^{2}h°k^4)
T_1 : viewing system temperature (ca. 333°K)
T_2 : environmental temperature (ca. 473°K)
A_1 : surface area of viewing system (ca. 7.5m^2)

A_2 : surface area of in-vessel wall (ca. 1016 m^2)
ε_1 : emissivity of viewing system (0.44)
ε_2 : emissivity of in-vessel wall (0.55)

The heat input due to the lighting equipment is also estimated to be 2580 kcal/h by assuming the lighting capacity of 3kW. As a whole, the total thermal loads applied to the viewing system are 8650 kcal/h.

In case of a periscope type viewing system, the maximum operating temperature is normally limited to 60°C, so that a cooling system should be incorporated within the viewing system so as to remove the thermal loads and to maintain the system below 60°C. Two types of coolant, which are air and water, are available for cooling the viewing system. If the inlet temperature of 30°C and the outlet temperature of 60°C are assumed, the required total flow rate is estimated to be 18 m^3/min(air) and 4.9 m^3/min(water). As a result, the water cooling system can be practical in terms of minimization of the coolant flow rate and the space for the cooling system.

(2) Electromagnetic loads
A electromagnetic load can be generally calculated from the equation (3) and the maximum load(Fm) acting on the viewing system is estimated to be 6N under the assumptions of a magnetic field of 0.1T in the all axes directions and a viewing system with 150mm diameter and 30m length. The estimated magnetic loads of 6 N(0.6kgf) is sufficiently small and the structure supports near the port region can be possible to sustain the viewing system.

$$Fm = \{(\mu_s - 1) \cdot B^2 \cdot A\} / (2 \cdot \mu_s \cdot \mu_0) \qquad (3)$$

where, μ_s : specific magnetic permeability (1.5)
μ_0 : magnetic permeability in vacuum ($4\pi x10^{-7}$ T·m/A)
B : magnetic field (0.1T)
A : surface area of the viewing system ($4.5x10^{-3}m^2$)

3.3 Optical image fiber type viewing system (Plan-D)

3.3.1 Outline of the system

The followings are given as the typical advantages and disadvantages of the optical image fiber type viewing equipment. Both advantages and disadvantages are relatively opposite aspects compared with the periscope type viewing equipment.
(1) Advantages :
- Possible to observe narrow and backward area
- Possible to approach close to the subject and observe the details

(2) Disadvantages :
- Viewing field is small and quality of the pictures is low compared with the periscope type
- Need to cooperate with a multi-joint type manipulator
- Complexity in structure and operation
- Long size equipment so as to observe all in-vessel surface
- Need to have rigid support

Figure 3.3.1 presents the outline of the image fiber type viewing system, which is basically composed of a multi-joint manipulator and a storaging cask. The multi-joint manipulator consists of a multi-joint arm, an in-vessel supporting arm and a support structure. The details of the storaging cask is presented in Fig. 3.3.2 and the cask height can be reduced by using a movable pulley. Figure 3.3.3 shows an outline of the multi-joint manipulator with a guide for the optical imagefiber and the total length including the support structure is specified to be about 20m so as to observe the divertor target plate. In this concept, a large moment caused by the multi-joint manipulator has to be supported at the base of the manipulator, so that a diameter of the access port becomes large. Figure 3.3.4 shows a structural concept of the support structure which is designed to sustain the manipulator moment using guide rollers located around the manipulator arm. The minimum space for this support is 500mm in diameter and 3.2m in length.

Figures 3.3.5-1 and 3.3.5-2 show a concept of the elbow joint of the multi-joint manipulator and the joint is designed to be able to rotate using a ball screw mechanism. Figure 3.3.6-1 shows an outline of the multi-joint arm, and the number of joint and the arm length are defined so as to satisfy a minimum bending radius of 300mm. Figures 3.3.6-2 and 3.3.6-3 show the detailed joint structure of the multi-joint arm. Each joint can be rotated by 90 degree and the image fiber as a viewing sensor is layouted in the center of the arm fram. Major specifications of the image fiber and the multi-joint manipulator are as follows.

(1) Image fiber
- Field angle : 30° (visible field diameter is estimated about 500mm from 1m distance)
- Visible distance : 10-1000mm
- Critical diameter of curvature : 150mm
- Lighting source : Xenon lamp(300W)
- Light guide : 5mm dia.
- Illuminance : 3000lx in front of 1m

(2) Multi-joint arm
- Number of joint : 7
- Total length & weight : 2.3m/ca. 50kg
- Diameter : 240mm(1st joint)-160mm(6th joint)
- Load moment & required motor power : 50000kgf·mm/37W(1st. joint), 2400kgf·mm/1.9W(6th. joint)

Figure 3.3.7 shows a typical picture obtained from the image fiber type viewing system. The movable range required to view all in-vessel surface depends on the number of access ports of the image fiber viewing system. Figure 3.3.8 represents a top of view of the movable range in the toroidal direction. It is obvious that the movable length required to the manipulator is 8m for 4 access ports and 5.7m for 6 access ports.

3.3.2 Examinations of mechanical strength on major components

The image fiber type viewing system requires high structural stiffness to sustain large momentum loads due to kinematics of heavy multi-joint manipulator, comparing with the periscope type viewing system. In this section, structural evaluation of the multi-joint arm, the in-vessel supporting arm and the support structure is described.

(1) Multi-joint arm
The multi-joint arm is composed of 7 joints and a maximum load is applied to the semi-circular gear(No.2 in Fig. 3.3.6-3) of the 1st joint during operation. According to the structural design mentioned above, the dead weight and maximum moment(M) of the arm are estimated to be 50kg and 50,000kg-mm, respectively. The circumference force(Ft) acting on the pitch circle of the gear can be represented by $Ft = M / r_0$. where, r_0 is the radius of the gear, which is 120mm in this design. As a result, the circumference force is about 417kg. The bending stress(σ_F) of the gear tooth can be calculated as follows.

$$\sigma_F = \{ Ft \cdot Y_F \cdot Y_E \cdot Y_B / (m_n \cdot b)\} \cdot \{K_V \cdot K_O \cdot / (K_L \cdot K_{FX})\} S_F \qquad (4)$$

where,
- Y_F : constant depending on tooth geometry (2.2)
- Y_E : load distribution factor (1/1.7)
- Y_B : factor of torsion angle (1)
- m_n : the number of module (2.5)
- b : width of teeth (30mm)
- K_V : dynamic factor (1)
- K_O : over load factor (1.25)
- K_L : life time factor (1)
- K_{FX} : dimension factor (1)
- S_F : safety factor (1.2)

Substituting Ft(417kg) and above values for the equation (4), the bending stress is calculated to be about 10.8 kg/mm^2 which is lower than the allowable one.

(2) In-vessel supporting arm
The in-vessel supporting arm has to sustain the momentum loads generated by the dead weight of the arm and the multi-joint arm. Figure 3.3.9 shows the typical loading condition and the cross-sectional view of the arm. In this figure, the dead weight of the arm and the multi-joint arm is represented as concentrated loads of w_1 and w_2, respectively. According to this assumption, the momentum loads are estimated to be $2x10^6$ kg-mm when w_1=360kg and w_2=50kg.
In order to support this moment, a concept of the in-vessel support arm composed of a connecting rod and screw has been developed as schematically shown in Fig. 3.3.10. Since the axial loads acting on the connecting rod and screw are estimated respectively to be 4390kg and 5070kg under the $2x10^6$ kg-mm moment, two

connecting rods with a 50x25 mm^2 cross-section are needed. In addition, the maximum deflection of the tip and bending stres at the support base are 50mm and 4.4 kg/mm^2 when the cross-sectional dimensions of the arm are assumed to be 300mm height(b_1 & h_1) and 10mm thickness(b_2 & h_2) in Fig. 3.3.9(b).

(3) Support structure
The moment applied to the support structure is supported by the roller guids which are attached at upper and lower of the support structure. Hertzian stress on the contacting surface between the roller and the inside wall of the port has been estimated using a simple model of a plane and a cylinder. The Hertzian stress(p) and the width of the contacting surface(b) can be expressed in the following equation.

$$p^2 = q / (\pi \cdot r) \cdot 1 / \{(1 - \nu_1^2) / E_1 + (1 - \nu_2^2) / E_2 \} \quad (5)$$

$$b^2 = 4 \cdot r / \pi \cdot q \{(1 - \nu_1^2) / E_1 + (1 - \nu_2^2) / E_2 \} \quad (6)$$

where, E_1, E_2 : Young's modulus
ν_1, ν_2 : Poisson's ratio
q : load per unit width of the contacting surface
r : radius of the guide roller

when $E_1=E_2=E$, $\nu_1=\nu_2=0.3$, p and b can be explained in the following relation

$$p = 0.418 \cdot (q \cdot E / r)^{1/2} \quad (7)$$

$$b = 1.522 \cdot (q \cdot r / E)^{1/2} \quad (8)$$

When r =30mm, E=21000 kg/mm^2, and a unit width of the contacting surface is 120mm, the Hertzian stress and the contacting surface width are 28.4 kg/mm^2 and 0.15mm under the assumed moment described above. This stress is lower than the tensile strength of stainless steel. In addition, this value is lower than the endurance limit of Hertzian stress estimated from the Brinell hardness.

(4) Storage cask mechanism
The insertion/removal movement of the multi-joint manipulator into/from the vacuum vessel is driven by the up-down actuator, two movable pulleys and rack & pinion mechanisms, as shown in Fig. 3.3.2. A preliminary structural calculation of the rack & pinion mechanism shows the bending stress of around 28 kg/mm^2 with a pinion width of 40mm, and the result is lower than the allowable one.

3.3.3 Influence of in-vessel and ex-vessel environments

The viewing capability and the system reliability of image fiber type viewing system strongly depend on the operating conditions such as dose rate, atmosphere, thermal loads and electromagnetic loads, as well as the periscope type viewing system. In case of image fiber type viewing, however, a multi-joint manipulator is required, resulting in more serious concerns relating to the environmental conditions compared with periscope type viewing. In particular, lubricants of joints, which are key structural elements to sustain heavy loads, have to be torelable for both vacuum and inert gas environments under the gamma radiation. Since coating type solid lubricants are not applicable to such large loading path, solid lubricants and grease lubricants will be candidates, and the radiation hard greae[3] is attractive for practical use.

In addition, electrical equipment such as motors for operating the multi-joint arm will cause a siginificiant temperature rise under the vacuum environments. For this, electrical components with high temperature resistance and low outgassing characteristics are additionally required as well as the radiation hardness. The radiation hard component development according to the R&D task(T35 & T252) covers all components required for viewing systems and the viewing system development is essentially based on the technological data base on the radiation hard components.

4. CONTROL SYSTEM

Figure 4.1 shows an example of the control system for the periscope type viewing system. As to the control system of the image fiber type viewing, the diagram is basically the same as the periscope type viewing one. The control system is mainly composed of four control panels(Site control panel, Main control panel, Site operation panel, Evacuation control panel) and three auxiliary equipments(Power supply system, Vacuum evacuation system, Cooling system) and these panels and equipments are installed in the torus hall and the central control room, respectively. The details of the control system will be designed after the decision of the viewing method, so that at this point the key functions of the control panels are described below.

(1) Site control panel
This control panel plays a key role with the main control panel in the work, and the equipments which are installed in the torus hall can be operated from the instructions of the site control panel.
(2) Main control panel
The main control panel unifies all over the system, and the operation mode is classified an automatic operation and a manual operation. The panel is basically composed of two Central Processing Units(CPU1, CPU2), and the CPU1 directly exchanges the signals to the site control panel and CPU2 functions as an assistance.
(3) Site operation panel
As a rule this operation panel is installed at every periscope and it is possible to operate only one periscope at the site. Main purposes of the site operation are maintenance and repairing of the periscope.
(4) Evacuation control panel
Inside the storaging cask is evacuated and maintained at a high vacuum condition, and the operational informations of the vacuum evacuation system is exchanged through the evacuation control panel to the main control panel.

5. RECOMMENDED VIEWING METHOD

According to the comparative studies on various viewing methods, two types of viewing concepts, which are a periscope type and an image fiber type, have been chosen for candidates of the ITER viewing system. Based on this, preliminaly design of both concepts have been conducted and finally a periscope type viewing system is recommended as a primary viewing system for ITER. In case of an image fiber type viewing system, however, further design efforts should be continued for specific application to leak detection and narrow space inspection. The recommended design outline of the periscope type viewing system is summarized below.

(1) Viewing method
- Periscope with 200mm dia. and 27m length (see Fig. 5.1)

(2) Access port
- Access from the top vertical port at a position of 7.27m from the machine center so as to view the divertor target plate (see Fig. 5.2)
- 10 access ports with a diameter of 250mm (these conditions are to be determined after the detailed specifications have been fixed)

(3) Structure and degree of freedom
- Unified type periscope with a movable mirror on the tip
- 3 degree of freedom (sliding, rotating and tilting)
- Water cooling (depending on materials of cylindrical mirror)

(4) Shielding plug
- Rotary shielding plug (see Fig. 5.3)

6. REMAINING ISSUES

The following issues relating to the periscope type viewing system are to be involved in the further design development and technology R&D program.

(1) Viewing capability of a long size periscope
In case of a long size periscope(ca. 27m), more than 20 of relay lenses made of radiation hard glasses are to be installed, so that degradation of transmittance and optical aberration have to be qualified through a mock-up testing.

(2) Radiation hardness of driving mechanisms
In order to view all of in-vessel walls, the periscope should have 3 degrees of freedom, which are the sliding and rotating of the periscope, and the tilting of a mirror. In particular, the tilting mechanism will be located at the front-end facing to objects, so that the radiation hardness to be qualified through irradiation test.

(3) Structural design (Compactness)
Design efforts should be made to develop a compact periscope viewing system according to the ITER design conditions and spatial constraint. Several issues such as cooling system, tilting mechanism, and alignment of optical axis are to be considered aiming at realization of a telescopic type system to reduce the length.

ACKNOWLEDGMENTS

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3. K. Obara et al., " Irradiation Test of Critical Components for Reemote Handling in Gamma Radiation Environment", JAERI-Tech 94-003, August (1994)
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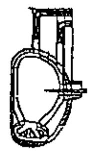
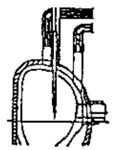
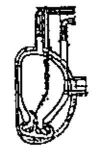
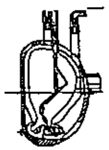
6. K. Yoshiuki et al., "Development of the In-vessel Inspection System on JT-60", JAERI-M 87-070, May (1987), (in Japanese)

Table 3.1.1 Comparison of various in-vessel viewing methods

◎ Better
○ Good
△ No Good

Purpose	Plan	Method	Access port and Necessary ports	Conceptual design	Estimation Items: Visualization	Technical difficulty	Reliability	Rescue	Maintainability	Scale of cont. system	Working time	Justification
In-vessel viewing	A	Periscope type	Horizontal port 6		◎	○	◎	◎	○	Medium	Short	○ It is necessary to correct the lighting due to a bending of the equipment.
	B	Periscope type	Upper port 6		◎	◎	◎	◎	○	Medium	Short	◎ The structure is simple and it is possible to inspect the whole in-vessel together with the multijoint type mirror.
In-vessel viewing /Leak detection	C	Multijoint manipulator type (Straight type)	Upper port 6		◎	○	○	◎	◎	Meidum	Medium	◎ The number of the parts is more than the periscope type. But it is suitable for the observation of narrow area.
	D	Multijoint manipulator type (Link type)	Upper port 6		◎	◎	○	○	◎	Medium	Medium	◎ It is suitable for the inspection of narrow area.
	E	Multijoint manipulator type (Vehicle type)	Horizontal port 2		○	○	△	△	△	Large	Long	△ The system is participated to become huge.
			Horizontal port 4 for viewing:2 for leak detection:2		○	○	△	△	△	Large	Long	△ The same as the above

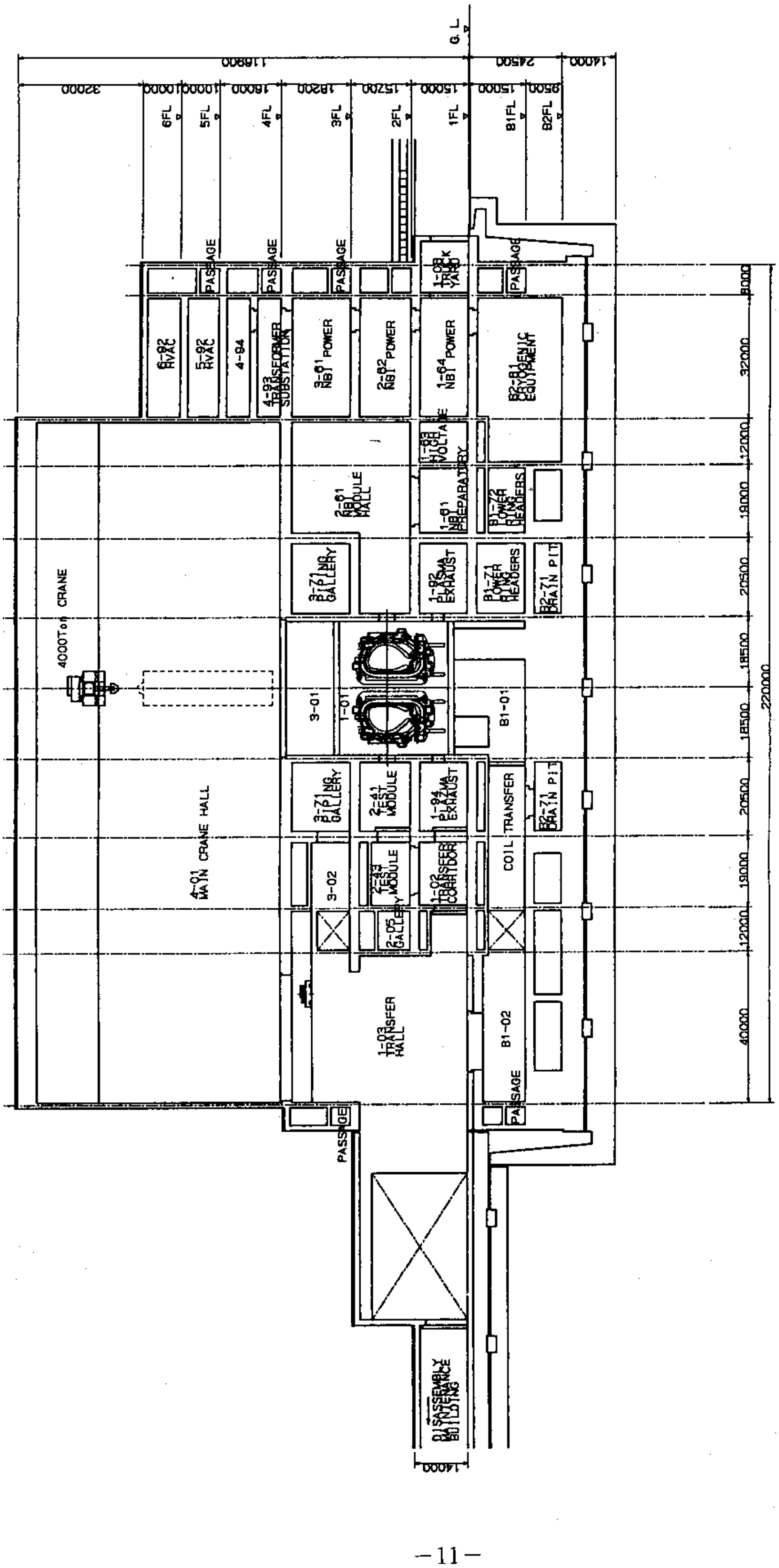


Figure 3.1.1 ITER Tokamak Layout

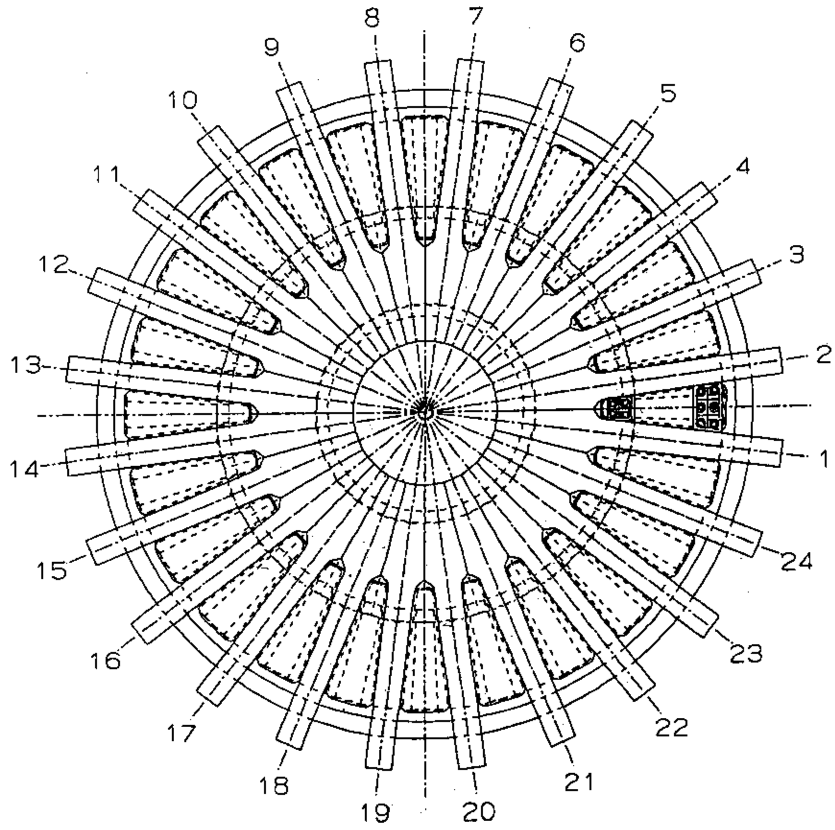


Figure 3.1.2 Upper port location

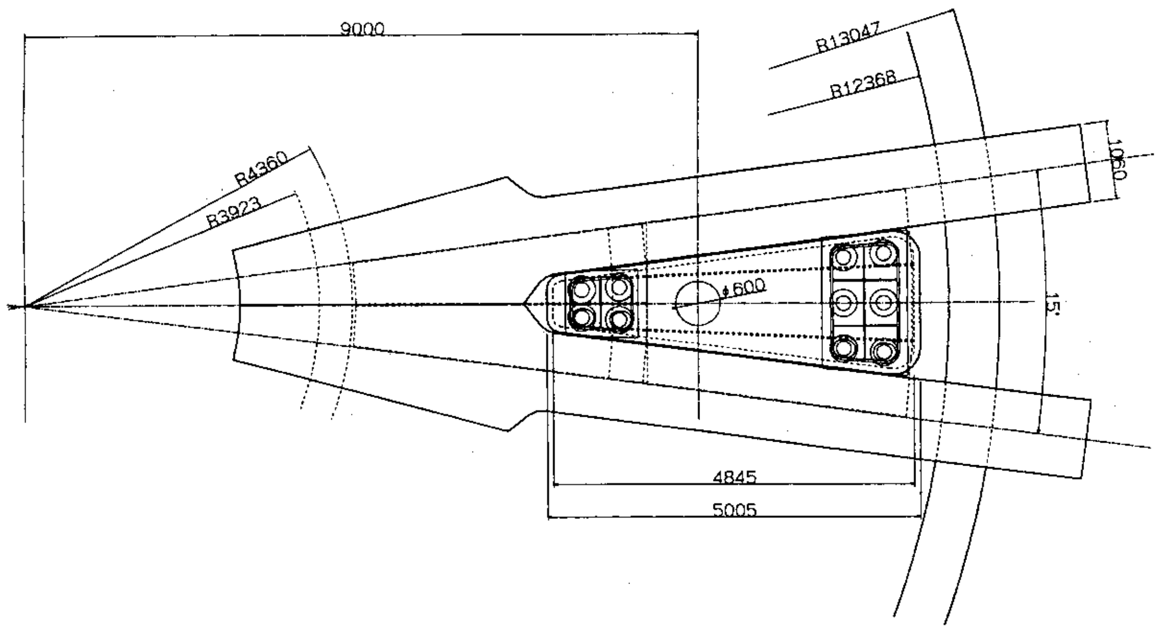


Figure 3.1.3 Details of the upper port for the viewing system insertion

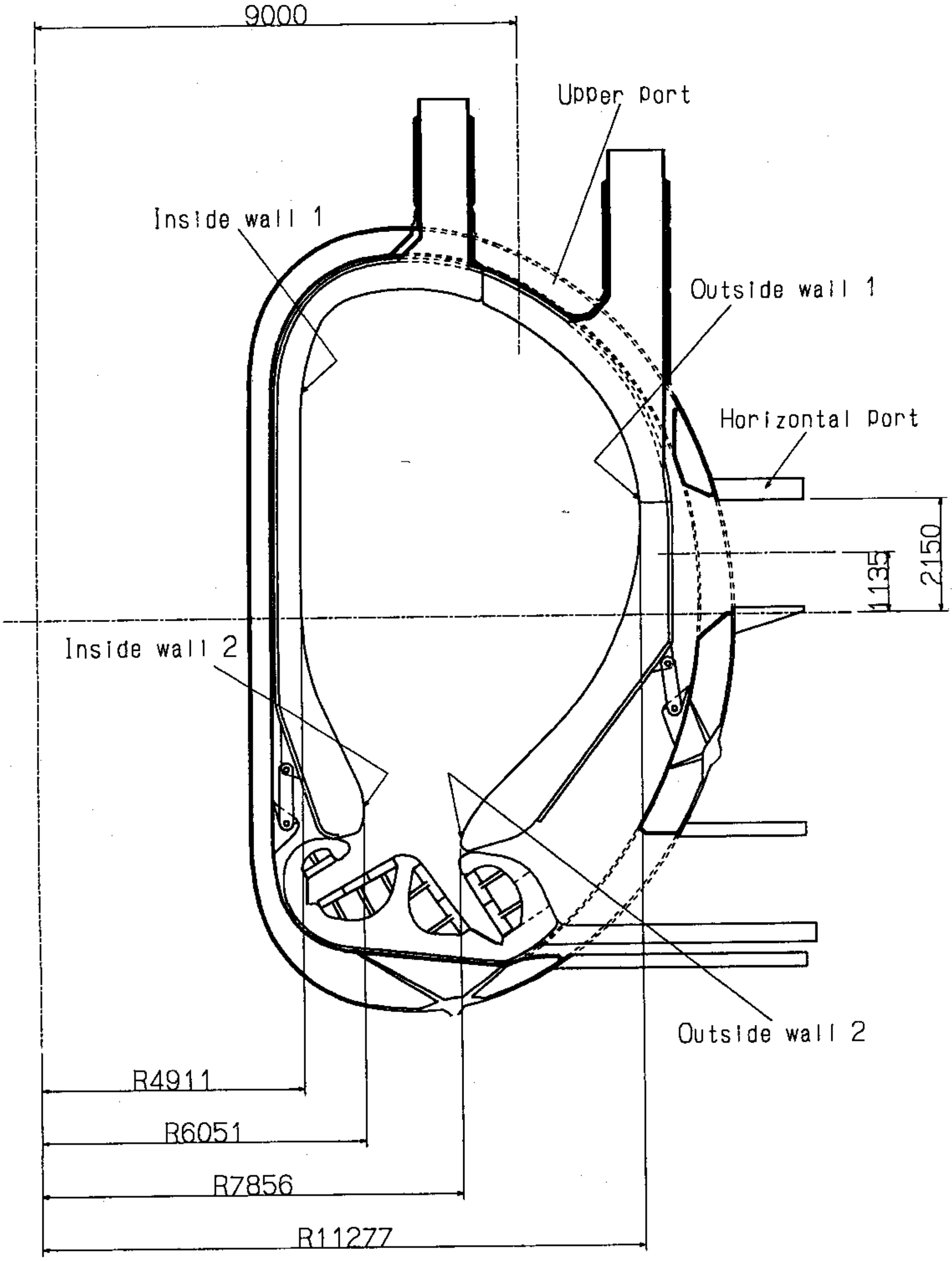


Figure 3.1.4 Plan view of the ITER in-vessel area

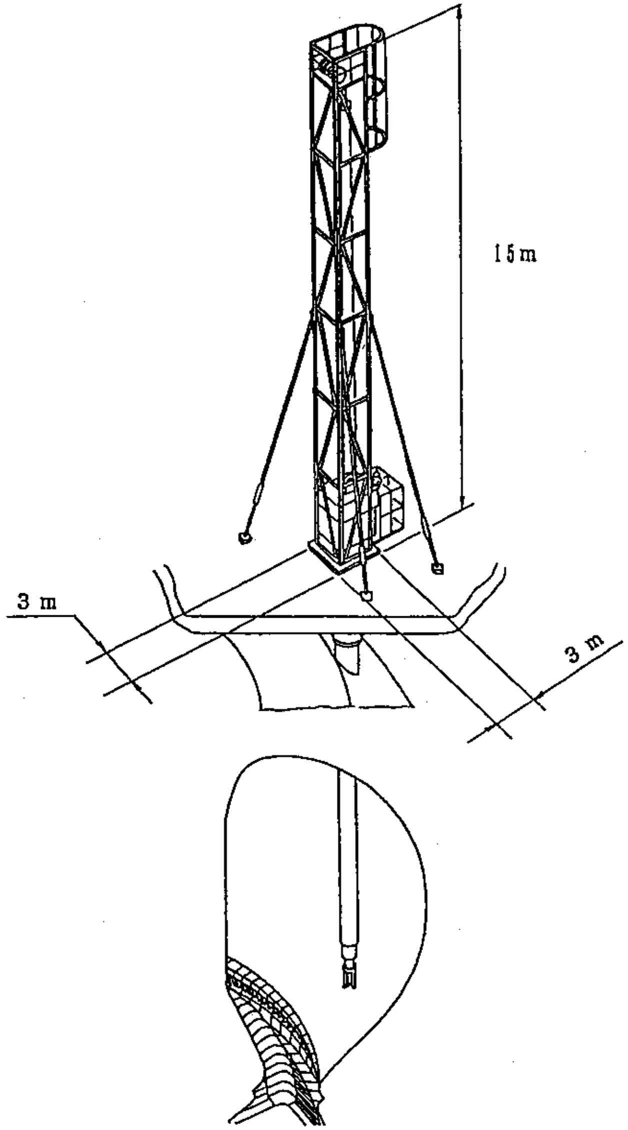


Figure 3.2.1 Configuration of the periscope type viewing system inside and outside the core of ITER

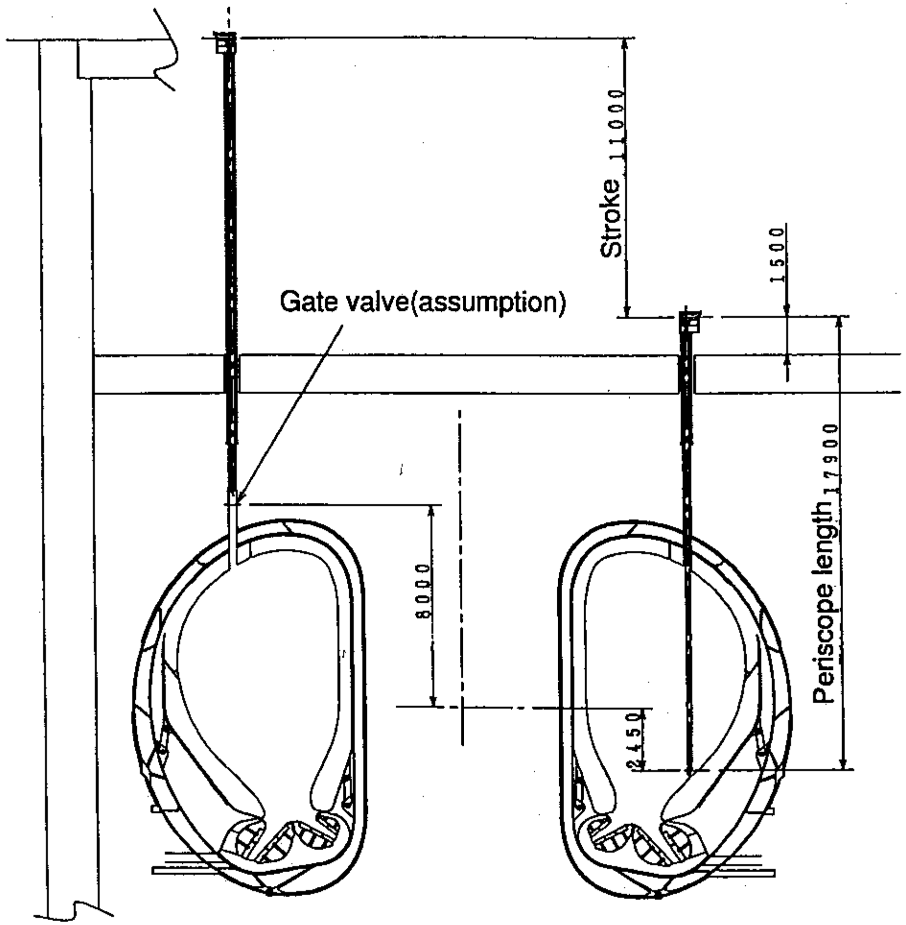


Figure 3.2.2 Required length for periscope insertion/removal

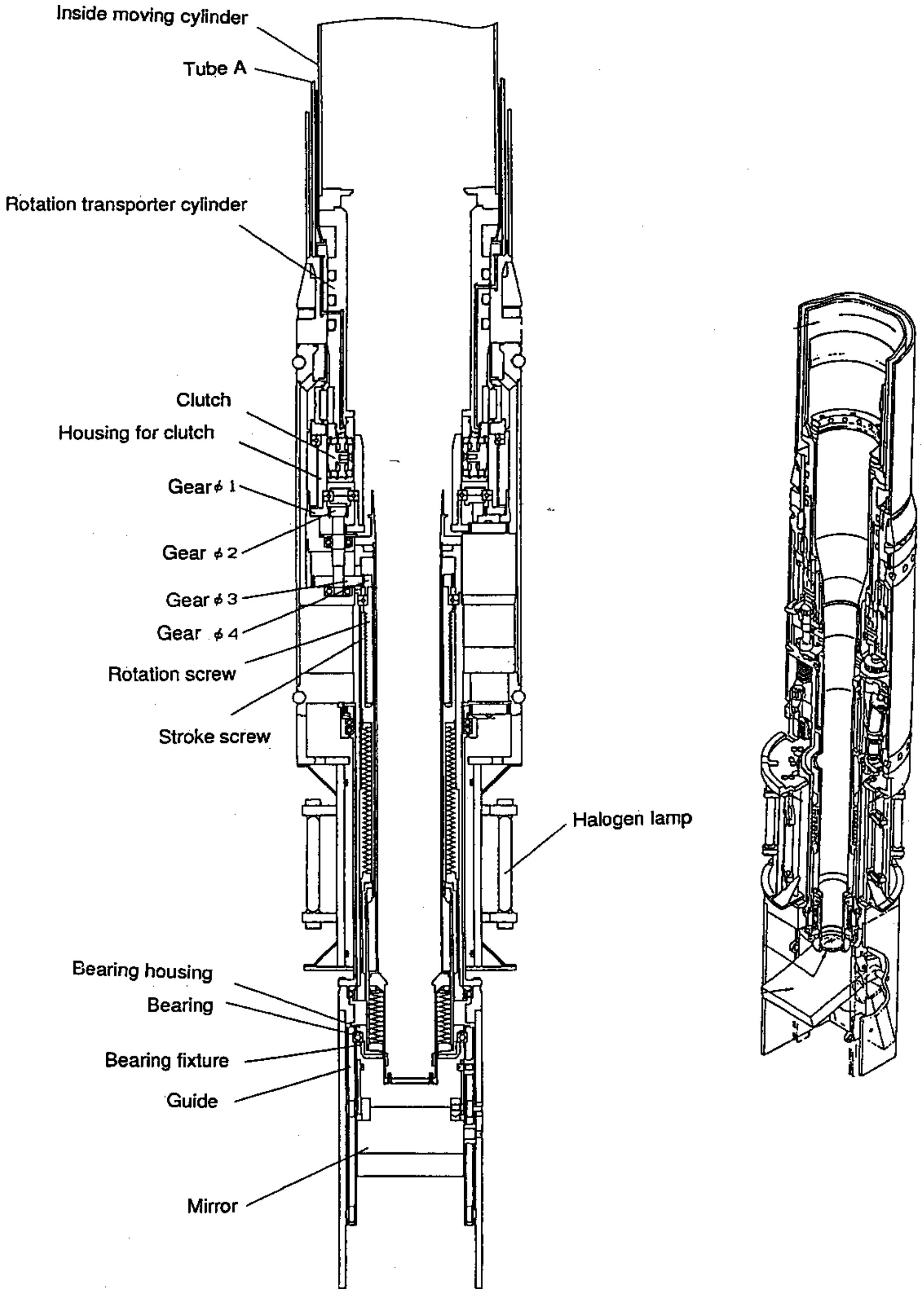


Figure 3.2.3 Structural concept of the periscope tip and the driving mechanisms

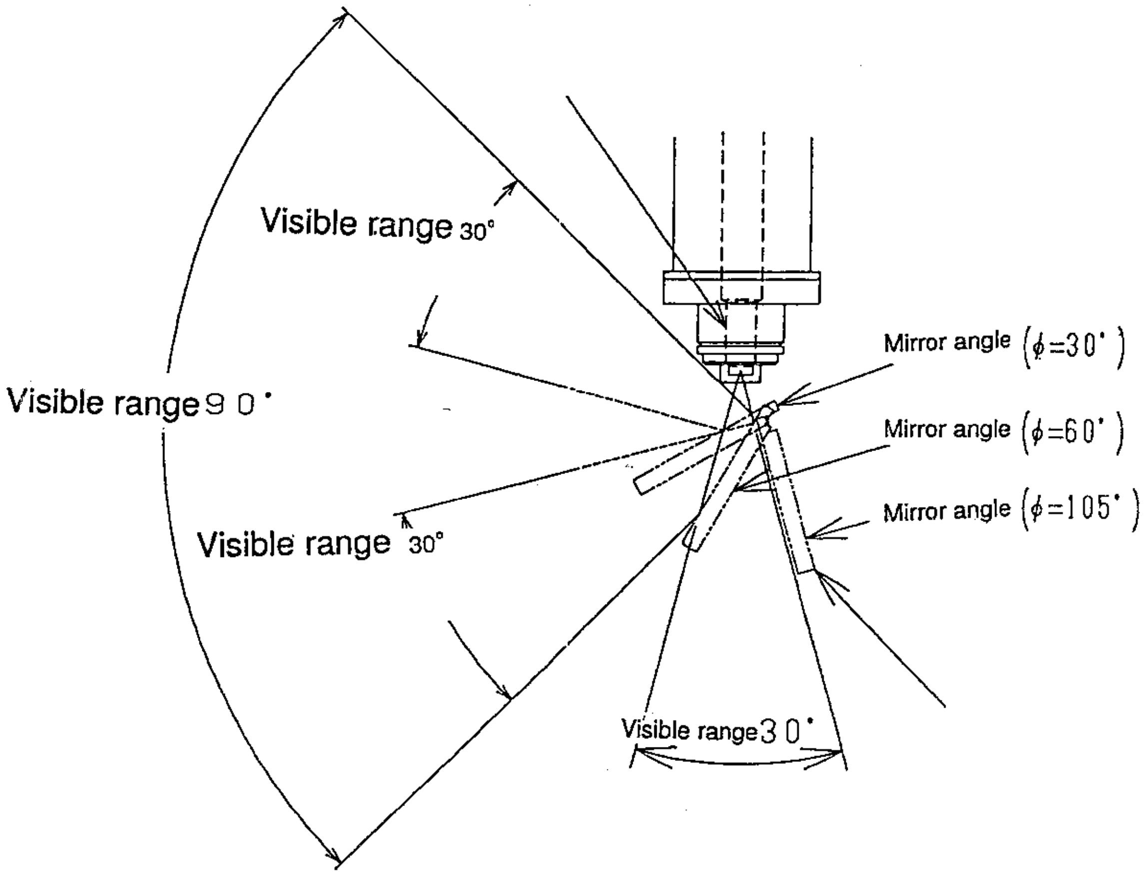


Figure 3.2.4 Relation between the visible range and the tilting angle of the mirror

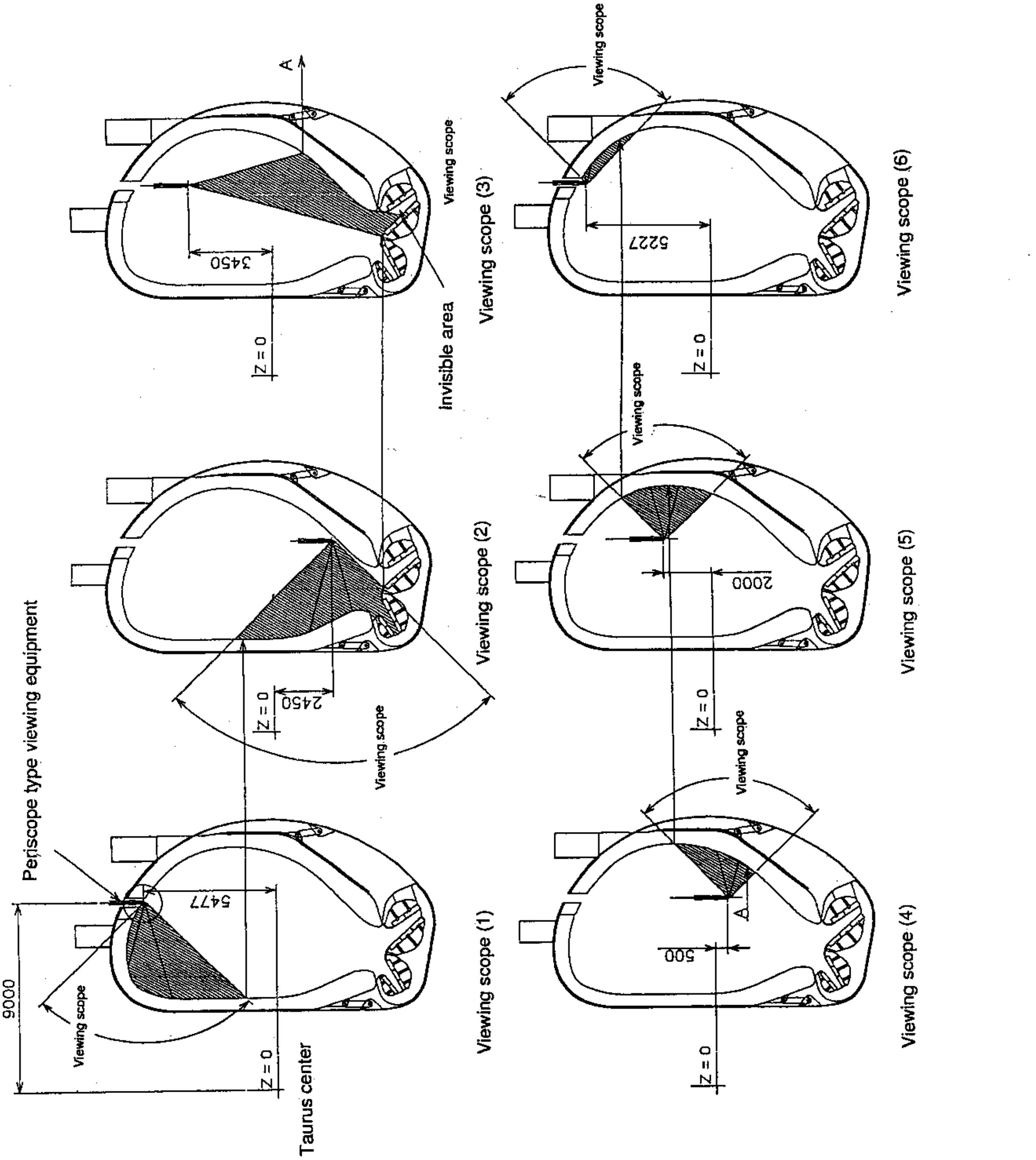


Figure 3.2.5 Visible range in the poroidal direction using the periscope type viewing system

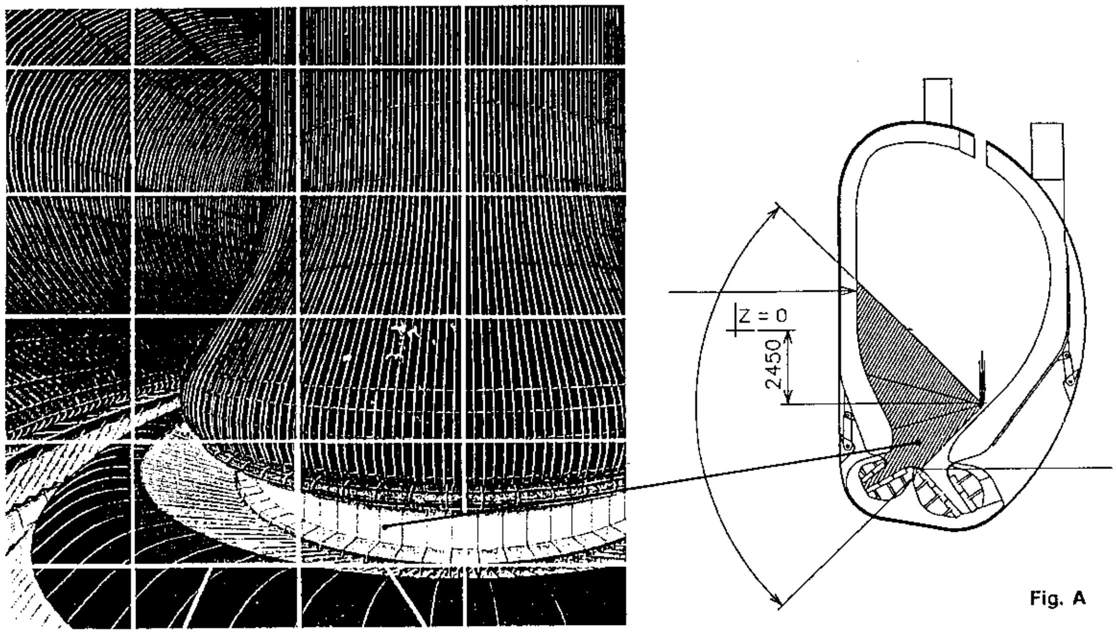


Figure 3.2.6 Imagined picture taken by the periscope type viewing system at the viewing position (2) in Fig. 3.2.5

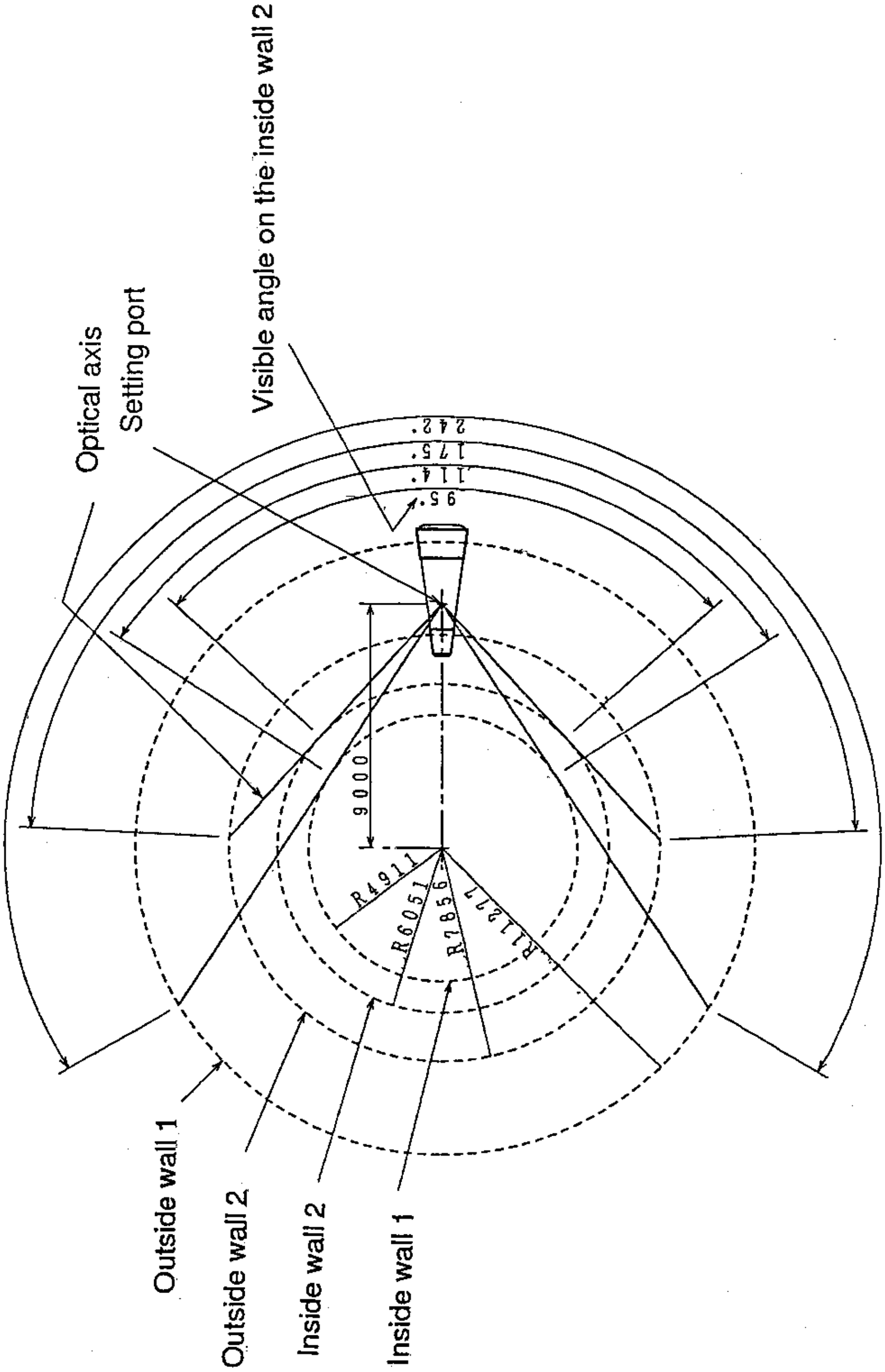


Figure 3.2.7 Visible range in the toroidal direction using the periscope type viewing system

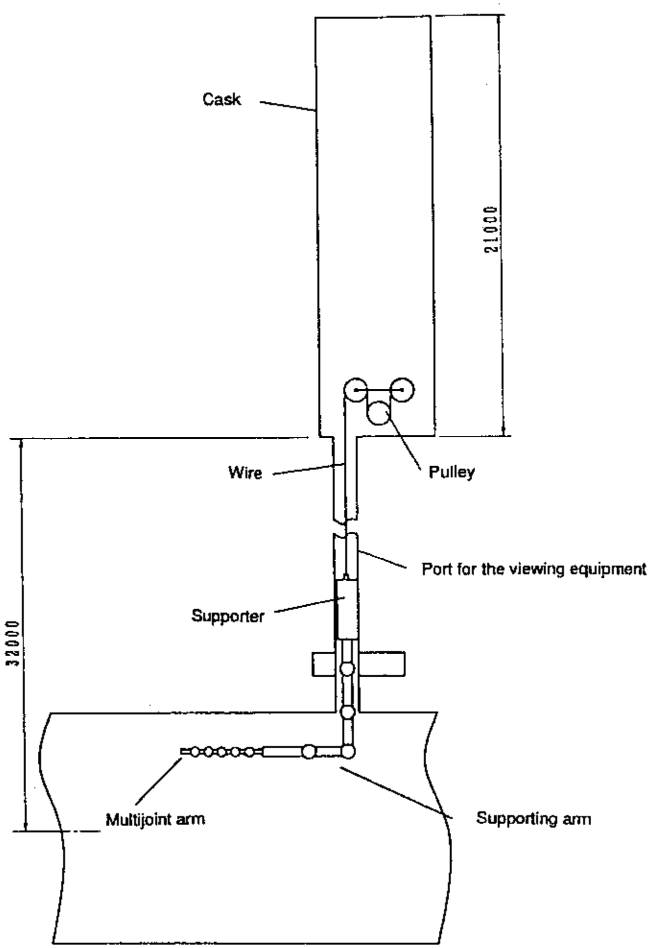


Figure 3.3.1 Outline of the optical image-fiber type viewing system for ITER

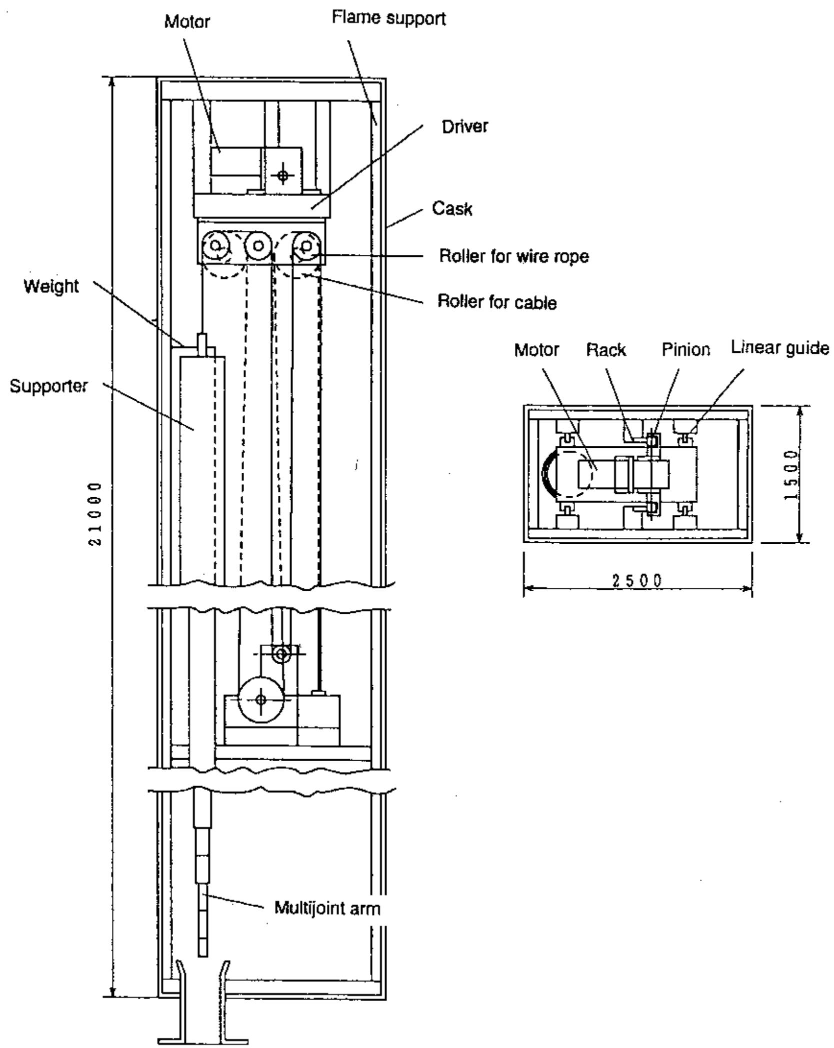


Figure 3.3.2 Cross section of the storage cask for the multi-joint manipulator

No.	Name
1	Motor
2	Gear
3	Inside gear
4	Linear guide
5	Rod
6	Rod holder
7	Guide roller
8	Cover
9	Fixed part of the support arm
10	Ball screw
11	Ball
12	Potentiometer
13	Outside mving cylinder
14	Inside moving cylinder
15	Base

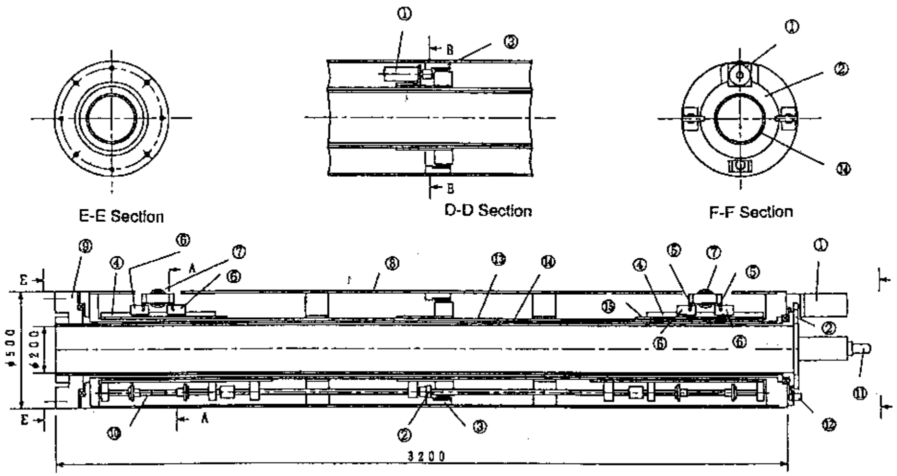


Figure 3.3.4 Cross section of the support structure for the multijoint arm

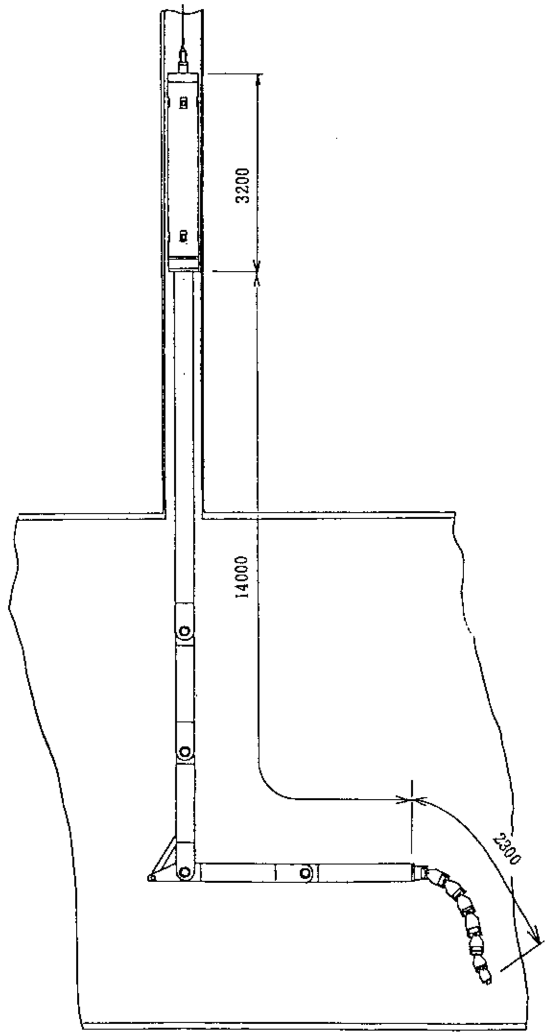


Figure 3.3.3 Outline of the multi-joint manipulator for the image fiber viewing

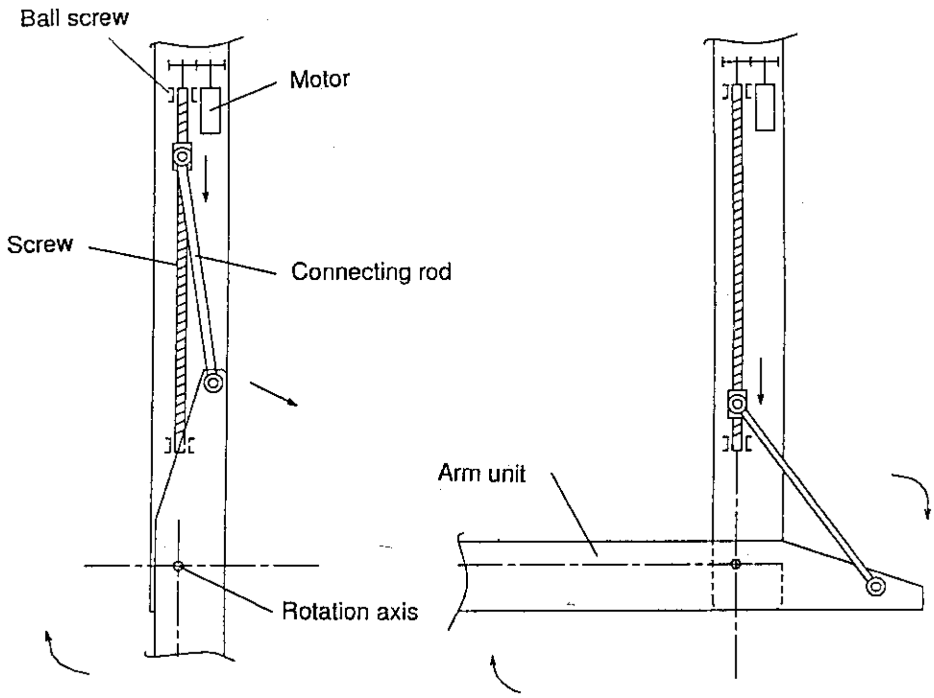
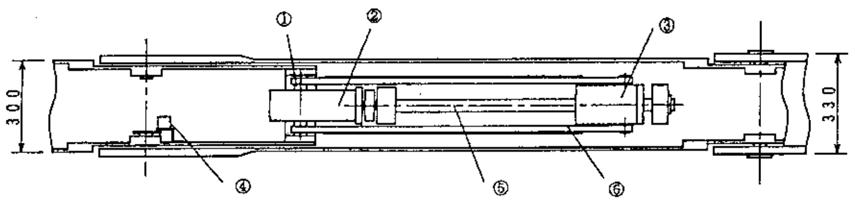


Figure 3.3.5-1 Basic mechanisms of the in-vessel supporting arm



No.	Name
1	Driving pin
2	Motor/Reduction gear box
3	Nut
4	Potentiometer
5	Ball screw
6	Connecting rod
7	Flame
8	Linear guide
9	Joint

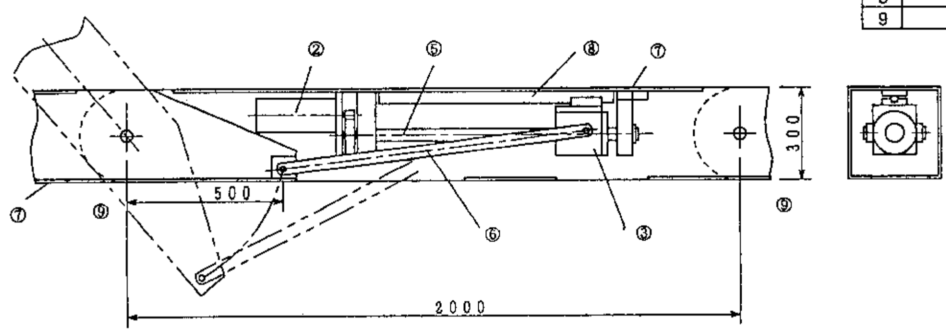


Figure 3.3.5-2 Cross section of the in-vessel supporting arm

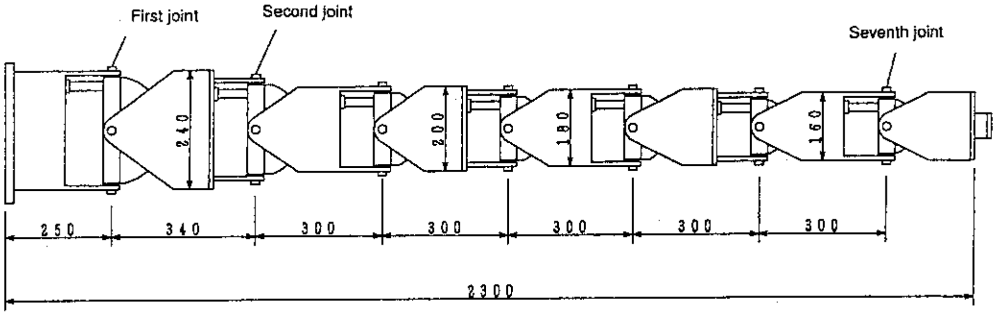


Figure 3.3.6-1 Outline of the multi-joint arm

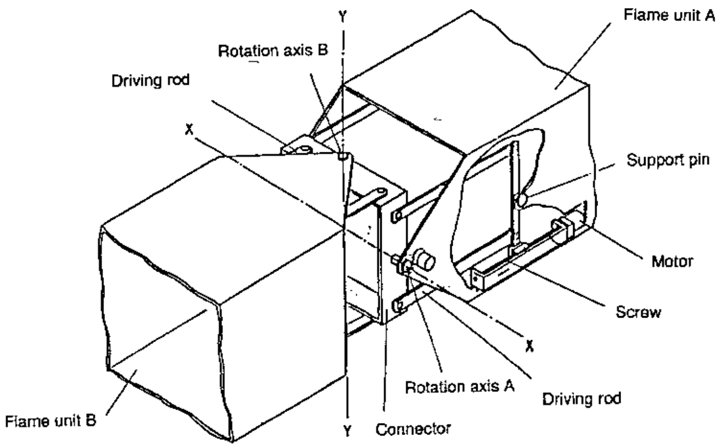
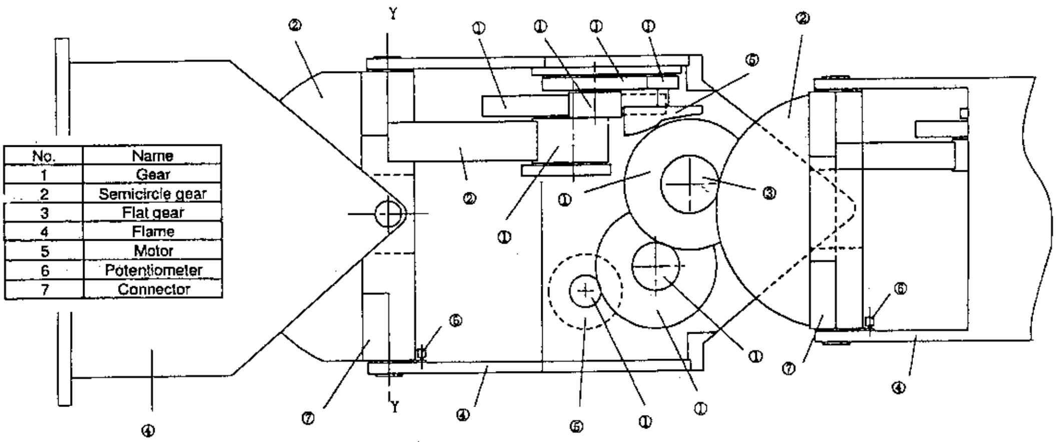


Figure 3.3.6-2 Conceptual design of the joint for the multi-joint arm



No.	Name
1	Gear
2	Semicircle gear
3	Flat gear
4	Flame
5	Motor
6	Potentiometer
7	Connector

Figure 3.3.6-3 Cross section between the first joint and the second joint (Plan)

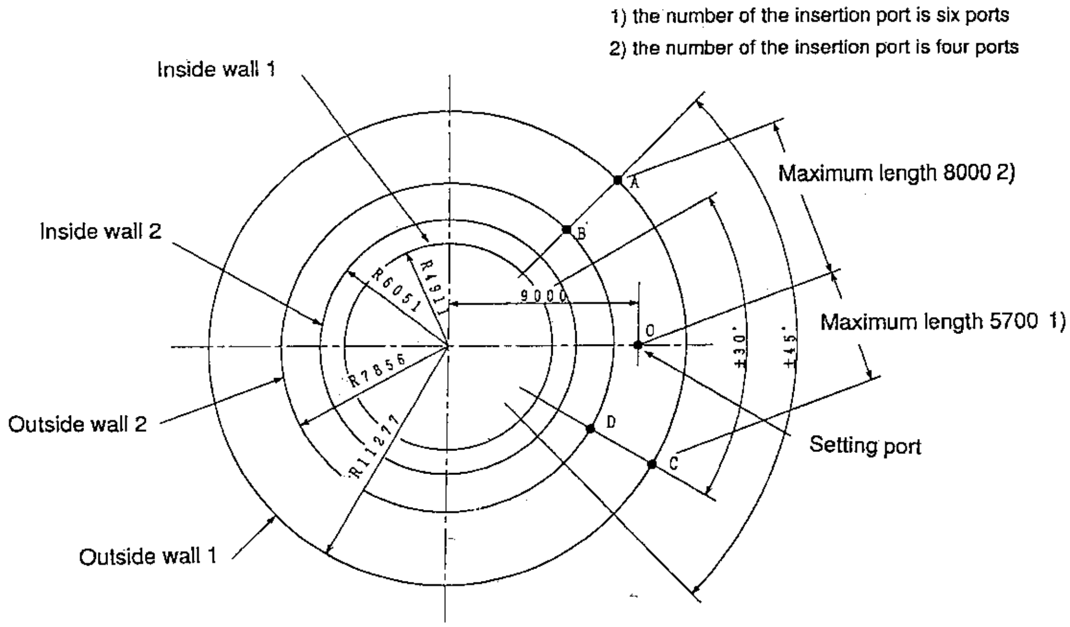


Figure 3.3.8 Requested movable range to the image fiber type viewing system in the troidal direction

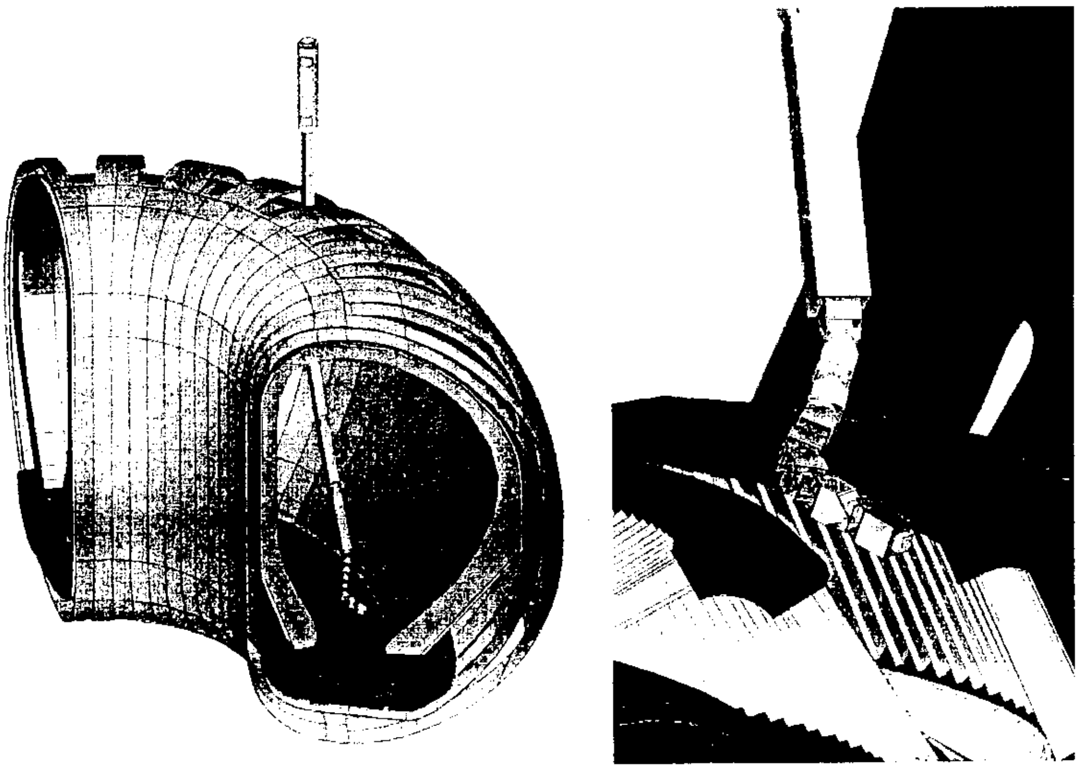


Figure 3.3.7 Typical schem of the image fiber type viewing system in the core of ITER

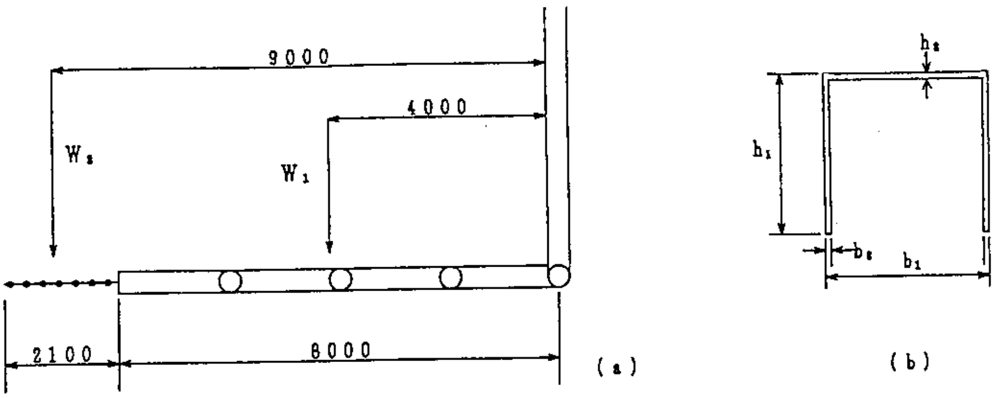


Figure 3.3.9 Loading conditions of the in-vessel supporting arm

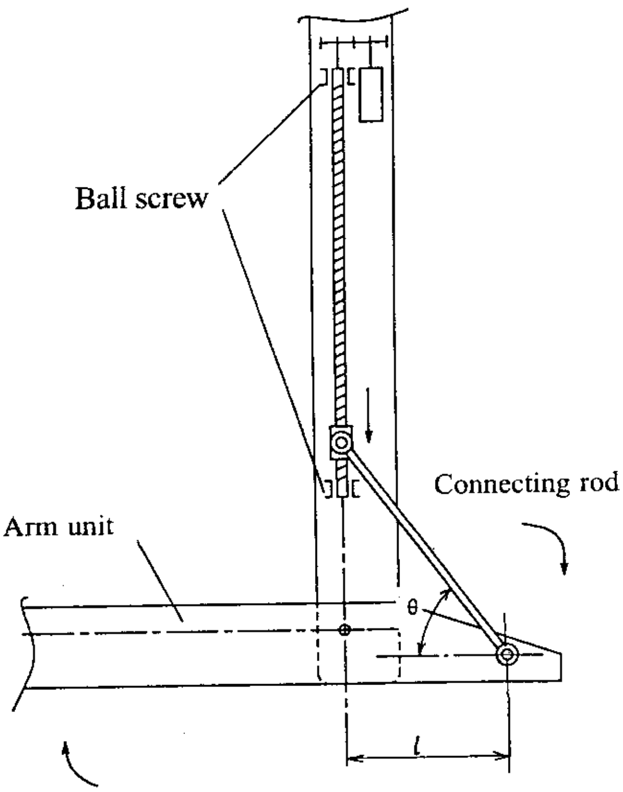


Figure 3.3.10 Structural concept of the in-vessel supporting arm

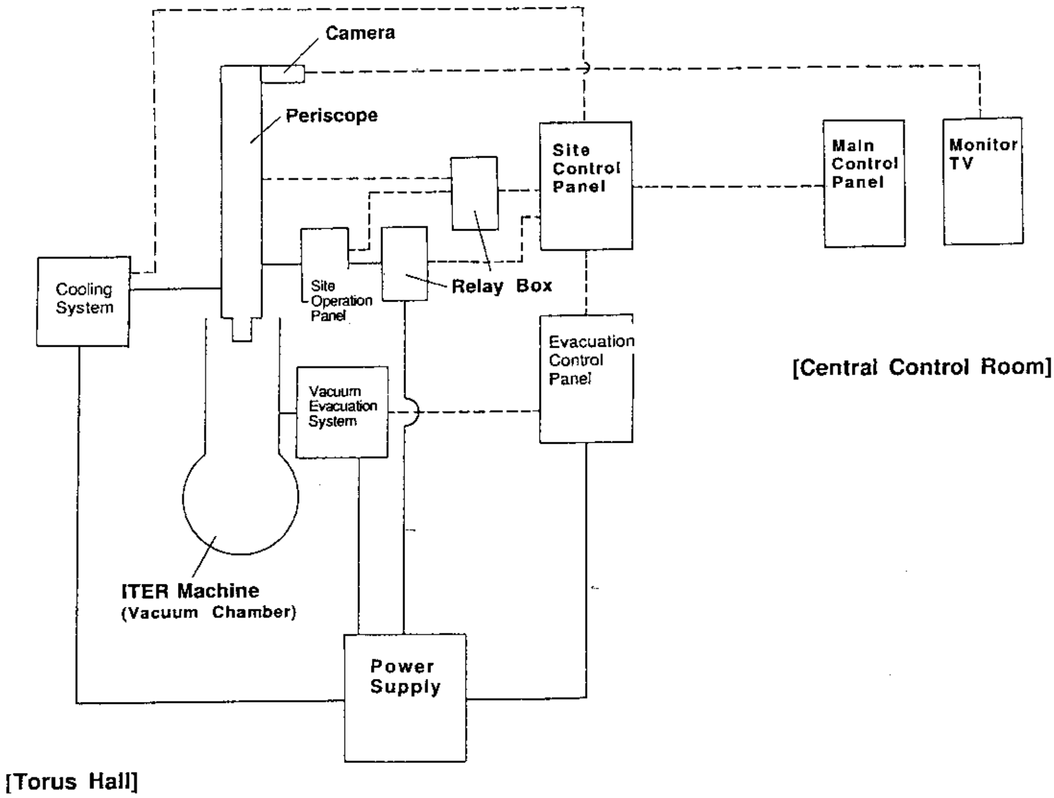


Figure 4.1 Basic block diagram of the control system for the periscope type viewing system

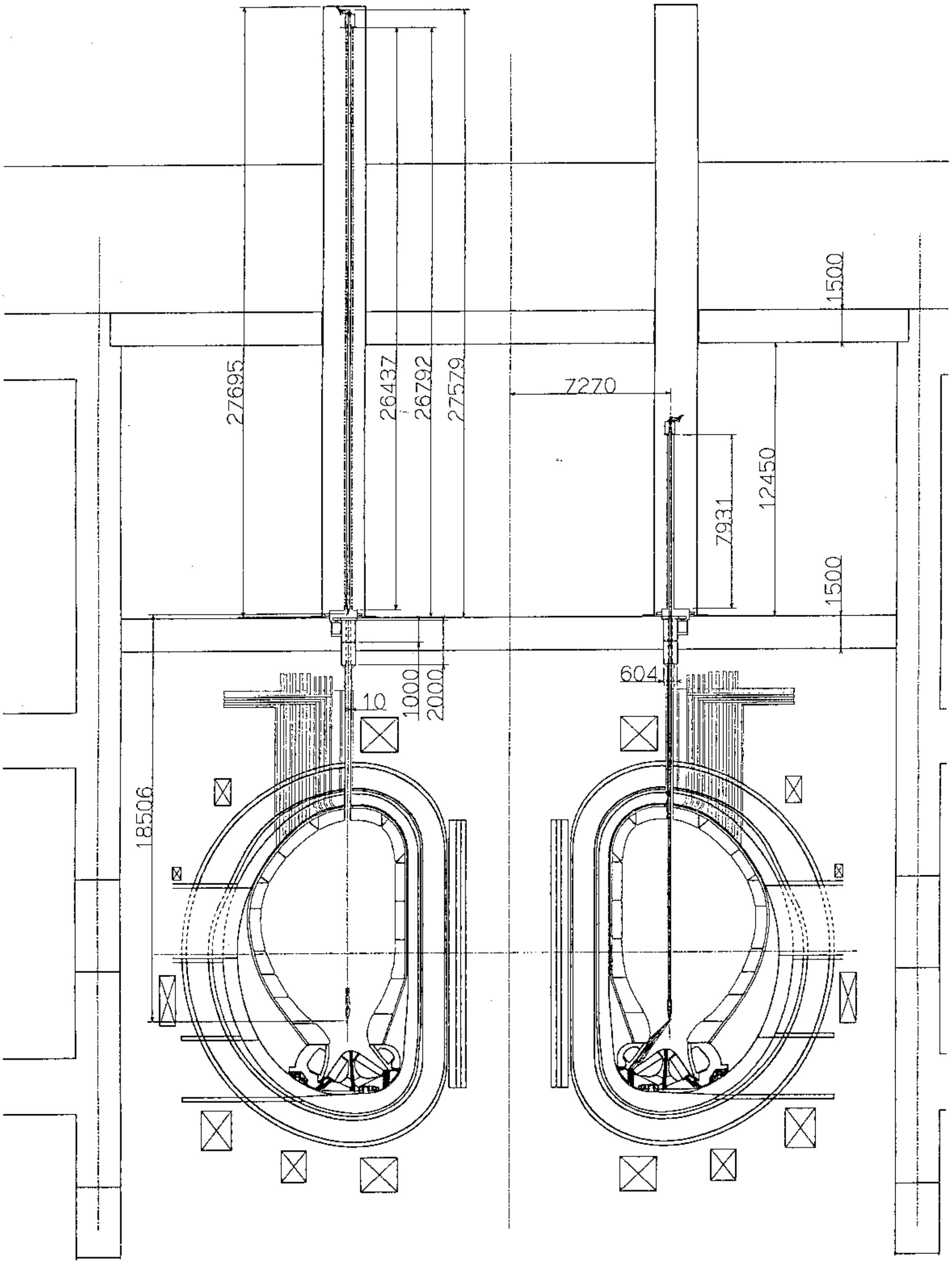
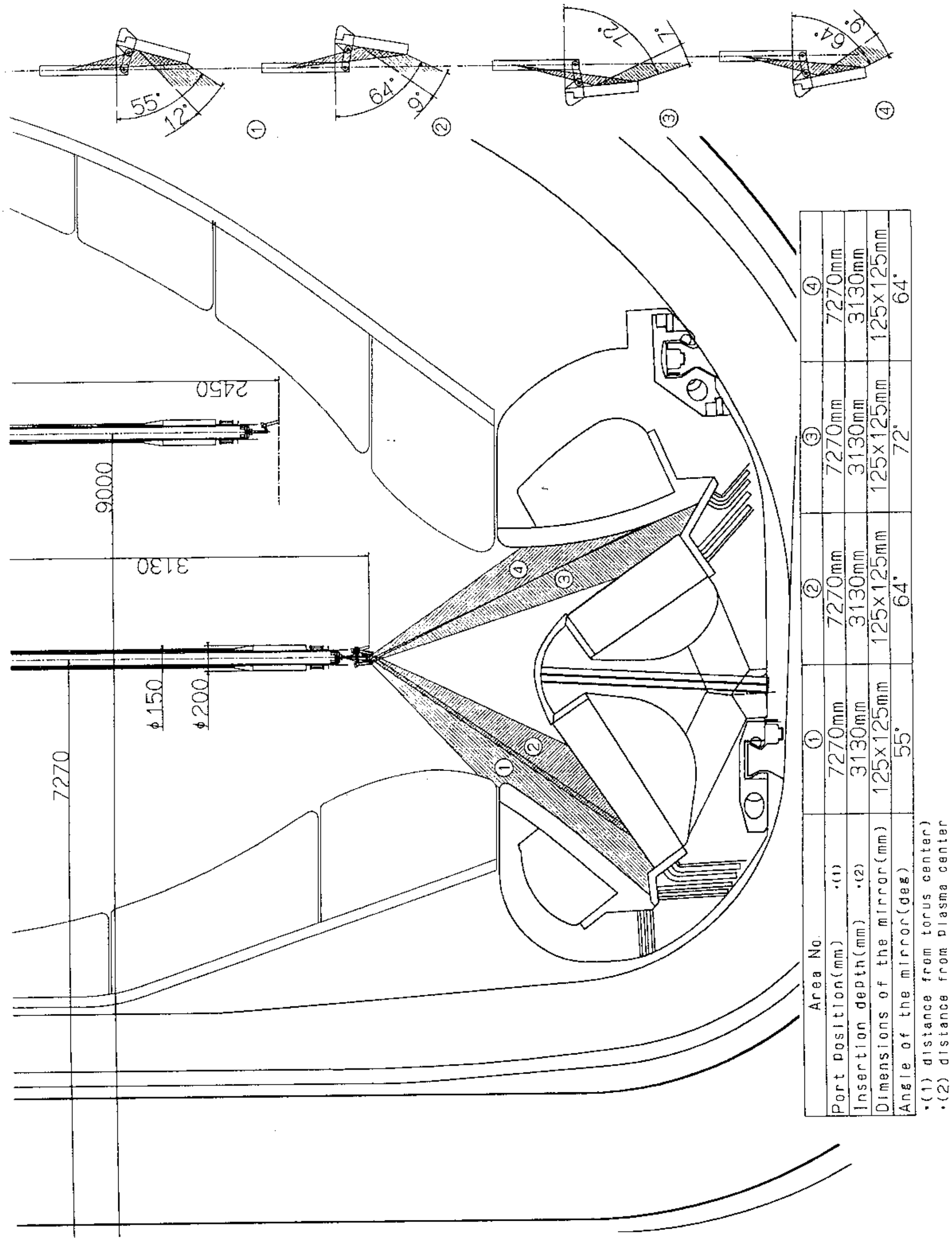


Figure 5.1 Typical configuration of the periscope type viewing system (located at 7.3m distance from machine center)



Area No.	①	②	③	④
Port position(mm) *(1)	7270mm	7270mm	7270mm	7270mm
Insertion depth(mm) *(2)	3130mm	3130mm	3130mm	3130mm
Dimensions of the mirror(mm)	125x125mm	125x125mm	125x125mm	125x125mm
Angle of the mirror(deg)	55°	64°	72°	64°

*(1) distance from torus center
*(2) distance from plasma center

Figure 5.2 Relation between the divertor plate and the viewing angles

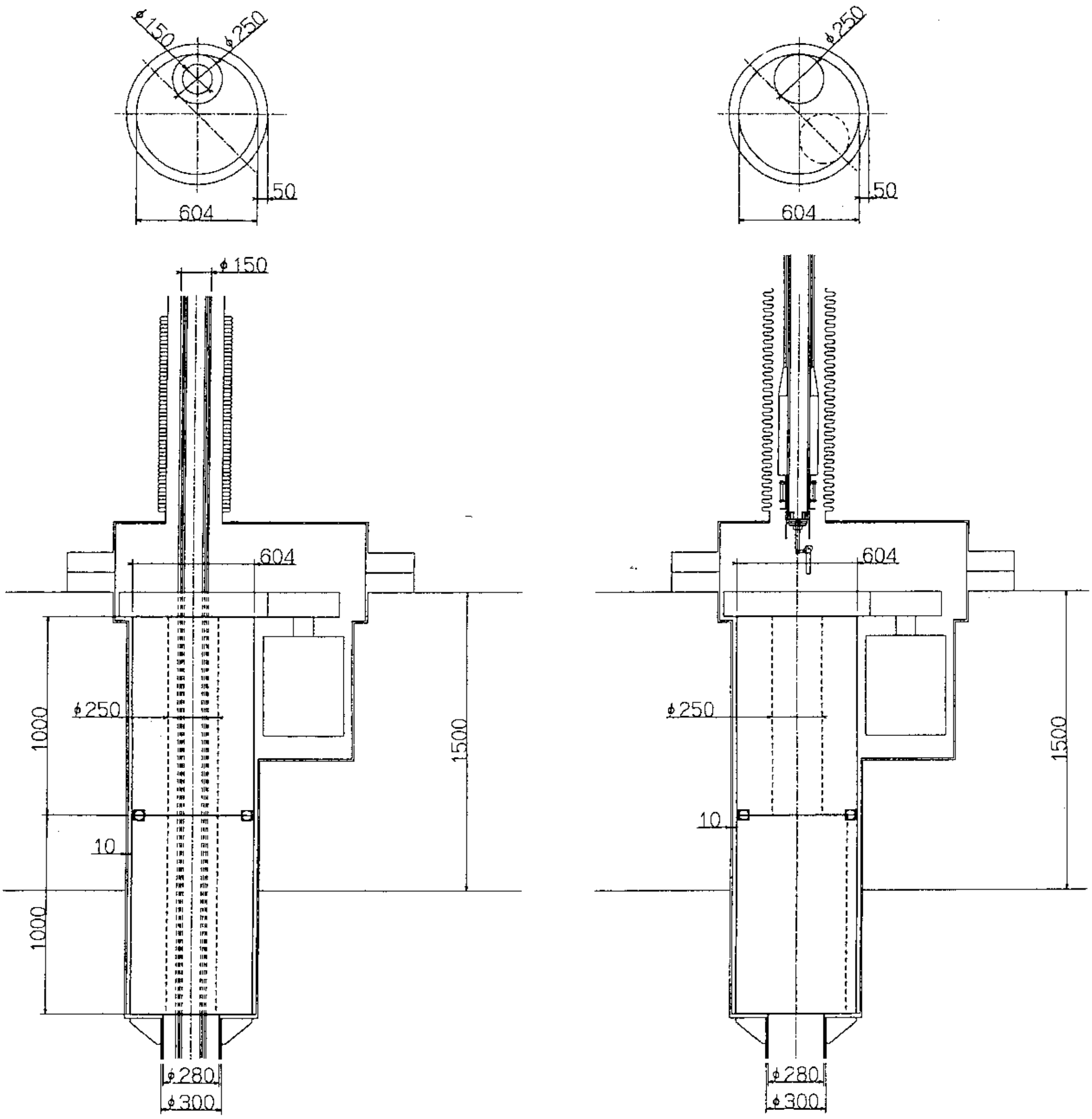


Figure 5.3 Details of the rotary type shielding plug