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Transportation of the in-vessel components to be repaired in the ITER hot cell is carried by two kinds of transporters, i.e., overhead cranes and floor vehicles. The access area for repair operations in the hot cell is duplicated by these transporters. Clear sharing of the respective roles of these transporters with the minimum duplication is therefore useful for rationalization. The overhead cranes, which are independently installed in the respective cells in the hot sell, cannot pass through the components to be repaired between cells, i.e., receiving cell and refurbishment cell as an example. If the floor vehicle with simple mechanisms can cover the inaccessible area for the overhead cranes, a global transporter system in the hot cell will be simplified and the reliability will be increased. Based on this strategy, the overhead crane and floor vehicle concepts are newly proposed. The overhead crane has an adapter for change of the end-effectors, which can be easily changed, to grasp many kinds of components to be repaired. The floor vehicle, which is equipped with wheel mechanisms for transportation, is just to pass through the components between cells with only straight (linear) motion on the floor. The simple wheel mechanism can solve the spread of the dust, which is the critical issue of the original air bearing mechanism for traveling in the 2001 FDR design.

Rescue scenarios and procedures in the hot cell are also studied in this report. The proposed rescue crane has major two functions for rescue operations of the hot cell facility, i.e., one for the overhead crane and the other for refurbishment equipment such as workstation for divertor repair . The rescue of the faulty overhead crane is carried out using the rescue tool installed on the rescue crane or directly traveled by pushing/pulling by the rescue crane after docking on the faulty overhead crane. For the rescue of the workstation, the rescue crane consists of a telescopic manipulator (maximum length of 6500 mm) with rescue tool such as wrench for operation of the faulty driving mechanism through the redundant mechanism in order to release the activated component.

Keywords: ITER, Hot Cell, Repair, Remote Handling, In-vessel Components, Rescue, Overhead Crane, Floor Vehicle, Transportation

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ITERホットセルにおける炉内機器の修理用共通機器の設計とレスキューシナリオの検討

日本原子力研究開発機構　核融合研究開発部門
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ITER ホットセル内における修理用炉内構造物の移動は天井クレーンと床走行台車の２種類の搬送機器によって行われる。これらの搬送機器のホットセル内での移動範囲は現在の設計では重複しているため、ホットセルの合理化を進めるためにはこれら２種類の搬送機器の役割分担を明確にする必要がある。天井クレーンはホットセル内の各部屋（セル）に独立に設置されているため、同じ天井クレーンを用いて、例えば受け入れセルから修理セル等の部屋間の仕切り壁を越えて構造物を移動させることは困難となる。ここで、例えばもう１つの搬送機器である床走行台車が単純な機構で天井クレーンの移動困難領域の移動を補完できれば、ホットセル内での搬送システム全体が単純化可能となり、信頼性も向上する。この考え方を基に、合理的な天井クレーンと床走行台車を新たに提案した。天井クレーンは、修理が必要となる各種の炉内構造物を把持し移動する必要から、容易に着脱可能なエンド・エフェクタの交換用アダプタを備える設計とした。床走行台車は、床上移動用の車輪を備えることにより、床上を単純な直線移動のみでホットセル内の部屋間の移動を可能とした。この車輪の採用は、従来の設計であるエアーベアリング方式によるホットセル内のダストの飛散の問題も同時に解決した。

ホットセル内の修理用遠隔機器の故障時におけるレスキューシナリオの検討も実施した。ホットセル内での機器の故障時におけるレスキューは、レスキュー用クレーンにより行われる。このレスキュー用クレーンは、天井クレーンのレスキューと炉内構造物の修理用遠隔機器のレスキューのために２つの機能を持つ。天井クレーンの故障時におけるレスキューでは、レスキュー用クレーン

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に備え付けたレスキューツールにより、または故障した天井クレーンを直接押すまたは引く機能により、故障したクレーンを所定の場所に移動し修理を行う。炉内構造物の修理用遠隔機器のレスキューに関しては、修理中の放射化した炉内構造物を移動し隔離するために、故障した駆動部に直接アクセスできる冗長機構を修理用遠隔機器に備え、さらに伸縮型マニピュレータをレスキュー用クレーンに備え付けることにより故障部の応急修理を可能とした。

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1. Introduction

The ITER hot cell building, as shown in Fig. 1, provides space and functions for:
(1) Repair and storage of radioactive or highly contaminated components and materials
(2) Rad-waste process and storage
(3) Storage and maintenance of remote handling tools
The equipment in these facilities is operated mainly by remote control, because the hot cell systems provide space and facilities for highly radioactive and contaminated in-vessel components, and the scheduled repair requirements should be achieved.

There are following many components will be repaired in the hot cell for reuse them as much as possible in the operation phase.

- Divertor
- Blanket module
- Test blanket module (TBM)
- Diagnostics
- Radio-frequency system
- Ion source of neutral beam injector (NBI)

The repair requirements are however not sufficient in the FDR for detail study because the concepts of the most of these components have not however been developed well. Therefore, this report describes a proposal of the basic scenario of common equipment in the hot cell, i.e., proposals of the common transporters (overhead crane and floor vehicle) from rationalization and rescue scenario of the equipment points of view in the hot cell. The study in the report is based on the available repair scenario and repair equipment for the representative component such as divertor, whose repair requirements are relatively developed as a basis of the other components. The study is performed based on the hot cell layout in the 2001 FDR [1] and divertor design in 2003 as much as possible.

The objective of this report is to study and propose the remote handling scenario and design of the common equipment such as overhead crane and floor vehicle and the rescue scenario and mechanism during the failure of the remote repair equipment /tool in the hot cell, based on the representative component design from a remote handling point of view in order to develop the basic common maintenance scenario and design in the hot cell.

2. Proposal of Common Refurbishment Equipment in Hot Cell

Two types of transporters as common equipment, i.e., overhead cranes and floor vehicles (floor mobile transporter), are adopted in the hot cell in 2001 FDR [1, 2]. These common transporters are reviewed from rationalization and reliability points of view. A typical workstation for refurbishment of the representative component such as divertor is also reviewed from feasibility and flexibility points of view. After review and clarify the issues, some studies are performed and new scenarios and concepts are proposed.

2.1 Transporters

Transportation of the components to be repaired is carried by two kinds of transporters, i.e., overhead cranes and floor vehicles. The access area for repair operations in the hot cell is duplicated by two kinds of transporters. Clear sharing of the respective roles of the transporters with the minimum duplication is useful for rationalization. If the access area by the overhead crane is the maximized, there is a possibility of the simplification of the requirements to the floor vehicle. The access of the overhead crane cannot be provided only during passing transportation of the components to be repaired between cells, i.e., receiving cell and refurbishment cell as an example. Therefore, the required function of the floor vehicle is simplified, i.e., only straight (linear) movement for passage on the floor between the cells is required.

Air bearing mechanism is adopted for the transfer mechanism of the floor vehicle in the 2001 FDR [1], as shown in Fig. 2. The floor vehicle consists of two staged mechanisms, i.e., sliding mechanism in the upper stage for receiving the components and air bearing mechanism in the lower (bottom) stage for transportation on the floor in the hot cell, as shown in Fig. 2. The management of the dust in the hot cell is a critical issue. If the air bearing is used in the cell, the spread of the dust makes additional problems in the cell.

The straight movement of the floor vehicle for passage on the floor can simplify the traveling mechanism on the floor without air bearing, which is composed of complicated systems such as cable handling system for air supply and control system for positioning during traveling.

Based on the above review results, a proposed approach of the transporter scenario is as follows.

- Maximum use of the overhead crane for transportation of the components to be repaired in the hot cell.
- Minimum requirement to the functions of the floor vehicle for transportation of the components

2.1.1 Overhead Crane

The overhead crane is the major transporter of the components to be repaired in the hot cell. Three overhead cranes are installed in parallel in the respective cells in the hot cell building in 2001 FDR, as shown in Fig. 1. The respective cranes have an adapter for change of the end-effectors to grasp many kinds of components. The end-effector can be easily changed at the adapter of the crane. Figures 3 and 4 show an example of the end-effector installed on the overhead crane for transportation of the divertor. The divertor is grasped from both sides at four positions.

2.1.2 Floor Vehicle (Floor Mobile Transporter)

Due to the maximum use of the overhead crane for transportation of the components to be repaired, the requirements to the floor vehicle is minimized, i.e., the requirement of the function of the floor vehicle is just to pass the components with only straight (linear) motion on the floor between cells, e.g., receiving cell and refurbishment cell. Figure 5 shows a schematic view of the floor vehicle. The floor vehicle consists of four fixing mechanisms by sliding of the components from four positions and two sets of wheel mechanisms for traveling on the rails installed on the floor with straight motion. The wheel mechanism consists of four wheels. The wheel mechanism on the rail for traveling in the hot cell, in which the dust is accumulated, can solve the spread of the dust, which is the critical issue of the air bearing mechanism for traveling in the 2001 FDR design. The wheel mechanism can also simplify the mechanism and increase the reliability of the mechanism for traveling on the floor in the cell without increase the additional requirements to the overhead crane.

Figure 6 shows a transfer scenario of the in-vessel component, divertor as an example in this figure, in the hot cell. The combination of the overhead crane and floor vehicle for the transportation of the component is schematically shown in Fig. 6.

a) After docking of the transfer cask on the entrance of the hot cell, divertor is handled and transferred on the floor vehicle by handling manipulator
b) Divertor is lifted from the floor vehicle, transferred and lowered on the floor vehicle by the overhead crane in the receiving cell
c) Divertor passes through the wall between receiving cell and refurbishment cell by the floor vehicle
d) Divertor is lifted from the floor vehicle and transferred on the repair work table for refurbishment in the refurbishment cell by the overhead crane

2.2 Workstation for Refurbishment

As a typical workstation for refurbishment of the representative component, that for the divertor was reviewed. The description in the 2001 FDR is as follows.

Divertor cassette plasma-facing component (PFC) replacement workstation has two identical workstations in the common refurbishment cell and consists of the following equipment.

- Cassette supporting stand for refurbishment: 2 lines
- Handling robot: column-type robot arm
- End-effectors/tools:
  - Bolting tool: torque wrench
  - Cutting tool: with laser cutting head
  - Drilling tool: with drill tool

- Expansion tool: with special mandrel to expand fastener connecting PFC to cassette body
- Welding tool: with TIG welding head
- Weld inspection tool: ultrasonic transducer or electro-magnetic acoustic transducer

- End-effector tool storage: all end-effectors and tools are parked in a tool storage stand

Although major equipment for divertor repair is a handling robot and a repair (work) table, the concept of the equipment is inconsistent with the requirements. As shown in Fig. 7, the handling robot cannot have access to the required positions such as welding and cutting positions of the cooling pipe and supporting pins of the PFC for replacement of the PFC. In addition, the configuration of the repair table in the workstation is not consistent with that of the divertor, i.e., the interference between the cooling pipe located at the rear side of the divertor cassette and the repair table (tray) as shown in Fig. 7.

To solve these issues, the following concepts of the handling robot and repair table for divertor refurbishment are proposed. As a basic strategy of the handling robot, the function of the one robot in the FDR is divided into two functions in to two robots, i.e., one robot for heavy duty manipulation such as replacement of the PFC up to 2 t and the other for light duty manipulation such as pipe welding/cutting/inspection and bolt connection/disconnection. The basic concept of the proposed two types of the robots (heavy work robot and light work robot) is shown in Figs. 8 and 9. The two type robots are located at the both sides of the divertor cassette for effective parallel operations. The robots also travel to access to the required positions at the respective sides in parallel along the rails installed on the floor. These robots will be applicable to the other components such as blanket to be repaired in the hot cell. The concept of the repair table is also shown in Fig.8. The elevation mechanism using a link system is adopted with a grasping mechanism for fixture of the divertor on the table, so as to locate the divertor in a good position for the effective operations by the heavy and light duty robots

2.2.1 Function and Mechanism of Two Types of Handling Robots

(1) Heavy work robot

Heavy work robot is composed of a cylindrical coordinate type body and end-effector. Major objectives of the robot are to replace and transfer the PFC up to 2 t from the cassette body in the workstation. The degrees of freedom of the cylindrical type robot are four, i.e., traveling, elevation, sliding and rotation to access and replace the three types of the PFC, i.e., inner target, dome and outer target, as shown in Fig. 10 and 11. The end-effector has an interface with the cylindrical type robot in order to be easily changed for application to the other components such as blanket. The degrees of freedom of the end-effector for divertor refurbishment are six, i.e., four for grasping the PFC, sliding and rotation to access and replace the three types of the PFC, i.e., inner target, dome and outer target, as also shown in Fig. 10.

(2) Light work robot

Light work robot is an articulated arm type robot with an interface applicable to the variety of tools for refurbishment of the divertor (and the other components such as blanket). The concept of the light work robot is shown in Fig. 12 and 13. Major objectives of the robot are to perform the pipe welding/cutting/inspection, insert/drilling the connection pins and bolt connection/disconnection for replacement of the PFC. The payload is around 100 kg for tool handling with a positioning accuracy less than 2 mm. The degrees of freedom of the articulated arm robot are six for access to the required positions (see Fig. 13).

2.2.2 Approach for PFC Installation into the Deformed Cassette Body

When the deformation of the interface between the PFC and the cassette body after removal of the fault PFC is found to be lager than the allowable level due to intense heating and EM loads under the allowable condition of the deformation of the interface between the cassette body and supporting rail on the vacuum vessel, the repair of the cassette body is assumed to be difficult in the hot cell because the stiffness of the cassette body is too high to modify the deformation within the allowable configuration. Based on the above assumption, the scenario of the installation of the new PFC is studied in order to reduce the rad-waste as much as possible. It is also suitable for the cassette body to be reinstalled in the initial position in order to reduce the misalignment due to change of the interface with the supporting rail. The critical issue is a difficulty of pin inserting connection through the two holes located at the PFC and cassette body due to mismatch between deformed cassette body and new PFC fabricated according to the reference drawing (see Fig. 14).

To solve the this issue, it is proposed that the interface (pin connection hole) of the new PFC side only is customized in the outside of the hot cell according to measurement result of the deformation (change of the location of connection hole) of the cassette body in the hot sell. The above proposal will be applicable to the other components to be repaired in the hot cell.

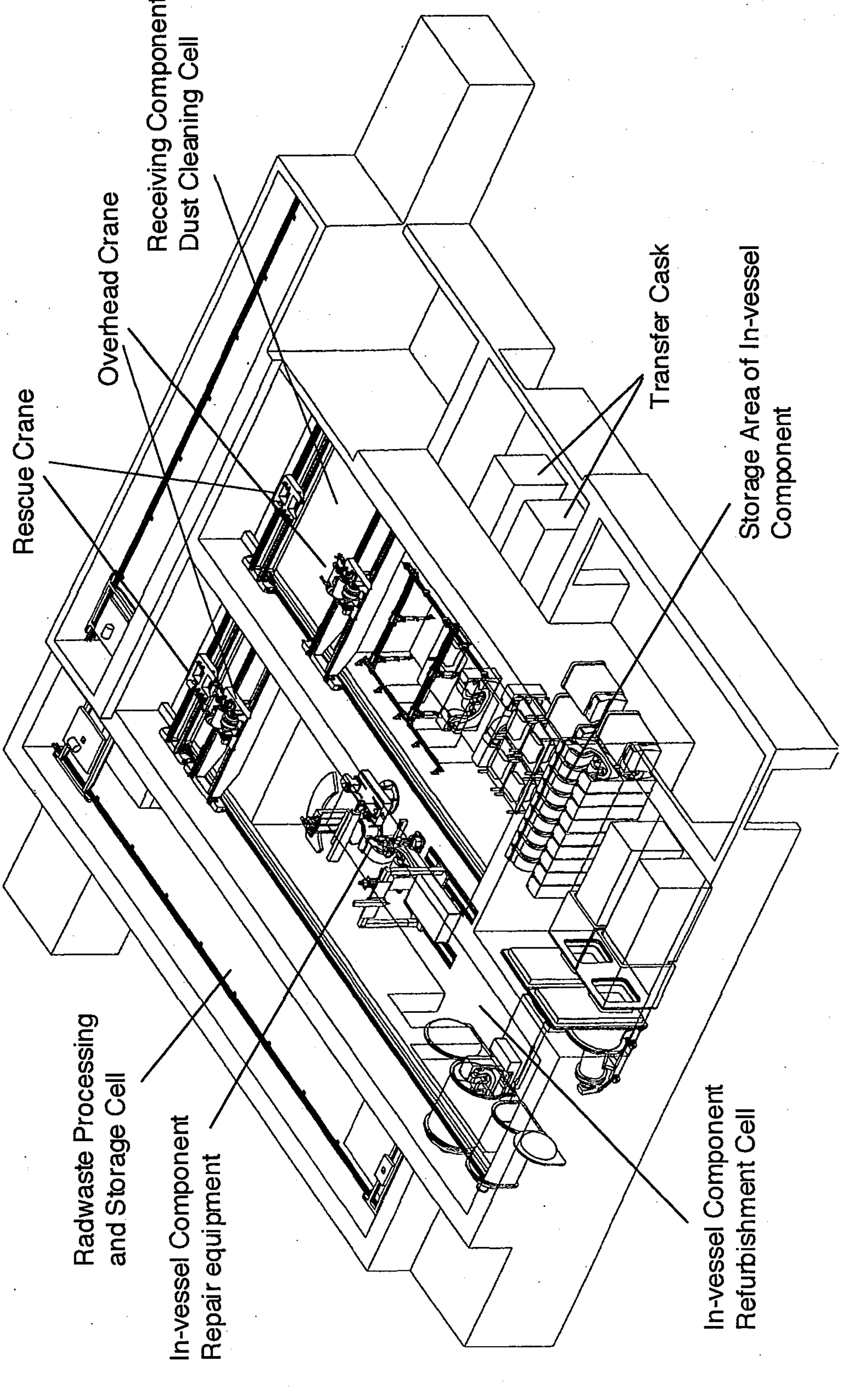

Fig. 1 Schematic view of ITER hot cell

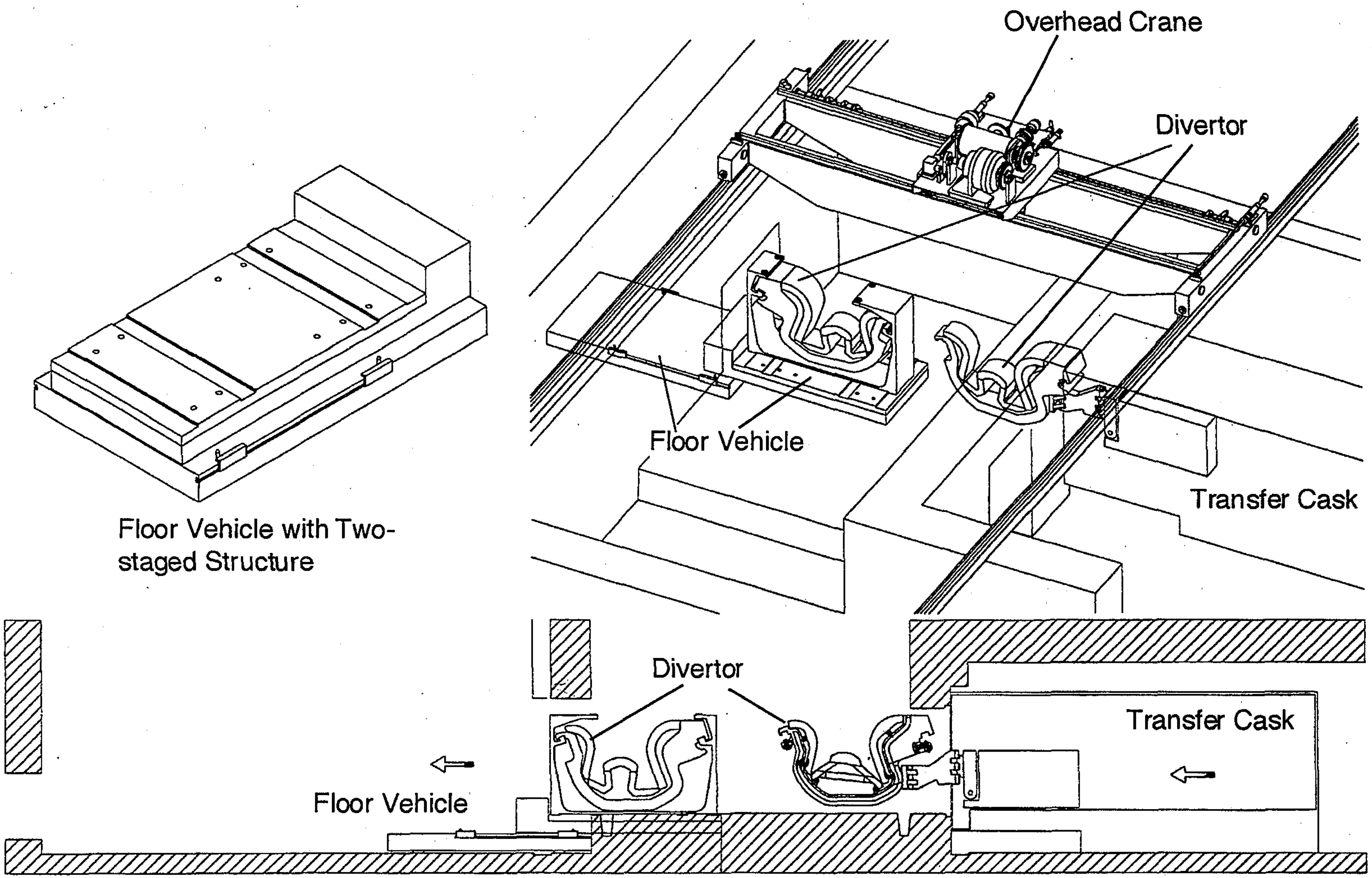

Fig. 2 Schematic view of floor vehicle for transportation of the in-vessel components in the hot cell

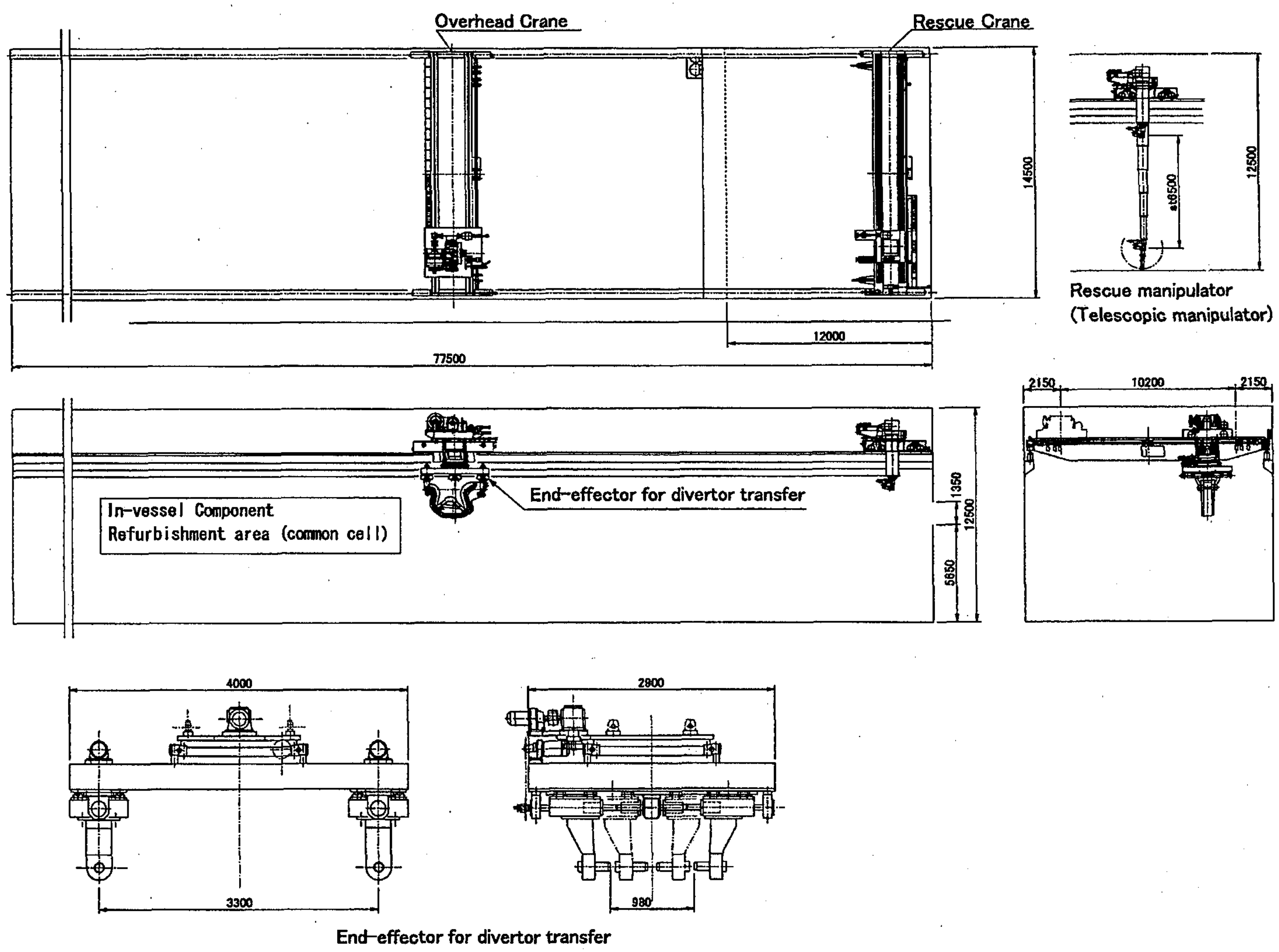

Fig. 3 Schematic view of the overhead crane with end-effector for divertor transportation as an example

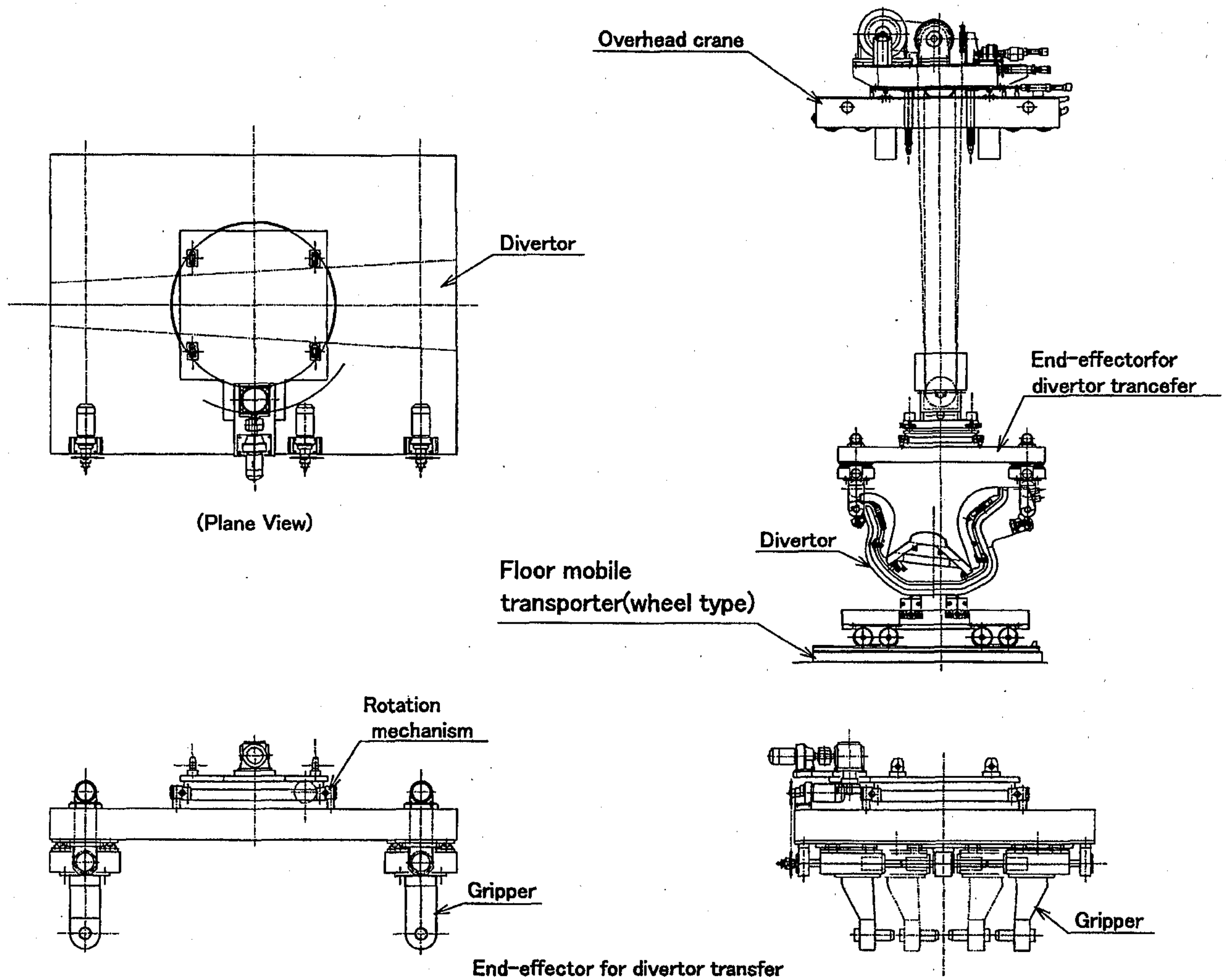

Fig. 4 Schematic view of the end-efector installed on the overhead crane for divertor transportation as an example

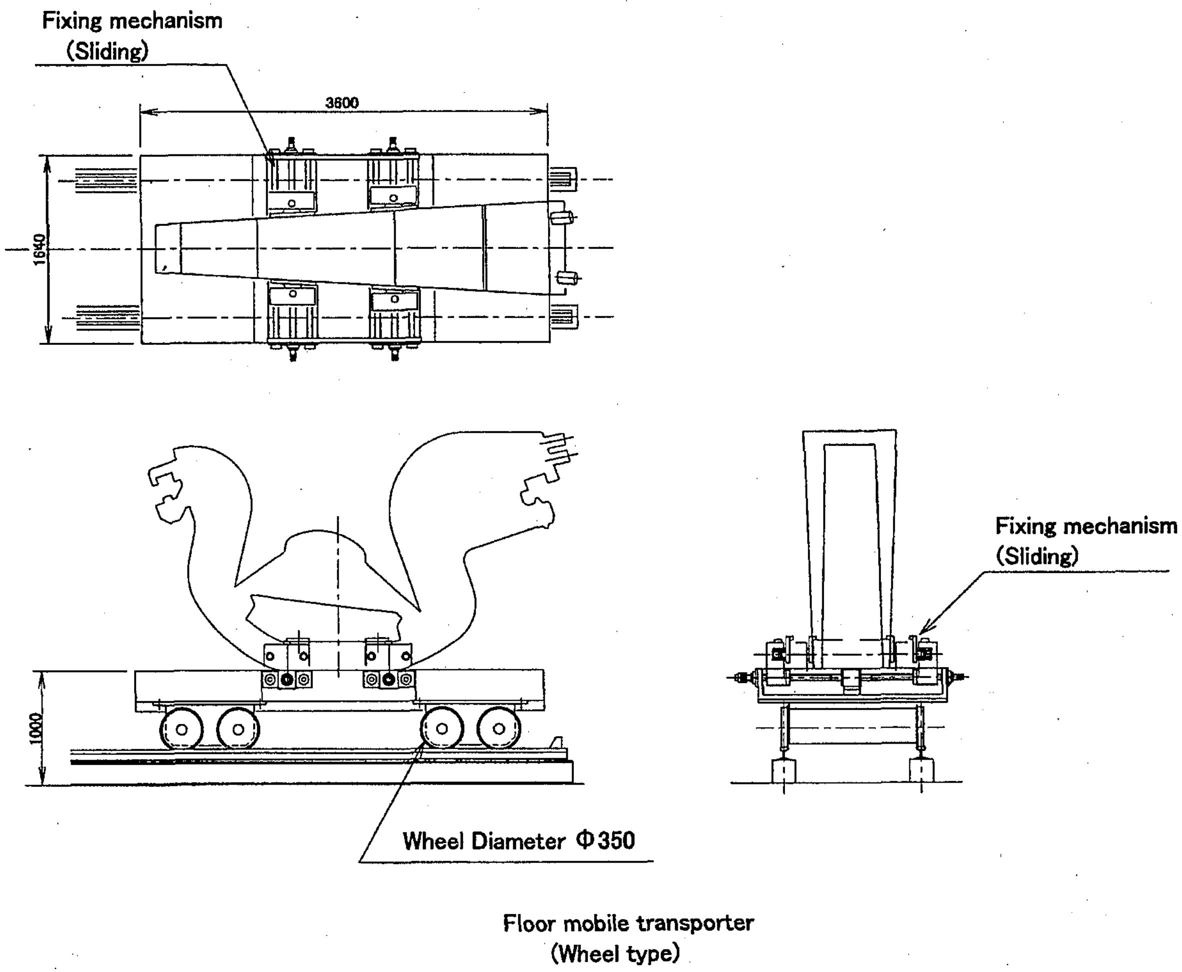

Fig. 5 Schematic view of the floor vehicle transporter (Floor mobile transporter) using a wheel system on the rails installed on the floor

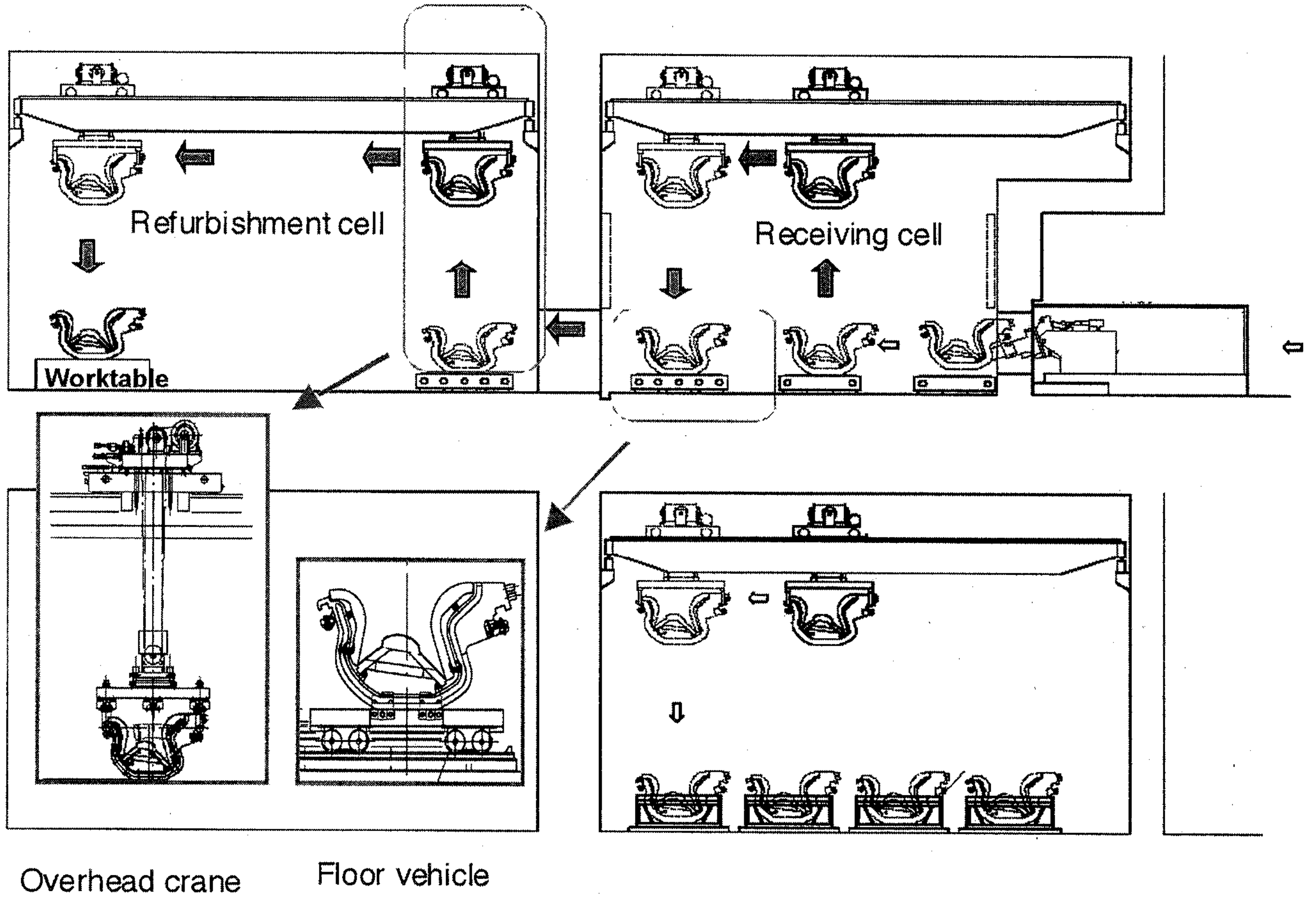

Fig. 6 Transfer scenario of the in-vessel component such as divertor using a combination of the overhead crane and floor vehicle

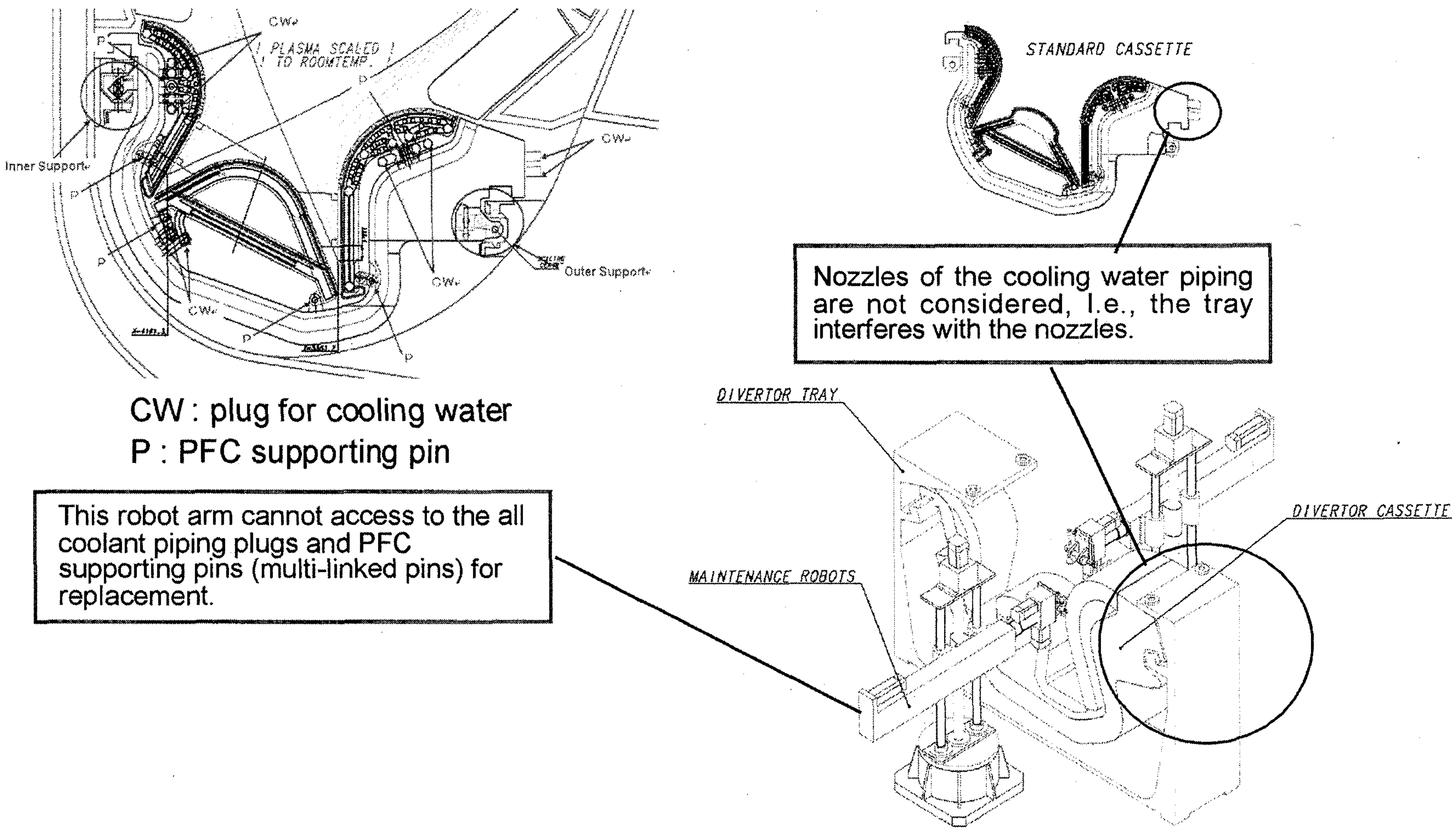

Fig. 7 Schematic view of the handling robots in 2001 FDR for divrtor refurbishment

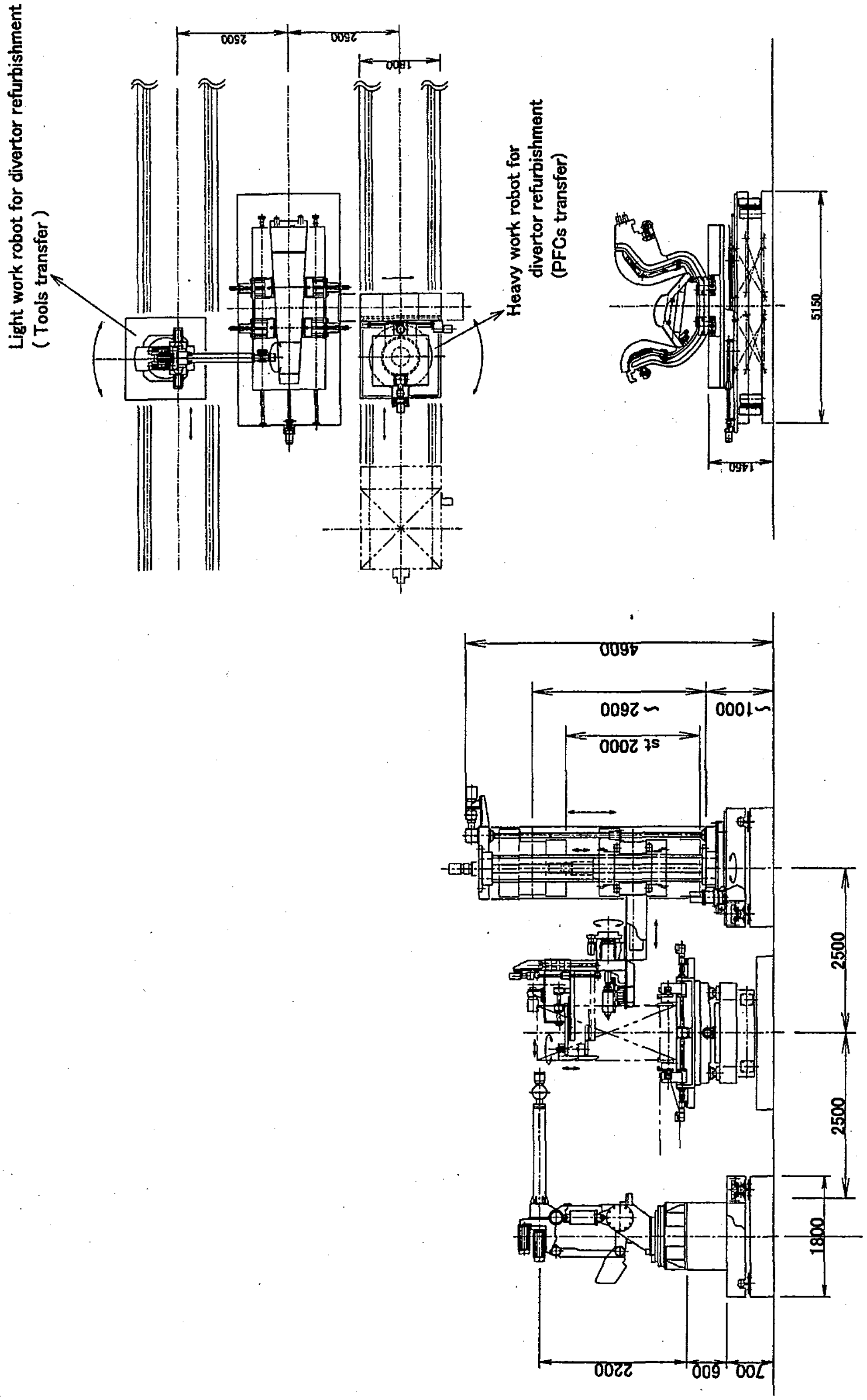

Fig. 8 Basic concept and layout of the proposed two types of the robots (heavy work robot and light work robot)

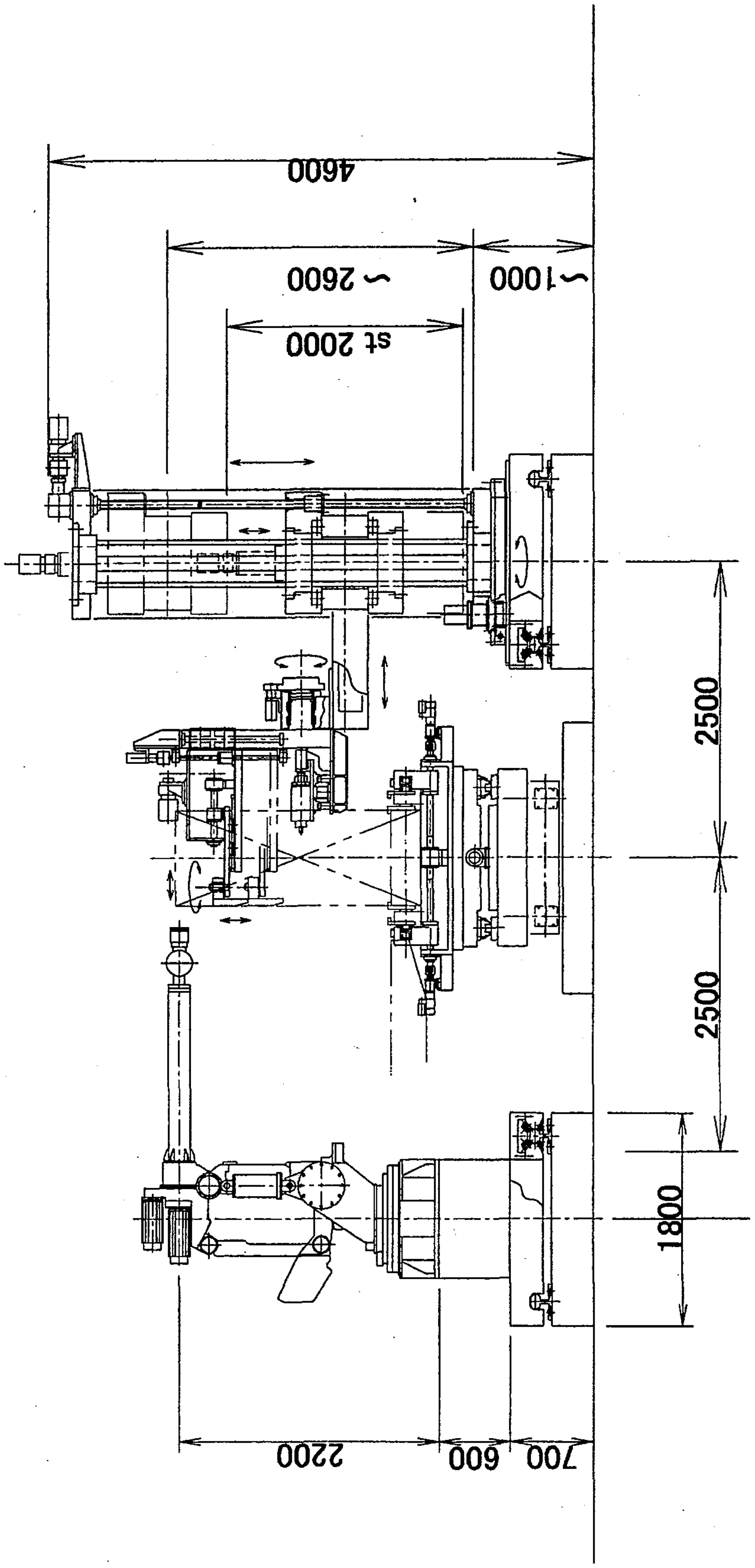

Fig. 9 Schematic view of the combination of the refurbishment operations using two robots

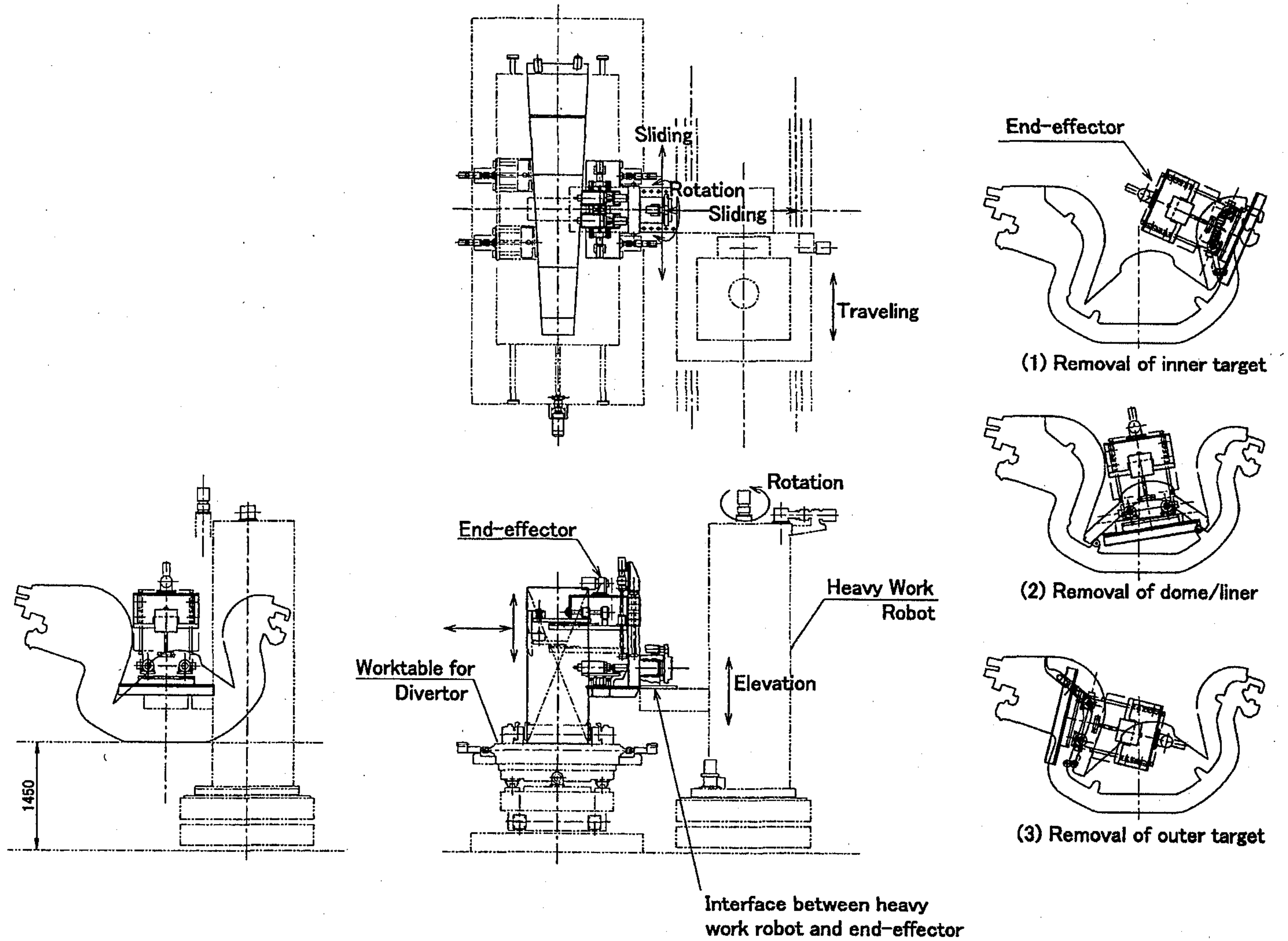

Fig. 10 Replacement procedures of the PFC of the divertor using heavy work robot

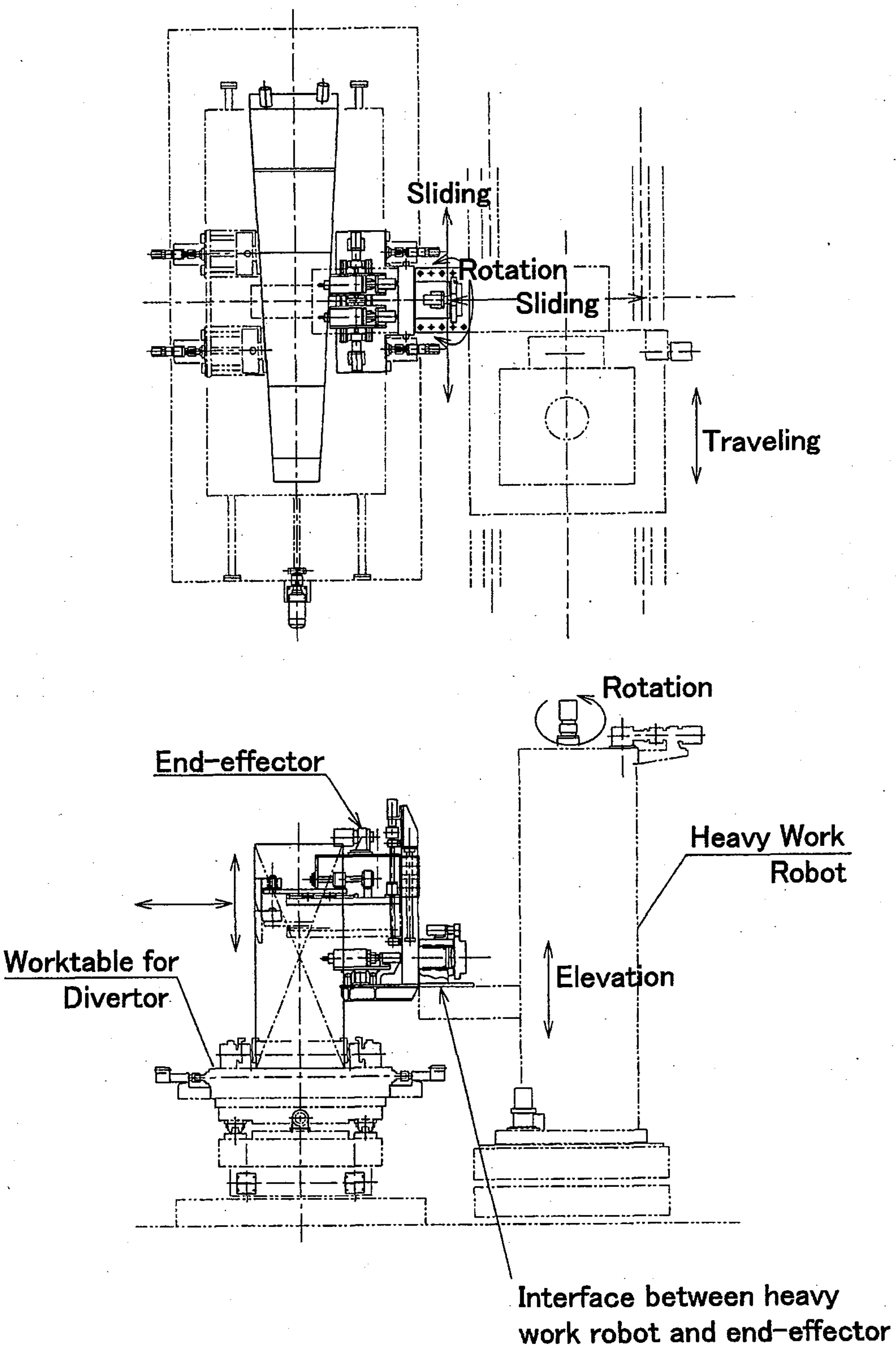

Fig. 11 Cylindrical coordinate type heavy work robot with end-effector for replacement of the PFC

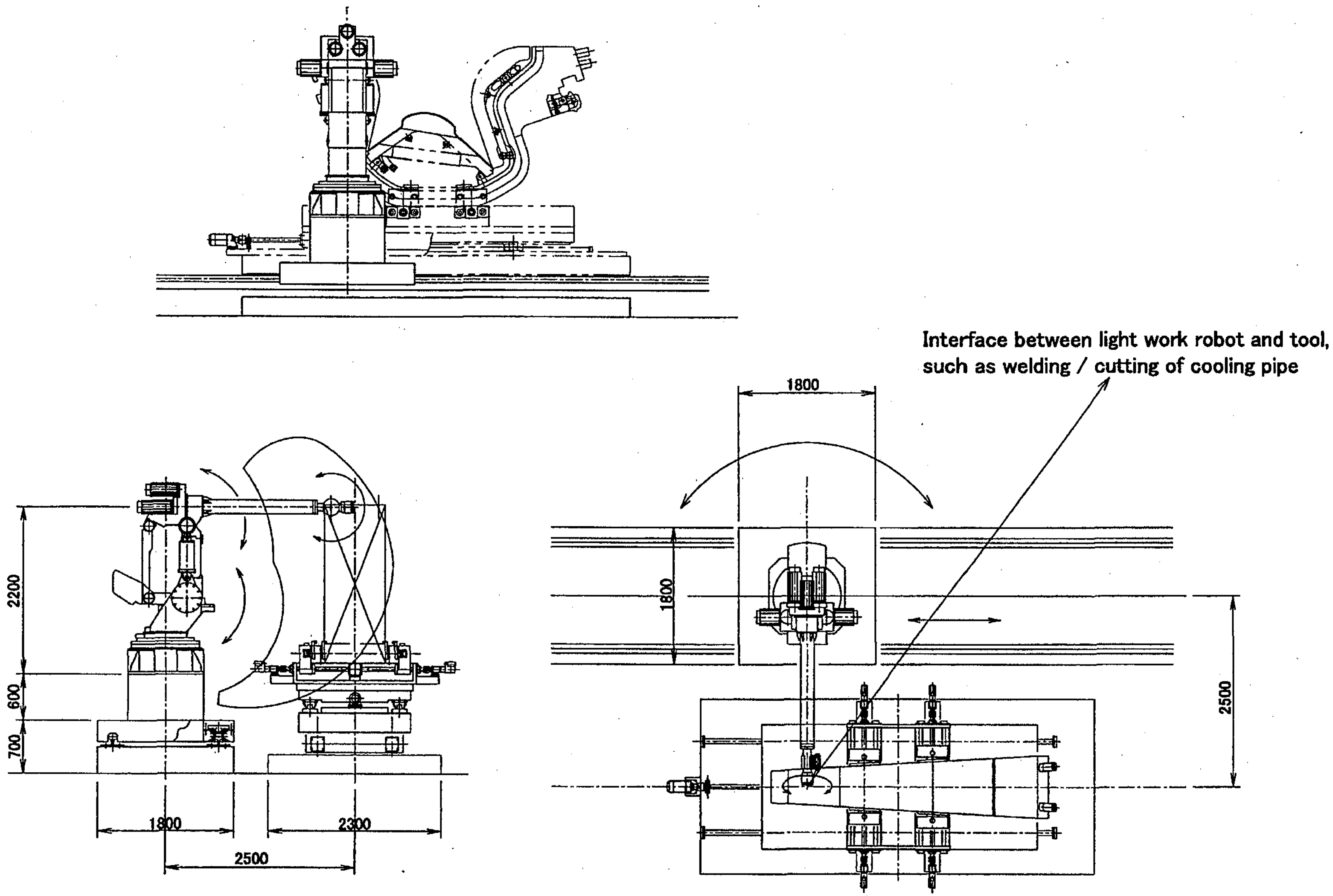

Fig. 12 Schematic view of the articulated arm type light work robot and the location to the component for refurbishment

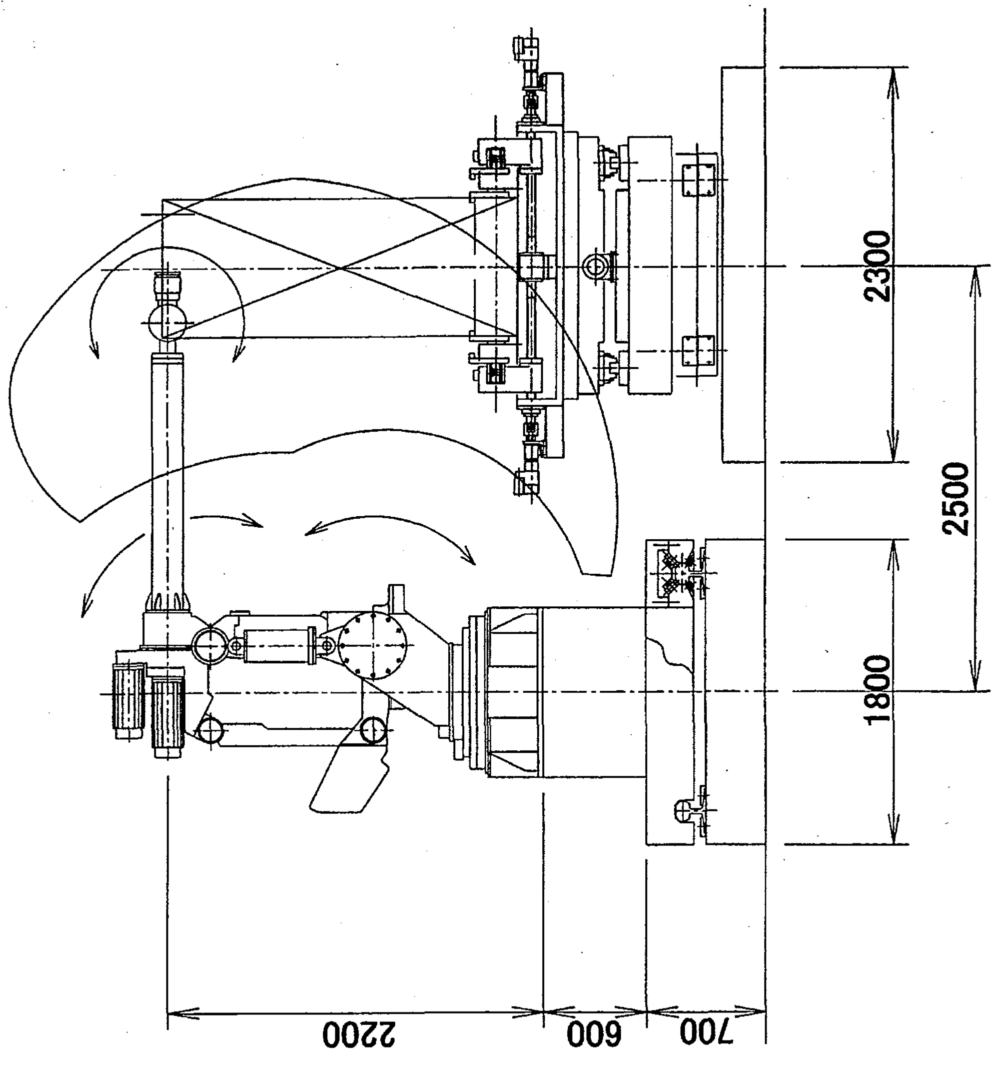

Fig. 13 Mechanism concept of light work robot with end-effector for access repairing positions for pipe welding/cutting

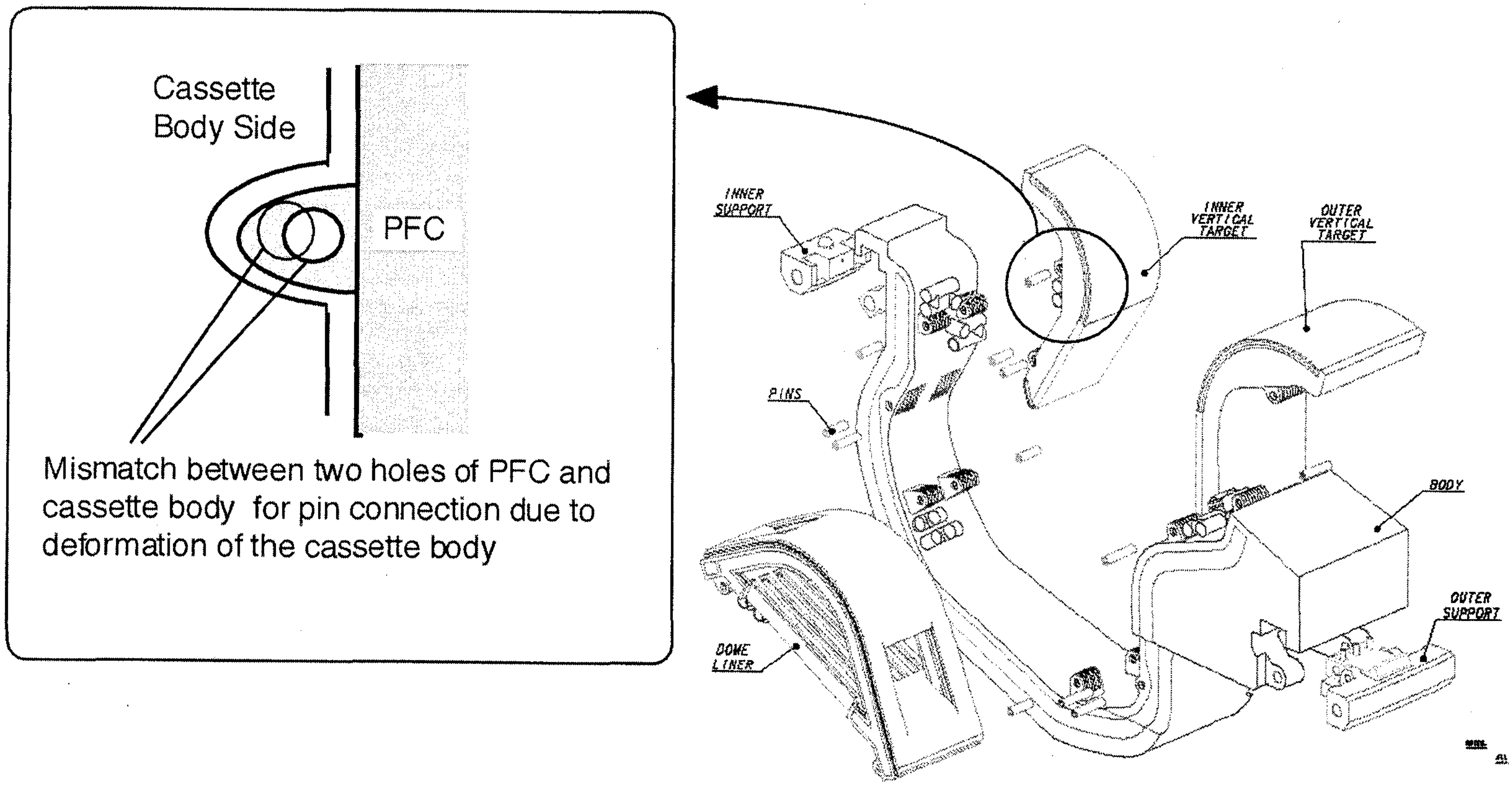

Fig. 14 Pin insertion connection through two holes located at the PFC interface with divertor cassette bod

3. Proposal of Rescue Scenario

Rescue scenario is not studied in the 2001 FDR although the rescue cranes are shown in the description of the hot cell, as shown in Figs. 1 and 15. The rescue scenario is also common issue to be studied. A basic strategy of the rescue scenario can be studied based on the representative component such as divertor, whose requirements are relatively clear, although the lack of information of the repair requirements of the various components to be repaired.

3.1 Basic Rescue Approach

Basic rescue approach in the hot cell is as follows.

- Rescue operations of the fault equipment and tool including overhead crane in the hot cell are to remove the activated components from the fault equipment by a rescue crane as a basic approach
- After removal, activated component is transferred by the overhead crane and floor vehicle for temporary storage into the storage area with biological shield
- After evacuation of the activated components from the fault equipment, repair and maintenance of the fault refurbishment equipment and tool is carried out by hands-on access

3.2 Basic Rescue Mechanism Concept

Based on the above approach, the rescue requirement to the equipment and tool in the hot cell is that the fault driving mechanism can be operated in order to remove the activated components from the fault equipment. The failure of the mechanisms of the equipment is caused by many reasons such as insulation break, loss of power or signal and jamming of transmission gear. In spite of the caused reasons, if the temporary operation of the fault driving mechanism is possible by an additional simple mechanism, the activated component is removed from the fault equipment for repair and maintenance by hands-on access. Therefore, a redundant mechanism is proposed as shown in Fig. 16. This redundant mechanism is simple and installed between motor and reduction gear, as shown in Fig. 17, in order to operate temporally the driving mechanism for release of the activate component from the outside by the wrench installed on the rescue equipment (rescue crane). The redundant mechanism is required to every driving mechanism of the refurbishment equipment and tool. The redundant mechanism is also required for installation considering a good accessibility from the outside.

3.3 Typical Rescue Scenarios

Figure 18 shows the layout of the hot cell in the 2001 FDR. Location and function of the in-vessel component storage area is proposed to be changed based on the rescue scenario proposed above, i.e., the location of the in-vessel component storage area is proposed to be lower floor with a lid for biological shield in the hot cell in order to isolate the activated component as much as possible as shown in Figs. 19 and 20. The size and layout of the storage area is temporary shown in the figures and will be determined after more detailed study based on the clearer requirements and scenarios developed in the future.

Concept of the rescue crane is shown in Fig. 21. The rescue crane has major two functions for rescue of the refurbishment facility, i.e., one for the overhead crane and the other for refurbishment equipment such as workstation except overhead crane. The rescue mechanism concept for overhead crane consists of two wrenches on the sliding mechanism in order to access and operate the redundant mechanisms for the vertical elevation and lateral movement of the overhead crane as shown in Fig. 22. These redundant mechanisms are already installed in the overhead crane for rescue operation as shown in Fig. 22. The rescue of the fault of the traveling mechanism of the overhead crane is carried out by the wrench installed on the rescue crane or directly traveled by pushing/pulling by the rescue crane after docking on the overhead crane as shown in Fig. 22.

The rescue mechanism concept for workstation as an example consists of a telescopic arm (maximum length of 6500 mm) with rescue tool such as wrench for operation of the redundant mechanism of the fault driving mechanism in order to release the activated component as shown in Fig. 23.

3.3.1 Rescue Scenario of Over Head Crane

Simplified scenario and procedures for the rescue of the overhead crane are shown in the following and Fig. 24.

a) Overhead crane is in trouble during divertor handling
b) Rescue crane is docked on the fault overhead crane
c) Divertor is lowered and released on the floor vehicle including the operations of the fault mechanism through the redundant mechanism by the wrench installed on the rescue crane
d) Activated divertor is transferred into the shunt area (finally into the storage area) by floor vehicle
e) After evacuation of the activated divertor, hands-on access is carried out for repair and maintenance of the fault mechanism of the overhead crane.

3.3.2 Rescue Scenario of Workstation

Simplified scenario and procedures for the rescue of the workstation are shown in the following and Fig. 25.

a) Heavy work robot in the workstation is in trouble during grasping of the PFC of divertor
b) Wrench attached on the telescopic arm operates the fault mechanism of the heavy work robot
c) PFC is removed from the cassette body by the heavy work robot operated through the redundant mechanism using the telescopic arm
d) Cassette body is removed by the overhead crane
e) Heavy work robot with PFC moves by itself or telescopic arm to the PFC transfer rack
f) PFC grasped by the heavy work robot is released on the transfer rack by the telescopic arm

g) After evacuation of activated PFC, hands-on repair and maintenance is carried out (Option 1)

h) Heavy work robot moves in to the maintenance area for hands-on repair and maintenance (Option 2)

4. Summary

There are many ITER components will be repaired in the hot cell for reuse them as much as possible in the operation phase. The repair requirements are however not sufficient in the FDR for detail study because the concepts of the most of these components have not however been developed well. Therefore, this report describes a proposal of the basic scenario of common equipment in the hot cell, i.e., proposals of the common transporters (overhead crane and floor vehicle) from rationalization and rescue scenario of the equipment points of view in the hot cell. The study in the report is based on the available repair scenario and repair equipment for the representative component such as divertor, whose repair requirements are relatively developed as a basis of the other components. The study is performed based on the hot cell layout in the 2001 FDR and divertor design in 2003 as much as possible.

The objective of this report is to study and propose the remote handling scenario and design of the common equipment such as overhead crane and floor vehicle and the rescue scenario and mechanism during the failure of the remote repair equipment /tool in the hot cell, based on the representative component design from a remote handling point of view in order to develop the basic common maintenance scenario and design in the hot cell.

(1) Proposal of common facility in the hot cell

Transportation of the components to be repaired is carried by two kinds of transporters, i.e., overhead cranes and floor vehicles. The access area for repair operations in the hot cell is duplicated by two kinds of transporters. Clear sharing of the respective roles of the transporters with the minimum duplication is useful for rationalization. The proposed strategy of the transporter scenario is therefore as follows.

- Maximum use of the overhead crane for transportation of the components to be repaired in the hot cell.
- Minimum requirement to the functions of the floor vehicle for transportation of the components

The overhead crane has an adapter for changeable end-effector to grasp many kinds of components to be repaired. The floor vehicle is just to pass the components between cells with only straight (linear) motion on the floor using two sets of wheel mechanisms for traveling on the rails installed on the. The simple wheel mechanism can solve the spread of the dust, which is the critical issue of the original air bearing mechanism for traveling in the 2001 FDR design.

The handling robot in the workstation was modified to improve the accessibility to the components to be repaired. The function of the one robot in the FDR is divided into two functions into two robots, respectively, i.e., one robot for heavy duty manipulation such as replacement of the PFC up to 2 t and the other for light duty manipulation such as pipe welding/cutting/inspection and bolt connection/disconnection.

(2) Proposal of rescue scenario of hot cell facility

Basic rescue approach in the hot cell is proposed in the following Refurbishment.

- Rescue operations of the fault equipment and tool including overhead crane in the hot cell are to remove the activated components from the fault equipment by a rescue crane as a basic approach
- After removal, activated component is transferred by the overhead crane and floor vehicle for temporary storage into the storage area with biological shield
- After evacuation of the activated components from the fault equipment, repair and maintenance of the fault refurbishment equipment and tool is carried out by hands-on access

Based on the above approach, the rescue requirement to the equipment and tool in the hot cell is that the fault driving mechanism can be operated in order to remove the activated components from the fault equipment. Therefore, a redundant mechanism is proposed. This redundant mechanism is simple and installed between motor and reduction gear in order to operate temporally the driving mechanism for release of the activate component from the outside by the wrench installed on the rescue crane. The redundant mechanism is required to every driving mechanism of the refurbishment equipment and tool.

The proposed rescue crane has major two functions for rescue of the hot cell facility, i.e., one for the overhead crane and the other for refurbishment equipment such as workstation. The rescue of the fault of the traveling mechanism of the overhead crane is carried out by the wrench installed on the rescue crane or directly traveled by pushing/pulling by the rescue crane after docking on the overhead crane. For rescue of the workstation, the rescue crane consists of a telescopic arm (maximum length of 6500 mm) with rescue tool such as wrench for operation of the fault driving mechanism through the redundant mechanism in order to release the activated component. Typical rescue scenarios and procedures of the overhead crane and workstation are studied including the handling and storage of the activated component.

Acknowledgments

The author would like to acknowledge Drs. M. Seki, T. Tsunematsu and R. Yoshino of the Japan Atomic Energy Agency for their continuous suggestions and encouragement.

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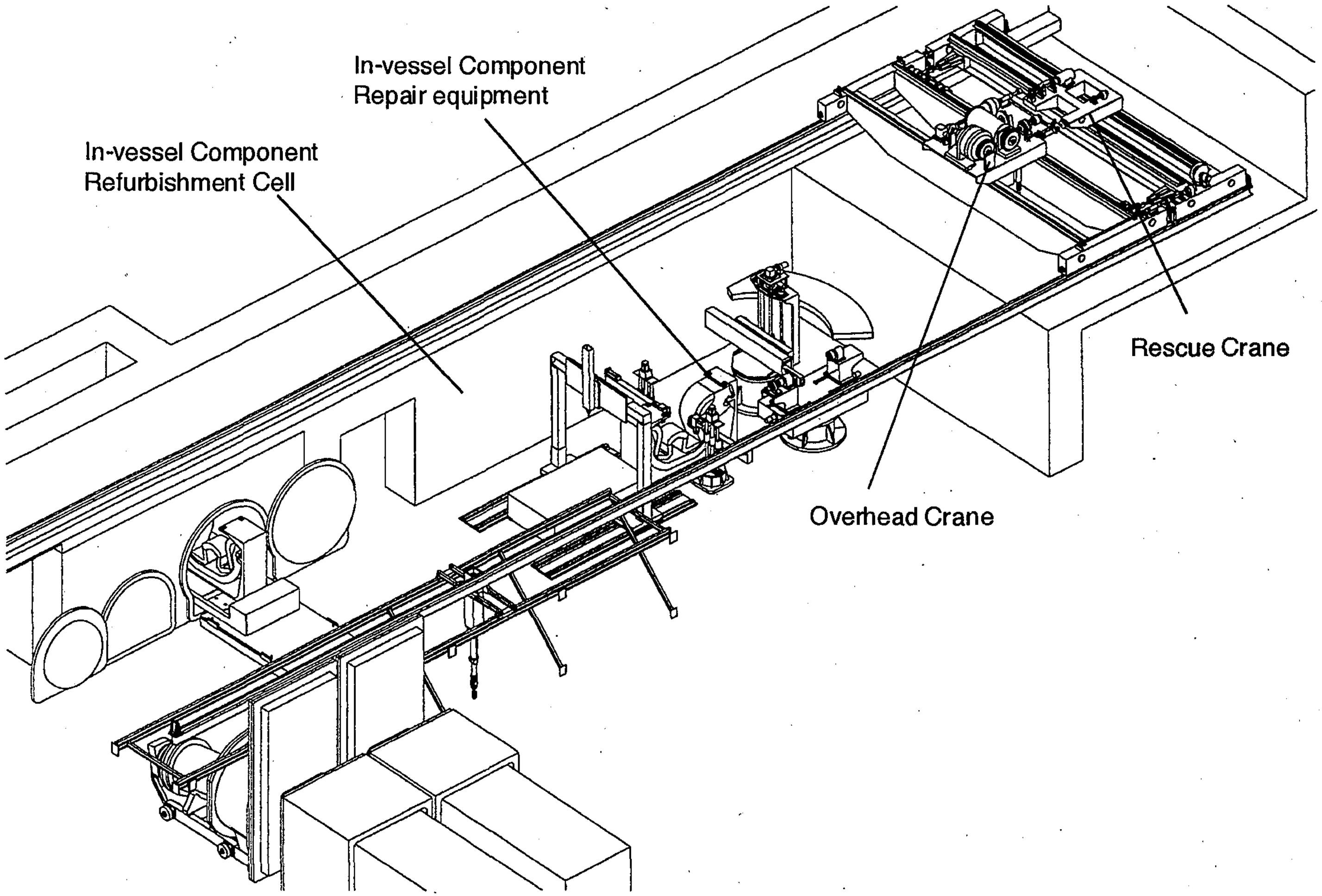

Fig. 15 Concept of the rescue crane in the hot cell

Failure mode

Electrical parts: Electrical cable for signal / power or motor

Mode: The breaking of cable for signal or power

Position of vehicle / manipulator : All position

Features

* Redundancy mechanism

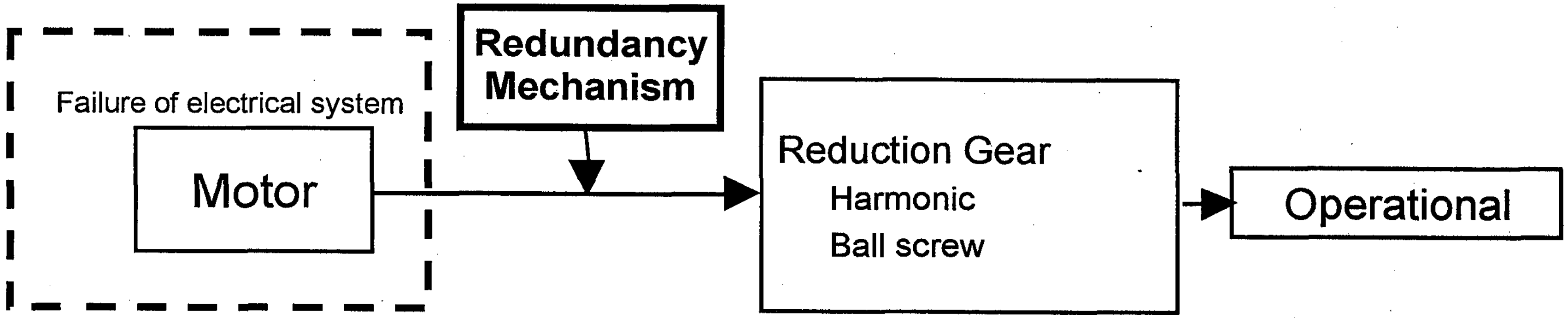

Fig. 16 Proposed redundant mechanism for rescue of the fault driving mechanism

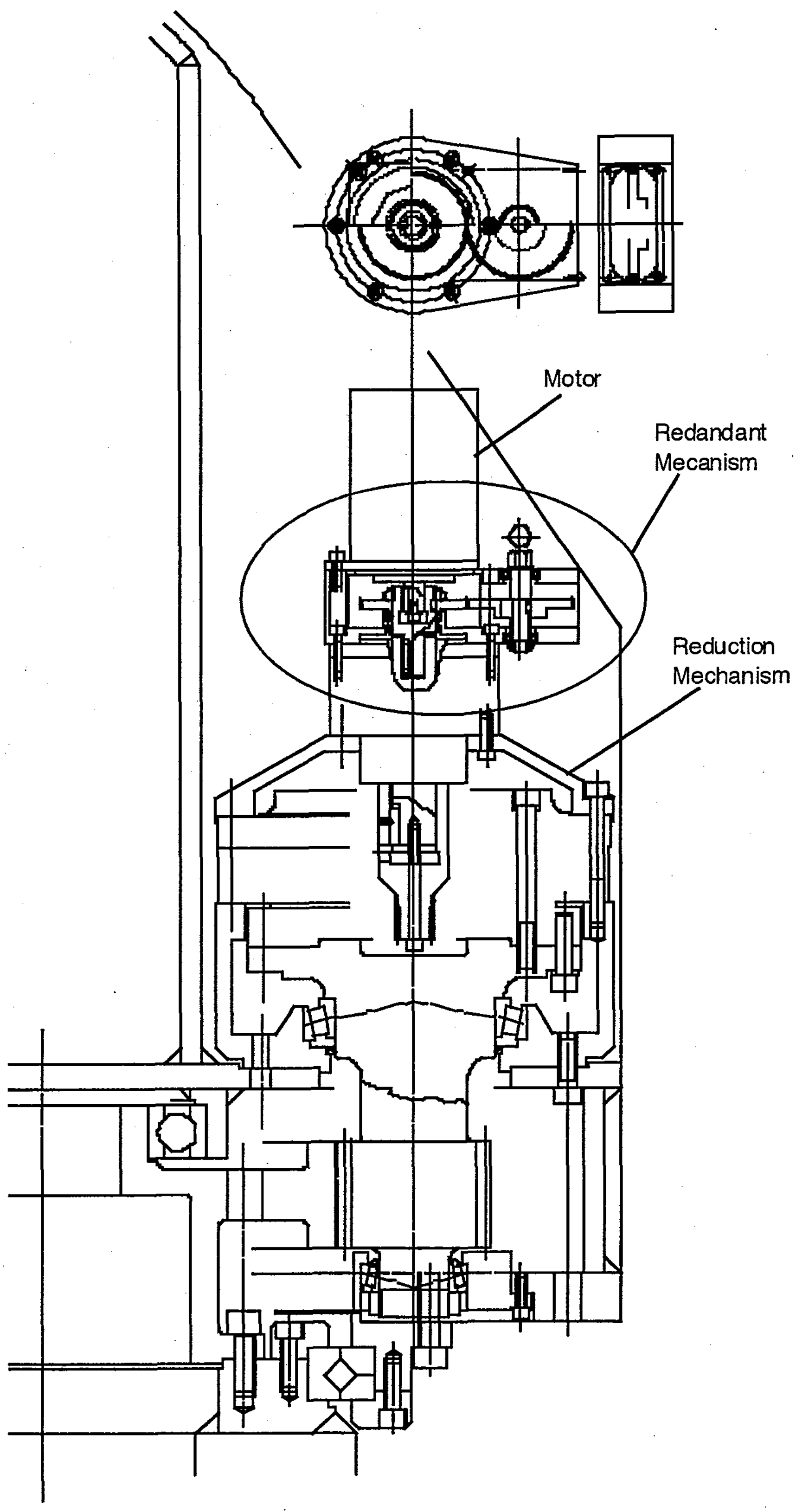

Fig. 17 Example of the redundant mechanism for rescue of the driving mechanism

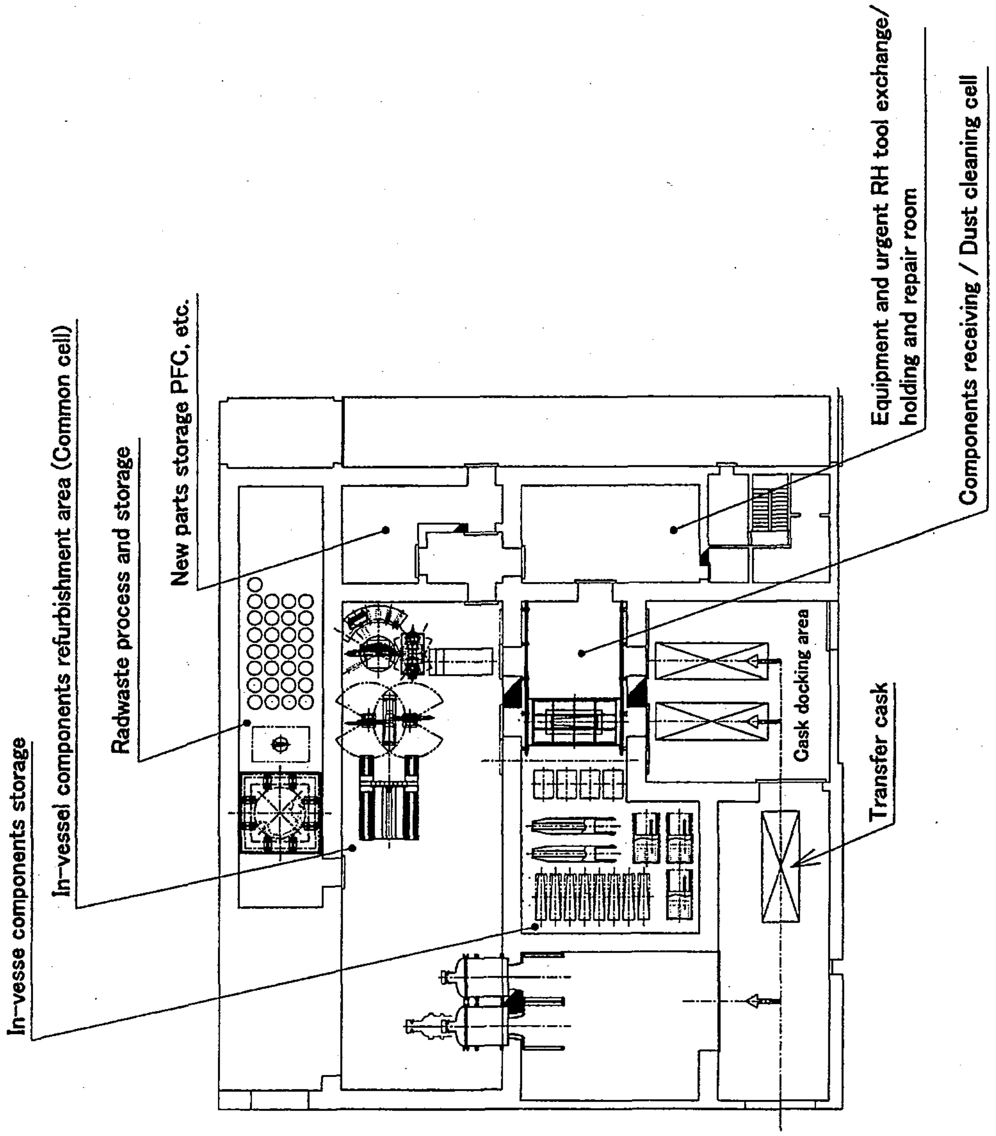

Fig.18 Layout of the hot cell in 2001 FDR

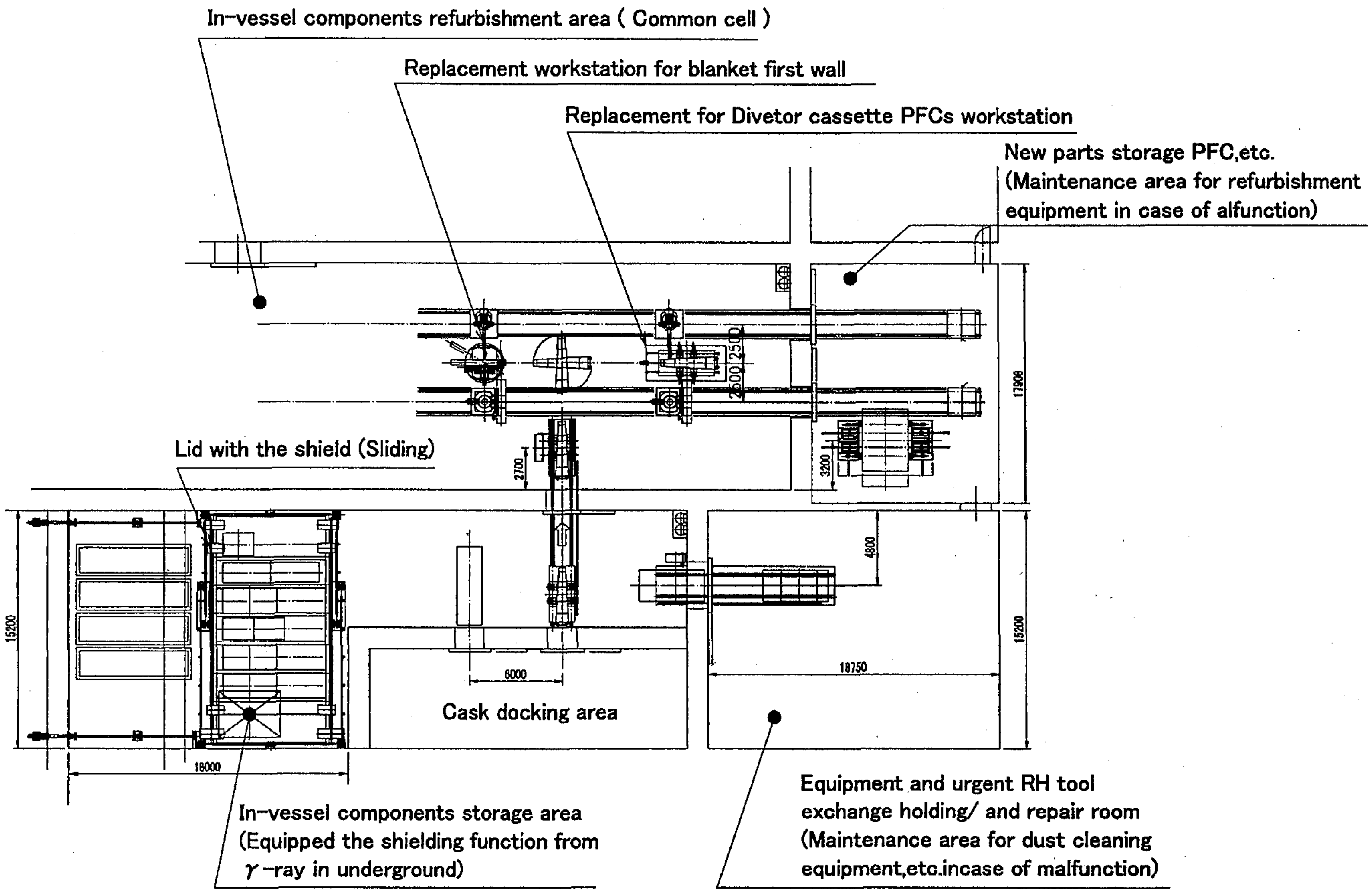

Fig. 19 Proposed in-vessel component storage area with biological shield lid (dimension: TBD)

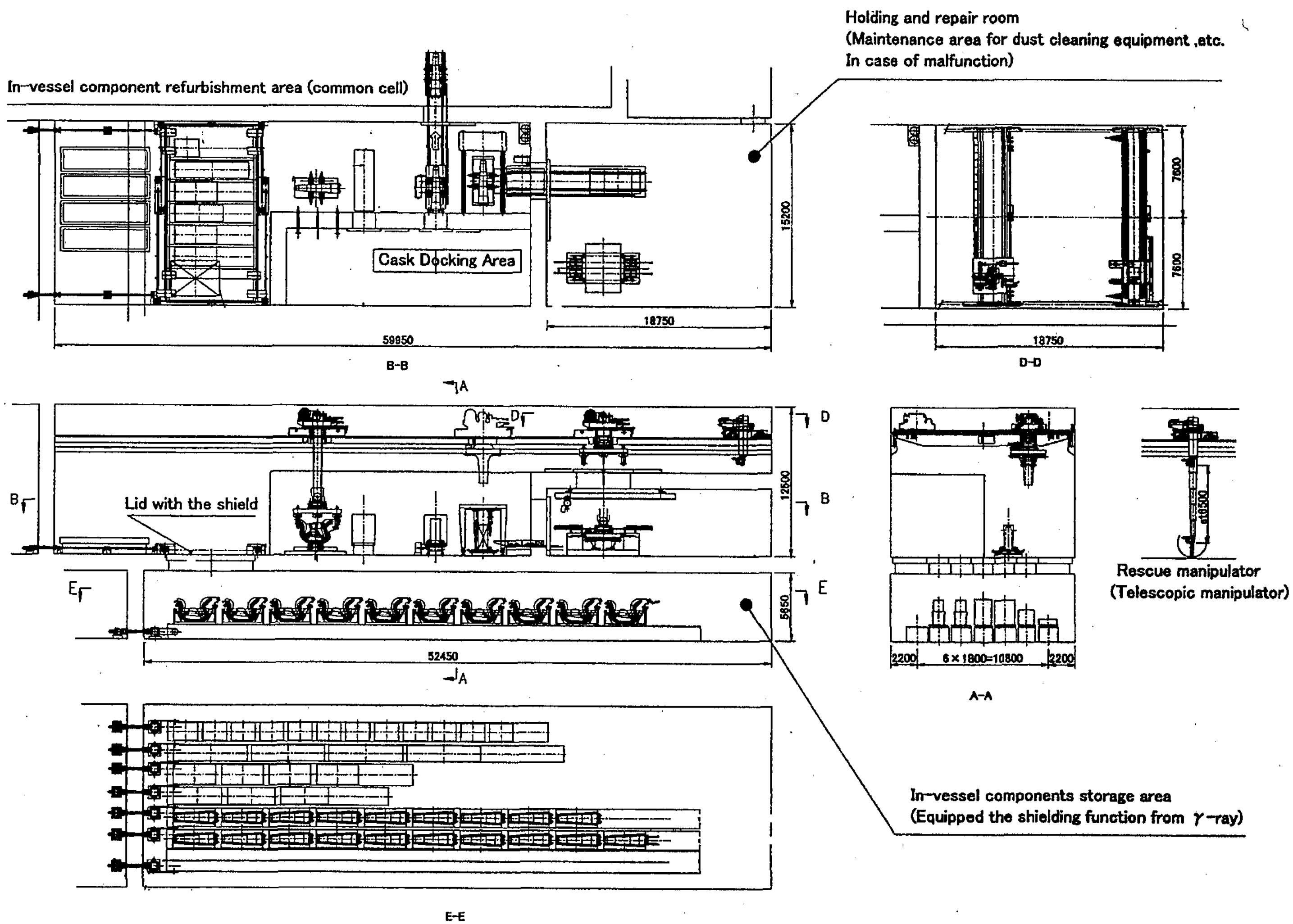

Fig. 20 Proposed layout of the in-vessel component storage area located in the lower floor with biological shield lid (dimension: TBD)

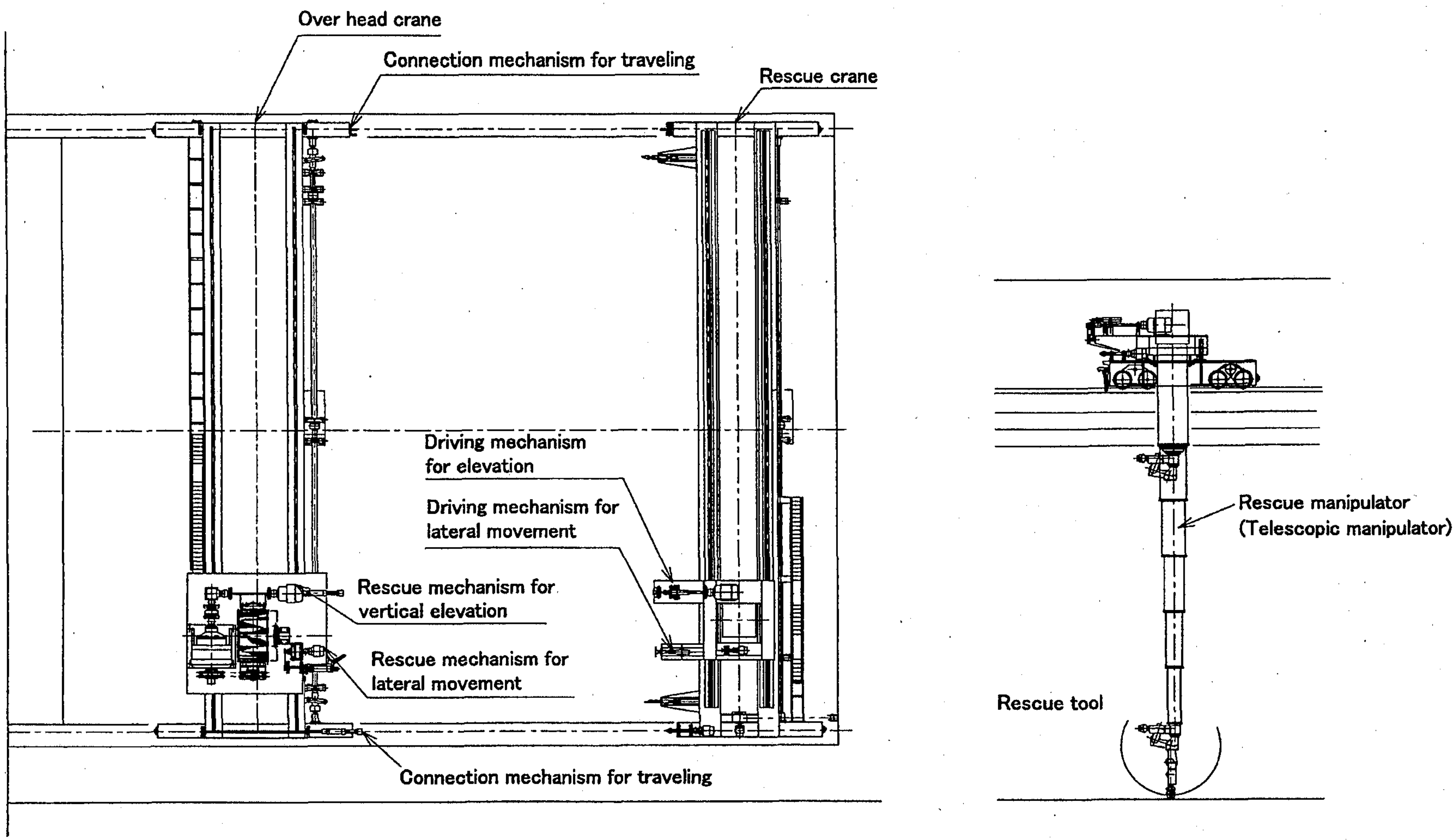

Fig. 21 Schematic view of the proposed rescue crane with telescopic arm

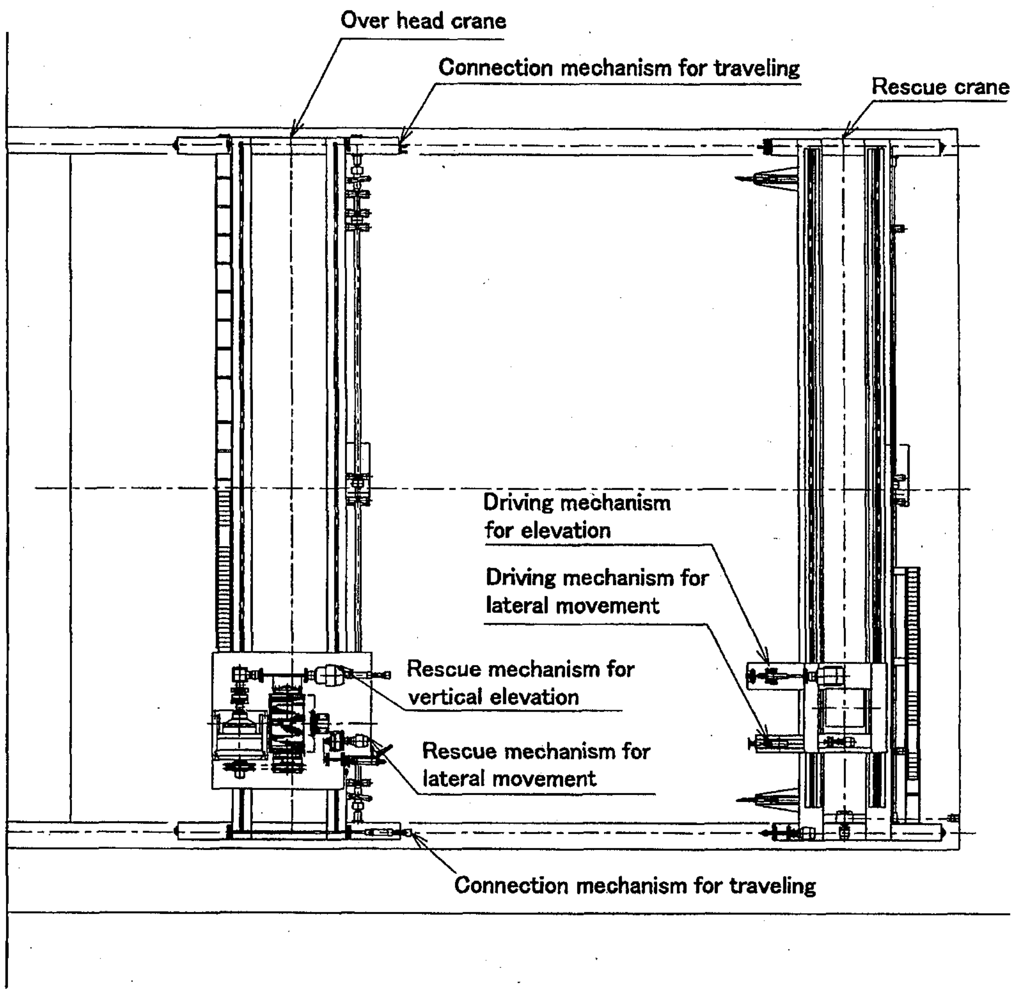

Fig. 22 Concepts of the rescue scenario of the overhead crane equipped with redundant mechanisms by the rescue crane equipped with wrenches for rescue of the fault driving mechanisms of the overhead crane

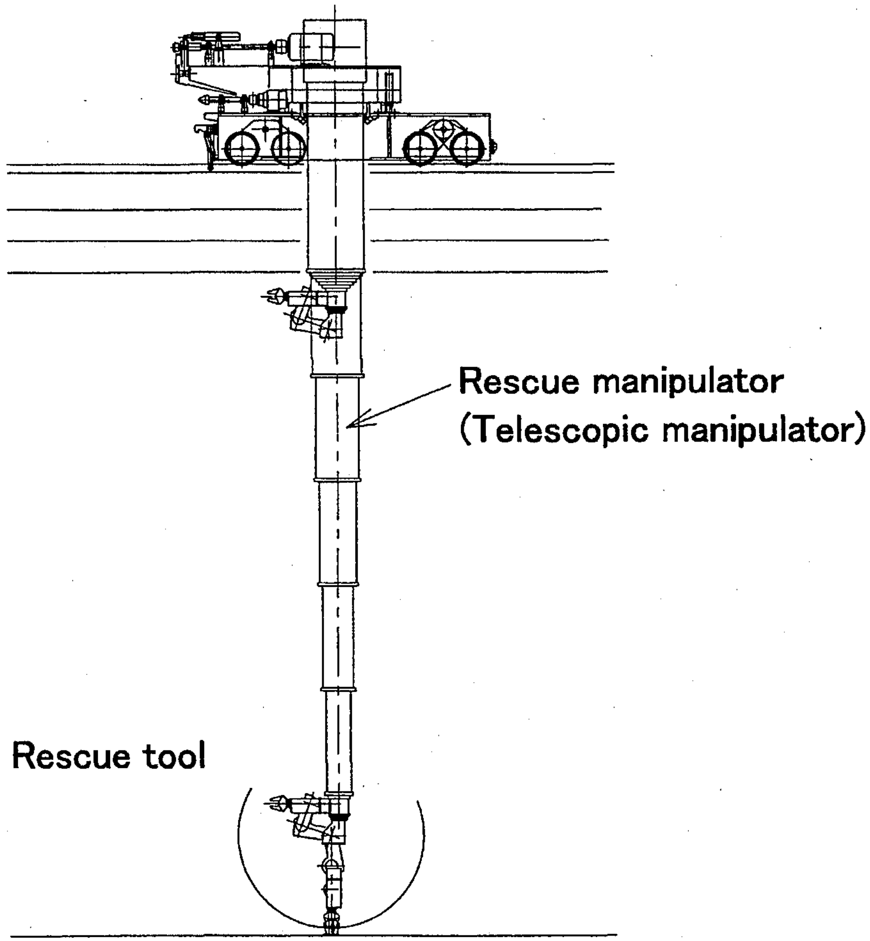

Fig. 23 Concept of the rescue crane with telescopic arm with rescue tool to access the faulty driving mechanisms of the robots in the workstation

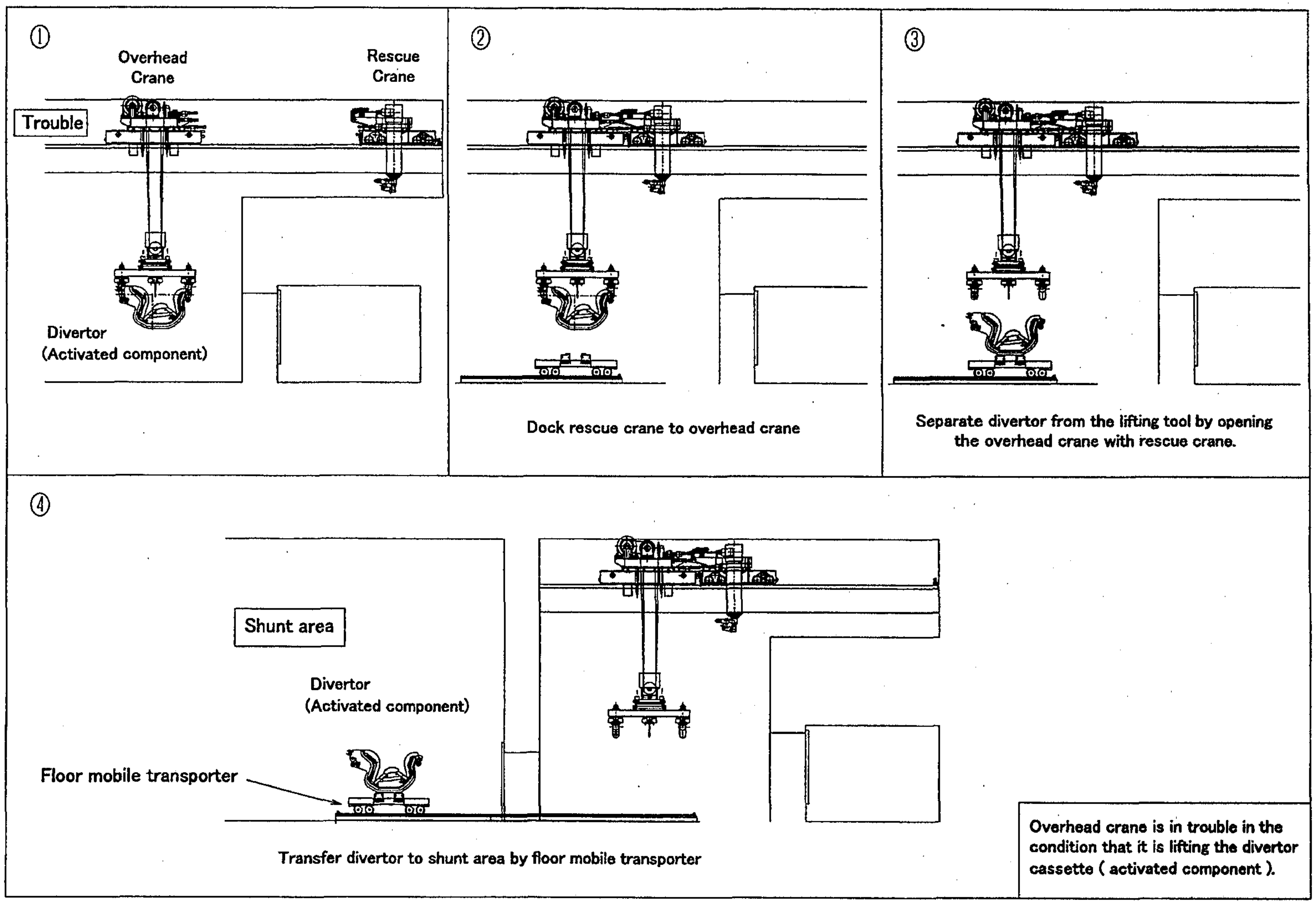

Fig. 24 Basic scenario and procedures for the rescue of the overhead crane

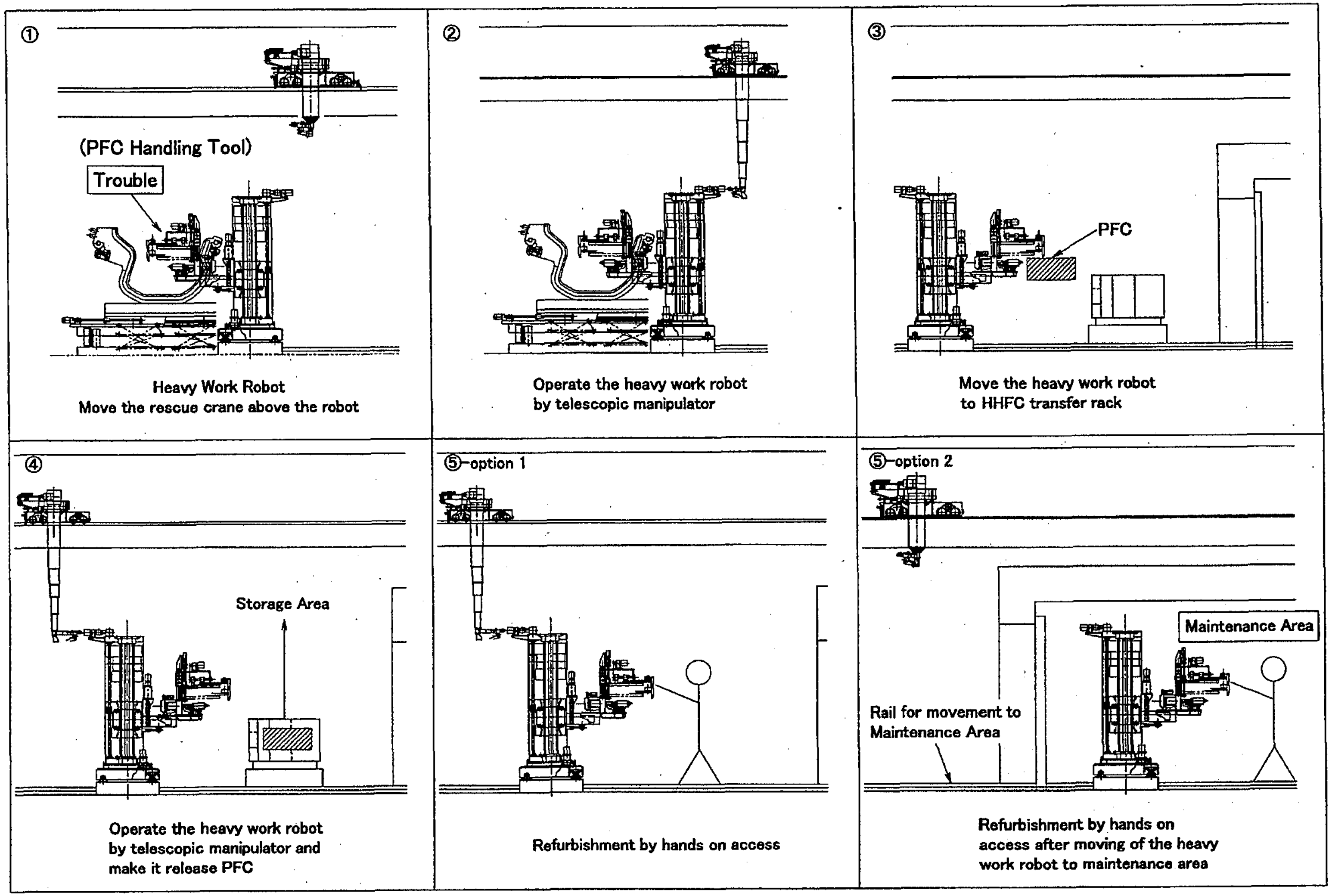

Fig. 25 Basic scenario and procedures for the rescue of the workstation

国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表２．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m-1
密度（質量密度）	キログラム毎立法メートル	kg/m^3
質量体積（比体積）	立法メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
（物質量の）濃度	モル毎立方メートル	mol/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率	（数の）1	1

表５．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	μ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^{9}	ギガ	G	10^{-12}	ピコ	p
10^{6}	メガ	M	10^{-15}	フェムト	f
10^{3}	キロ	k	10^{-18}	アト	a
10^{2}	ヘクト	h	10^{-21}	ゼプト	z
10^{1}	デカ	da	10^{-24}	ヨクト	y

表３．固有の名称とその独自の記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン(a)	rad		$m \cdot m^{-1}=1$ (b)
立体角	ステラジアン(a)	sr(c)		$m^2 \cdot m^{-2}=1$ (b)
周波数	ヘルツ	Hz		s^{-1}
力	ニュートン	N		$m \cdot kg \cdot s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
エネルギー，仕事，熱量	ジュール	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
工率，放射束	ワット	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
電荷，電気量	クーロン	C		$s \cdot A$
電位差（電圧），起電力	ボルト	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
電気抵抗	オーム	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
磁束	ウエーバ	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
セルシウス温度	セルシウス度(d)	℃		K
光束	ルーメン	lm	$cd \cdot sr$ (c)	$m^2 \cdot m^{-2} \cdot cd=cd$
照度	ルクス	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd=m^{-2} \cdot cd$
（放射性核種の）放射能	ベクレル	Bq		s^{-1}
吸収線量，質量エネルギー分与，カーマ	グレイ	Gy	J/kg	$m^2 \cdot s^{-2}$
線量当量，周辺線量当量，方向性線量当量，個人線量当量，組織線量当	シーベルト	Sv	J/kg	$m^2 \cdot s^{-2}$

(a) ラジアン及びステラジアンの使用は、同じ次元であっても異なった性質をもった量を区別するときの組立単位の表し方として利点がある。組立単位を形作るときのいくつかの用例は表４に示されている。
(b) 実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号“1”は明示されない。
(c) 測光学では、ステラジアンの名称と記号srを単位の表し方の中にそのまま維持している。
(d) この単位は、例としてミリセルシウス度m℃のようにSI接頭語を伴って用いても良い。

表６．国際単位系と併用されるが国際単位系に属さない単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86400 s
度	°	1° =(π/180) rad
分	’	1’ =(1/60)° =(π/10800) rad
秒	”	1” =(1/60)’ =(π/648000) rad
リットル	l、L	$1l=1\ dm^3=10^{-3}m^3$
トン	t	$1t=10^3$ kg
ネーパ	Np	1Np=1
ベル	B	1B=(1/2)ln10(Np)

表７．国際単位系と併用されこれに属さない単位で
SI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位であらわされる数値
電子ボルト	eV	$1eV=1.60217733(49)\times10^{-19}J$
統一原子質量単位	u	$1u=1.6605402(10)\times10^{-27}kg$
天文単位	ua	$1ua=1.49597870691(30)\times10^{11}m$

表８．国際単位系に属さないが国際単位系と
併用されるその他の単位

名称	記号	SI 単位であらわされる数値
海里		1海里=1852m
ノット		1ノット=1海里毎時=(1852/3600)m/s
アール	a	$1\ a=1\ dam^2=10^2m^2$
ヘクタール	ha	$1\ ha=1\ hm^2=10^4m^2$
バール	bar	$1\ bar=0.1MPa=100kPa=1000hPa=10^5Pa$
オングストローム	Å	1 Å$=0.1nm=10^{-10}m$
バーン	b	$1\ b=100fm^2=10^{-28}m^2$

表４．単位の中に固有の名称とその独自の記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	$Pa \cdot s$	$m^{-1} \cdot kg \cdot s^{-1}$
力のモーメント	ニュートンメートル	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
表面張力	ニュートン毎メートル	N/m	$kg \cdot s^{-2}$
角速度	ラジアン毎秒	rad/s	$m \cdot m^{-1} \cdot s^{-1}=s^{-1}$
角加速度	ラジアン毎平方秒	rad/s^2	$m \cdot m^{-1} \cdot s^{-2}=s^{-2}$
熱流密度，放射照度	ワット毎平方メートル	W/m^2	$kg \cdot s^{-3}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
質量熱容量（比熱容量），質量エントロピー	ジュール毎キログラム毎ケルビン	$J/(kg \cdot K)$	$m^2 \cdot s^{-2} \cdot K^{-1}$
質量エネルギー（比エネルギー）	ジュール毎キログラム	J/kg	$m^2 \cdot s^{-2} \cdot K^{-1}$
熱伝導率	ワット毎メートル毎ケルビン	$W/(m \cdot K)$	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
体積エネルギー	ジュール毎立方メートル	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
電界の強さ	ボルト毎メートル	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
体積電荷	クーロン毎立方メートル	C/m^3	$m^{-3} \cdot s \cdot A$
電気変位	クーロン毎平方メートル	C/m^2	$m^{-2} \cdot s \cdot A$
誘電率	ファラド毎メートル	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
透磁率	ヘンリー毎メートル	H/m	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
モルエネルギー	ジュール毎モル	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
モルエントロピー，モル熱容量	ジュール毎モル毎ケルビン	$J/(mol \cdot K)$	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
照射線量（X線及びγ線）	クーロン毎キログラム	C/kg	$kg^{-1} \cdot s \cdot A$
吸収線量率	グレイ毎秒	Gy/s	$m^2 \cdot s^{-3}$
放射強度	ワット毎ステラジアン	W/sr	$m^4 \cdot m^{-2} \cdot kg \cdot s^{-3}=m^2 \cdot kg \cdot s^{-3}$
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2 \cdot sr)$	$m^2 \cdot m^{-2} \cdot kg \cdot s^{-3}=kg \cdot s^{-3}$

表９．固有の名称を含むCGS組立単位

名称	記号	SI 単位であらわされる数値
エルグ	erg	$1\ erg=10^{-7}\ J$
ダイン	dyn	$1\ dyn=10^{-5}N$
ポアズ	P	$1\ P=1\ dyn \cdot s/cm^2=0.1Pa \cdot s$
ストークス	St	$1\ St\ =1cm^2/s=10^{-4}m^2/s$
ガウス	G	$1\ G$ ^$10^{-4}T$
エルステッド	Oe	1 Oe ^(1000/4π)A/m
マクスウェル	Mx	$1\ Mx$ ^$10^{-8}Wb$
スチルブ	sb	$1\ sb\ =1cd/cm^2=10^4cd/m^2$
ホト	ph	$1\ ph=10^4lx$
ガル	Gal	$1\ Gal\ =1cm/s^2=10^{-2}m/s^2$

表10．国際単位に属さないその他の単位の例

名称	記号	SI 単位であらわされる数値
キュリー	Ci	$1\ Ci=3.7\times10^{10}Bq$
レントゲン	R	$1\ R = 2.58\times10^{-4}C/kg$
ラド	rad	$1\ rad=1cGy=10^{-2}Gy$
レム	rem	$1\ rem=1\ cSv=10^{-2}Sv$
X線単位		$1X\ unit=1.002\times10^{-4}nm$
ガンマ	γ	$1\gamma=1\ nT=10^{-9}T$
ジャンスキー	Jy	$1\ Jy=10^{-26}W \cdot m^{-2} \cdot Hz^{-1}$
フェルミ		$1\ fermi=1\ fm=10^{-15}m$
メートル系カラット		$1\ metric\ carat = 200\ mg = 2\times10^{-4}kg$
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	
ミクロン	μ	$1\ \mu\ =1\mu m=10^{-6}m$

（第７版，1998年改訂）