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2.9.1 Introduction

Due to neutron activation, the repair, inspection or maintenance of ITER in-vessel components has to be carried out remotely. In-vessel first wall components are subject to plasma-wall interaction leading to erosion. This requires regular or infrequent refurbishment, depending on the erosion rate. Furthermore, components may need to be replaced due to unexpected failure. This requires the introduction of common and dedicated remote handling (RH) equipment into the vacuum vessel. Components have been classified according to the frequency with which they are expected to require remote repair or replacement. RH class 1 pertains to components requiring regular planned replacement (e.g., divertor cassettes, test blanket modules). RH class 2 applies to those that are likely to require repair or replacement (e.g., blanket modules, some diagnostics). RH class 3 is for components that are not expected to require maintenance or replacement during the lifetime of ITER but would need to be replaced remotely should they fail (e.g., vacuum vessel). RH class 4 is for components that do not require remote handling. All in-cryostat components are RH class 3, although it is expected that up to the end of ITER operations short-term personnel access will be feasible within the cryostat for simple repair operations.

RH class 1 and 2 procedures and operations (i.e. those involving components in these RH classes) must be verified by tests prior to ITER construction, whereas the feasibility of RH class 3 operations should be verified by studies. Some specific aspects of RH class 3 operations may require testing for verification.

The repair of in-vessel components can, in principle, either be accomplished by in-situ operations, or by removing the component and replacing it by a new one or re-installing the component after repair or refurbishment in a hot cell. However, studies have shown that, mainly due to access problems, in-situ repair operations are generally not feasible. The ITER strategy is therefore based on the removal of components from the vacuum vessel, and remote transfer to the hot cell where the components will be either repaired by common and dedicated RH equipment, or replaced with new components. In the latter case the removed component will be prepared for waste disposal in the hot cell.

The assembly and maintenance of the ITER machine will be affected from the very beginning by the presence of in-vessel components made of, or coated with, beryllium. Because of the health hazards associated with beryllium dust, such components must be handled in a controlled way, starting from the machine assembly stage, to ensure that plant workers are not exposed to unacceptable levels of beryllium. During plasma operation, the machine components will be activated and the in-vessel components will be both activated, and contaminated with tritium. Because of the beta and gamma activation of the component bulk and surface dust (beryllium, carbon, tungsten), and because of the presence of tritium, special handling techniques during machine maintenance periods will also be required. Tritium and dust contamination must therefore be confined during the transfer of components between the machine and the hot cell. A system of sealed, remotely operated transfer casks will be used to assist the above handling operations (port handling). Docking to the machine will be directly at the vacuum vessel (VV) port flanges through openings in the cryostat and bioshield. A similar docking procedure is carried out in the hot cell where adapters are used to cater for different cask sizes. In some cases (neutral beam maintenance, others), due to the large size of the component to be handled, a special cask is provided.

When port handling is required,a cask is positioned inside the designated port cell and docked to the relevant VV port after the port cell has been cleared of all equipment. Such equipment consists mainly of pipes and cables. After this, the bioshield plug in the bioshield wall and the cryostat closure plate in the cryostat wall must also be removed (together with sections of pipes and other feedthroughs) to allow the cask docking to the VV port flange. The radiation level inside the port cell is expected to be negligible a few days after shutdown, thus allowing the above clearing operations to be done manually. However, cutting of the pipes may require the use of tools which, although in principle deployed manually, will most likely be operated remotely. During such operations, the atmosphere inside the port cell is controlled and an intermediate depression is maintained relative to the (higher) pressure in the building (gallery) and to the (lower) pressure inside the vacuum vessel. For this purpose, sealing (and where required, shielded) doors are fitted at the port cell entrance. The subsequent operations required to remove components from within the VV port (shielding plug, diagnostic/heating systems, etc.) call for the use of a cask and of remote tools operated from within the cask. Typically, these tools perform the bolting/un-bolting of the component as well as the cutting, re-welding and inspection of a vacuum seal. Following these operations, an empty cask is remotely driven to the VV port and docked. The port component is disconnected, extracted from the port into the cask and transferred to the hot cell. Sealing of the VV port opening after removal of the component is performed by the same cask using a dedicated sealing door.

The HC is located adjacent to the reactor building and is connected by a corridor. Component transfers between different floor levels are performed by elevator.

For in-vessel RH operations, components are removed from the vacuum vessel (VV) by accessing the main ports of the VV at three levels, i.e., the upper port level, the equatorial port level and the divertor port level.

At the equatorial level there are four RH ports used for blanket maintenance. During operation, these RH shield plugs are used for diagnostics and the port limiters. Similarly to the other ports housing radio frequency heating system antennae, diagnostics, and test blanket modules, these ports are closed with water-cooled shield plugs that are vacuum seal welded to the outboard end of the port, and have the shielding equivalence of the blanket and the VV. The VV ports are connected to the cryostat wall via rectangular ducts. The corresponding openings in the cryostat shell are closed by a flange at the cryostat wall (secondary closure plate). To gain access to the VV port the cryostat closure plate as well as a bioshield plug have to be removed.

At the divertor port level, three equally spaced RH ports are used for to divertor maintenance (and again for diagnostics during operation). The remaining 15 ports at the divertor level house the in-vessel viewing system, the cryopumps, diagnostics, etc.

At the upper port level, RH class 1 and 2 operations are limited to the replacement of diagnostics and EC systems. Maintenance of these components in the upper ports is performed by the same general methods used in the horizontal ports at the equatorial level.

If a RH class 3 operation is required for components such as the VV and the TF coil (i.e. they need to be replaced) then, after removing intervening systems, a complete vessel sector with TF coils is lifted from the cryostat and moved through the building to the laydown area of the laydown, assembly and RF heating building. Here, if necessary, it is disassembled for repair.

In-cryostat repairs such as inspection and PF coil redundant turn bypassing are performed hands-on. Personnel access is through hatches located at the upper and lower parts of cryostat, and through the hatches located at the equatorial RH port ducts.

Remote handling equipment testing and maintenance, as well as cask storage, will be at the remote handling equipment test stand located at the upper area of the hot cell.

2.9.2 Divertor Maintenance

Due to the erosion of the plasma-facing components and the possible need for improving the design of critical items, the replacement of the divertor and its refurbishment in the hot-cell are foreseen a few times during the ITER lifetime. To meet this requirement, a cassette-type divertor has been selected. The cassette is made in two parts: the high heat flux components, which require replacement, and the cassette body (supporting structure, shielding and manifold) which can be re-used.

2.9.2.1 System/Interface Description

The divertor handling concept has the following features.

- Divertor segmentation into 54 cassettes: the cassette width allows installation via the divertor handling ports. A segmentation of three cassettes per port gives the largest cassette size whilst providing an integral number of cassettes per port.
- Three RH ports (Figure 2.9.2-1): these are located 120° apart from each other and allow the radial transport of the cassettes in and out of the vacuum vessel, using radial rails.
- The cassette multi-functional mover (CMM, Figures 2.9.2-1, 2 and 3): the radial transport of the equipment through the RH ports is carried out by the CMM. It includes a radial tractor, together with a set of specific end-effectors, to grip, push, pull, position in a cantilevered manner, and lock/assemble the following equipment using a manipulator arm (MAM):

- the primary closure plates (closing the RH ports)
- the diagnostics racks (inside the RH ports)
- the central cassettes (in front of the RH ports)
- the second cassettes (located to the left hand-side of the central cassettes)
- the cassette toroidal movers
- the standard cassettes (all other cassettes).

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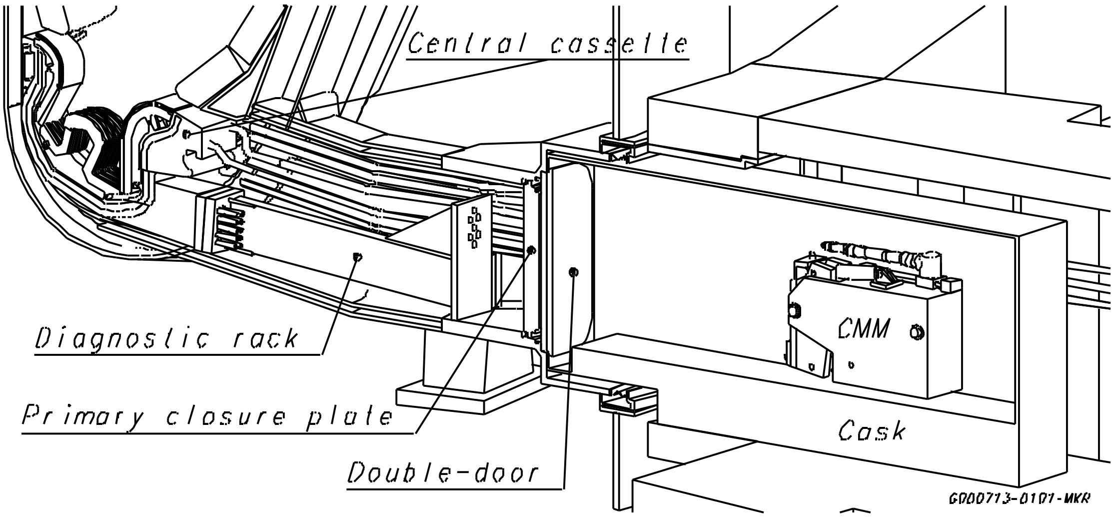

Figure 2.9.2-1 Divertor RH Port

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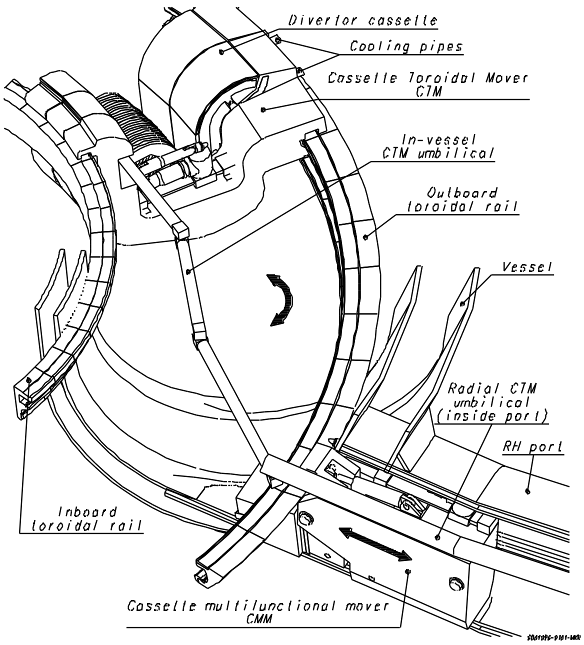

Figure 2.9.2-2 In-Vessel Cassette Handling

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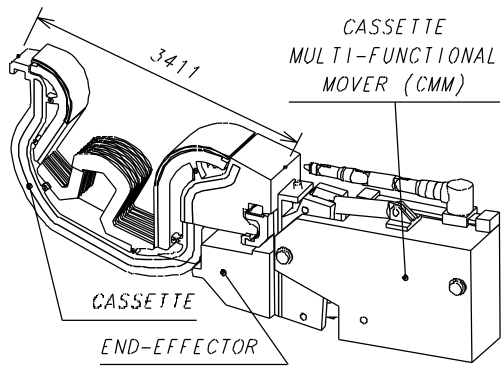

Figure 2.9.2-3
Cassette Cantilevering from the Cassette Multi-Functional Mover

- Two concentric in-vessel toroidal rails (Figure 2.9.2-2): in combination with the inboard and outboard cassette supports, these align the cassettes (maximum step between 2 adjacent cassettes: 4 mm) and sustain the current-induced loads during operation. These two rails are also used to guide the cassette toroidal mover (CTM, see below). While the inboard rail is continuous, the outboard one is interrupted in front of the RH port to allow access. The CMM end-effector includes a rail segment providing the outboard rail with a continuous path for toroidal handling.
- The CTM (Figure 2.9.2-2): this performs the in-vessel toroidal cassette handling operations, the final radial and toroidal positioning, the locking and unlocking of the supports using a manipulator arm (MAM), and the inspection of the assembled cassettes.
- Pipe tools: each cassette is fed by water via curved pipes routed inside the 18 divertor ports. Pipe tools are used for cutting these pipes close to the cassette body prior to cassette removal, and later for welding and inspecting them after installation of the refurbished cassettes.
- Transport casks and double-door (Figure 2.9.2-1): divertor cassettes, movers, and diagnostics equipment are transported between hot-cell and vessel inside confined and non-shielded casks guided by an air-cushion platform inside the building. Each cask is equipped with a double-door to dock at the RH and hot-cell ports.
- Control system: this allows the operations of RH equipment from either workstations in the RH control room, or hands-on, using local programmable handheld control panels. Moreover, it allows parallel operation, in RH conditions, of 3 RH ports and 2 hot-cell ports, the related RH equipment and two transport casks, using manual, semi-automatic, automatic and computer-assisted tele-operation (CAT) modes.

2.9.2.2 Maintenance Scenario

The divertor removal is in 3 stages (its installation is the reverse) as shown in Table 2.9.2-1.

Table 2.9.2-1 Divertor Removal

Stage 1: Transfer to maintenance configuration. This involves mainly hands-on assisted operations to prepare the RH port pit and inter-space		
Step	**Operations to perform**	**Equipment involved. Hands-on versus full RH operation(s)**
1	The maintenance operations start 2 weeks after shutdown	• Process and circuits
2	Measurement of the dose rates inside the pit prior to access	• Dose measurement package • Hands-on operation
3	Removal and storage of the diagnostics casks from the front of the RH port	• Handling equipment • Hands-on assisted
4	Cassette drainage and drying	• Involvement of DIV/LIM PHTS
5	Cutting of the 2 primary closure plate cooling pipes at each RH port	• Glove-box and pipe tools • Hands-on assisted
6	Installation of the 2 radial umbilicals of the cassette toroidal mover (CTM)	• Glove-box and RH pipe tools • Hands-on assisted
7	Cutting of the divertor cooling pipes at the 3 RH ports (6 pipes /RH port)	• Glove-box and RH pipe tools • Hands-on assisted
8	Removal and storage of the bio-shield plug	• Bio-shield plug handling tool • Hands-on assisted

Table 2.9.2-1 Divertor Removal (cont'd)

9	Removal and storage of the secondary closure plate	• Secondary closure plate handling tools • Hands-on assisted
10	Removal of the primary closure plate sealed cover	• Tool box • Hands-on assisted
Stage 2: RH port preparation. This involves mainly RH operations inside the RH port (primary closure plate, diagnostics rack, central and second cassette handling)		
Step	**Operations to perform**	**Equipment involved. Hands-on versus full RH operation(s)**
11	Removal and storage of the primary closure plate in the hot-cell	• Cask, CMM & MAM • RH operation
12	Removal and storage of the diagnostics rack in the hot-cell	• Cask, CMM & MAM • RH operation
13	Removal and storage of the central cassette in the hot-cell	• Cask, CMM & MAM • RH operation
14	Disconnection of the second cassette	• Cask, CMM & MAM • RH operation
15	Removal and storage of the second cassette in the hot-cell	• Cask, CMM & MAM • RH operation
Stage 3: In-vessel handling. This involves mainly RH operations inside the vessel (standard cassettes). Only the cooling pipes are handled in a hands-on assisted manner using RH pipe bore tools confined inside a glove-box		
Step	**Operations to perform**	**Equipment involved. Hands-on versus full RH operation(s)**
16	Cutting of the 2 pipes of the 15 standard cassettes	• Glove-box and RH pipe tools • Hands-on assisted
17	Installation of the right hand side (RHS) CTM inside the vessel	• Cask, CMM, RHS CTM, MAM • RH operation
18	Removal of the 9 next cassettes using RHS CTM	• Cask, CMM, RHS CTM, MAM • RH operation
19	Removal of the RHS CTM from the vessel	• Cask, CMM, RHS CTM, MAM • RH operation
20	Installation of the LHS CTM inside the vessel	• Cask, CMM, LHS CTM, MAM • RH operation
21	Removal of the 7 next cassettes using the LHS CTM	• Cask, CMM, LHS CTM, MAM • RH operation
22	Possibly cleaning (dust removal) of the vessel bottom	• RH cleaning equipment • RH operation

2.9.2.3 Rescue Scenario

A detailed failure mode effect analysis of the movers was performed by the EU-HT. The analysis proposes solutions for the rescue of faulty RH divertor equipment from the vessel. Besides the failure of the RH equipment, faulty in-vessel components might also have to be replaced as shown in Table 2.9.2-2.

Table 2.9.2-2 Divertor-related In-vessel Components for Possible Replacement

RH class 1 components	RH class 3 components
Divertor cassettes and supports	Rail hard-cover plates and bodies
Diagnostics equipment racks	Cooling and gas injection circuits
Primary closure plates	Cable conduits and RH connectors
Radial rail segments	Primary closure plate flange

2.9.2.4 Maintenance Time Estimation

A preliminary time assessment of in-vessel handling shows that it will take approximately 2 months (7 working days a week, 2 (8-hour) working shifts a day and a cask transport (8 hour) shift a day) to replace the 18 cassettes related to a given RH port. As a consequence of this, and managing the 3 RH ports in series, the full divertor replacement would take about 6 months, thus meeting the nominal time requirement. However, in order to account for final inspections (leak testing etc.), and provision for off-normal events (contingencies of the order of 25% needed), it is recommended to adopt some, although limited, parallel work at the 3 RH ports. This can be easily achieved using 2 transport casks and 2 hot-cell ports. A logistics study was performed by the EU HT. It assessed the impact of parameters such as cask number, divertor ports number, hot cell ports number, refurbishment workstations number, etc on the overall divertor replacement time. The study indicates that divertor cassette refurbishment inside the hot cell can be done both on-line (i.e. during the shutdown period) or off-line (i.e. after complete replacement of the old set of cassettes with a new one). In both cases the 6 months maximum shutdown time can be met, although the cassette storage requirement inside the hot cell vary depending on the refurbishment approach which is selected.

The replacement of a single faulty cassette should not take more than 2 months (as required), even in the worst case where it is located in the most inaccessible position.

2.9.2.5 Assessment/Future Work

The principle feasibility of the overall RH procedure that involves the replacement of divertor cassettes by toroidal and radial transporters has already been demonstrated for the 1998 ITER design in a test stand using full-scale prototype equipment within the L7 R&D Project. However, the modified divertor cassette design for the current ITER design requires the adoption of somewhat different handling techniques for the cassettes.

Design tasks are currently being performed on the movers, cassette supports and curved pipe tools which are the most critical items of the divertor maintenance. Nevertheless, significant development/design is still to be done to validate the new scheme, aiming at construction preparation, as listed below.

- Further design activities, including:
  - design task result implementation: movers, supports/rails, other interfaces;
  - cooling circuits: pipe diameter standardisation (2.5 inch), feed-throughs, supports, DIV/LIM PHTS interfaces, full RH process and tools, glove boxes, etc.;
  - divertor port integration: pipes, rails, umbilicals, diagnostics, shielding;
  - sizing rails, pipes, etc.;
  - first installation: procedure, tools, etc.;
  - rescue scenarios: RH equipment and in-vessel equipment.

- Testing activities, including:
  - cassette handling: CMM, CTM, umbilicals, supports/rails, other interfaces;
  - cooling pipe handing;
  - manipulator arm and tools;
  - diagnostics handling: components, interfaces, connectors;
  - radiation hard integrated equipment;
  - basic technology;
  - rescue scenarios: RH equipment and in-vessel equipment.

2.9.3 Blanket Maintenance

The shield blanket is composed of 421 modules (see 2.3). Replacement of some shield blanket modules is likely to be required a few times during the lifetime of ITER due to local erosion or defects, including leaks, and to change the shielding blanket to a breeding blanket (if decided upon).

Each blanket module is equipped with ten remote handling access holes through its plasma-facing first wall (for blanket option A - see 2.3). Four allow access for the tool that bolts and unbolts the flexible supports, four give access for welding, cutting and inspection of the cooling pipes and for bolting and unbolting of the electrical straps, and two are used to grasp the module and hold it securely during handing into and out of the VV.

As the cost of blanket modules is, to a considerable extent, dependent on the number of modules that are required, the design of the blanket RH system has been optimised with respect to size and weight of modules that can be handled. The result is a system that can handle large modules in terms of weight and size, just leaving sufficient space for manipulations inside the VV and for transfer through the ports.

2.9.3.1 System/Interface Description

The blanket handling concept has the following features.

- One or more in-vessel transporters (IVTs), with manipulator arm and various attachments, is mounted on a monorail deployed inside the vessel from a dedicated port-mounted cask.
- Module transporters, mounted at intermediate ports, are used to load modules into casks, thereby enabling the modules to be shuttled to and from the hot cell. The overall arrangement is shown in Figure 2.9.3-1.
- Each IVT consists of a vehicle manipulator, a segmented rail, rail-deploying equipment, a rail support device, and cable-handling equipment (see Figure 2.9.3-2). The IVT is used for general in-vessel maintenance tasks, and with a variety of end–effectors, depending on the task to be performed.
- The full circumferential rail is made up of two semi-circular rails. For robustness, neither sensors nor actuators are installed on the rails. An important feature of the rail system is that it can function in a reduced configuration. The rail system can be installed and used in the following configurations: 80/100°, 180° and 360° (see below). The rails are held in position by support devices, which are used to install the links that make up the rails.
- Since the vehicle/manipulator moves up to 180° on the rail as it travels around the VV, a trailing, long complex cable with many conductors has to be fed without jamming. To do this, the cable handling equipment is installed in an intermediate cask between the VV port and the RH cask, after the vehicle manipulator and rail are installed in the VV.

- The module receiver portion of the module transporter is moved radially into the VV and the component is transferred to it from the IVT manipulator. Subsequently, the module transporter is moved radially outward and the in-vessel component is transferred into a RH cask docked to the port. The RH cask then transports the component to the hot cell. Figure 2.9.3-3 shows the blanket module transfer to the receiver at the VV port. The module receiver pallet can be retracted from the transporter and exchanged inside the RH cask by an in-cask storage rack system.

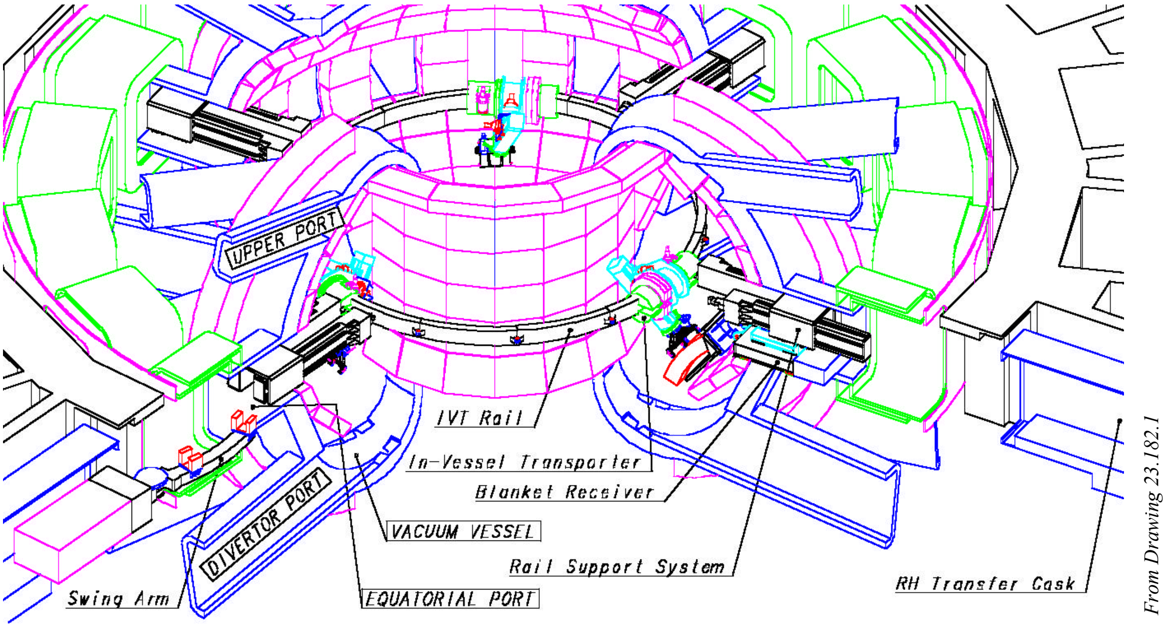

Figure 2.9.3-1 Blanket Maintenance Concept

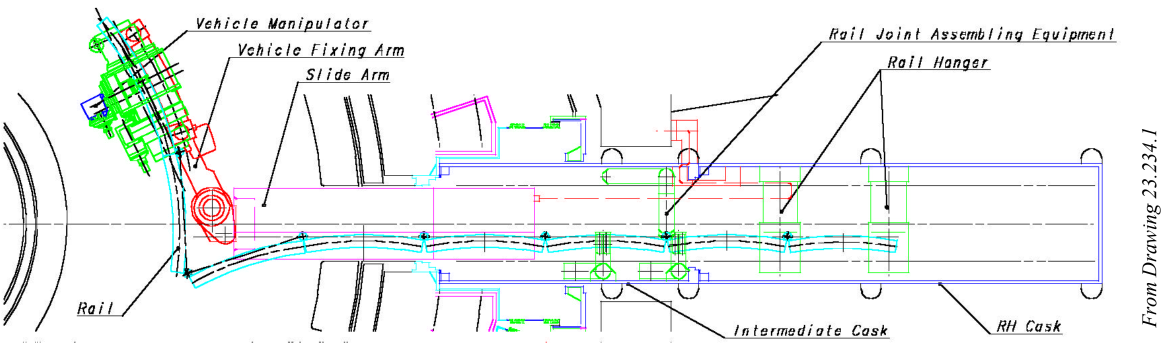

Figure 2.9.3-2 In-Vessel Transporter System

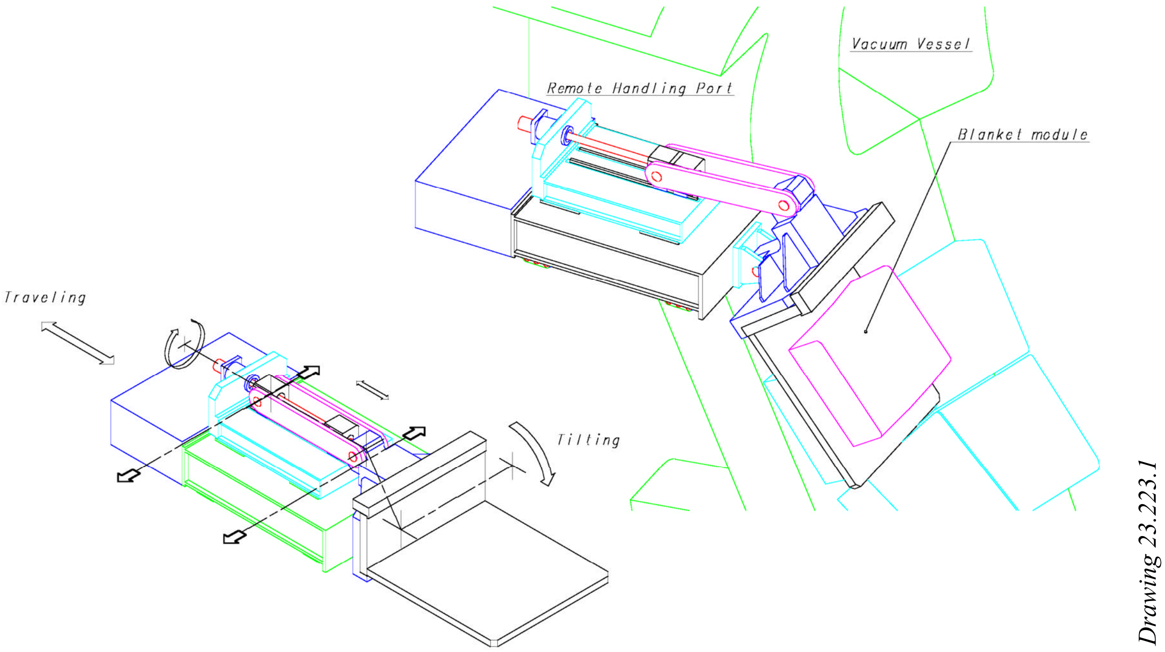

Figure 2.9.3-3 Module Transporter

2.9.3.2 Maintenance Scenario

The blanket maintenance procedure is outlined in Table 2.9.3-2.

Table 2.9.3-2 Blanket Module Maintenance Procedure

Sequence No.	Procedure	Operations
1	Port opening	• Removal of service line of port plug • Removal of port plug • Installation of port adapter
2	Intermediate casks docking to RH ports	• Intermediate cask travelling/docking to a RH port • Connection of umbilical for RH equipment and device movement
3	Installation of IVT inside the VV	• IVT system transport by RH cask • Installation of IVT (IVT system transport/rail joint assembly/rail deployment/rail support installation/cable handling equipment installation and cable connection/rail deploying equipment removal)
4	Preparation of tools at RH port	• RH cask-loaded blanket maintenance tools (pipe welding/cutting, bolting, pipe inspection) with blanket transporter docking to RH port

Table 2.9.3-2 Blanket Module Maintenance Procedure (cont'd)

Sequence No.	Procedure	Operations
5	Blanket module removal	• Electrical strap bolts exchanged to temporary fixing bolts (using bolting tool) • Flexible support bolts unbolting (using bolting tool) • Cooling pipe cutting (using pipe welding/cutting tool) • Blanket module removal
6	Blanket module transportation	• Blanket module transportation to the hot cell
7	Blanket module refurbishment	• FW replacement • Electrical straps replacement if necessary - Branch pipes replacement if necessary
8	Blanket module transportation	• Blanket module transportation to the VV
9	Blanket module installation	• Blanket module introduced into the VV by a blanket transporter • Blanket module attached to the VV wall by the IVT • Cooling pipe welding (using pipe welding/cutting tool) • Cooling pipe inspection (using pipe inspection tool) • Temporary fixing bolts attach to electrical strap bolts holes (using bolting tool) • Flexible support bolt fastening (using bolting tool)
10	Removal of tools from RH port	• RH cask loaded with blanket maintenance tools with blanket transporter removing them from the RH port
11	Removal of IVT from the VV	• IVT system transportation by RH cask • Removal of IVT (installation of rail deploying equipment/IVT returning to the vehicle fixing arm/cable disconnection and cable handling equipment retraction/rail support retraction/rail retraction and rail joint disassembly/IVT system removal)
12	Intermediate cask removal	• Disconnection of umbilical for RH equipment and transfer of all RH devices into cask • Intermediate cask undocking and removal from the RH port
13	Port closing	• Installation of port plug • Installation of port plug service lines

To implement the cask-based IVT system, up to four of the equatorial RH ports can be assigned for installation of the IVT system and transportation of the blanket modules. Therefore, both an 80/100° rail and 180° rail deployment system can be used for blanket maintenance, in addition to the full 360° configuration. The configuration of each system variant is shown in Table 2.9.3-3. It is likely that for initial machine operations one 80/100°

system will be adequate. Therefore, depending on the location of damaged modules, the 80/100° degree system and 180° degree system can be used.

Table 2.9.3-3 Configuration of System Variant

Equipment and device	80/100° system	180° system	360° system (full system)
Rail	100°	180°	360°
Vehicle manipulators	1	2	4
Rail-deploying equipment	1	1	2
Rail support devices	2	3	4
Cable-handling equipment	1	2	4
Intermediate casks	2	3	4
RH casks	2	3	4
Module/tool transporters	1/1	2/1	2/2
In-cask storage racks for modules/tools	1/1	2/1	2/2
Welding/cutting tools	1	1	2
Bolting tools	1	1	2
Inspection tools	1	1	2
Rescue tools	1	1	1

2.9.3.3 Rescue Scenario

One failure mode that has serious consequences is a malfunction of the actuator in the vehicle manipulator during blanket module handling. To cater for this eventuality, all the mechanisms of the vehicle manipulator have redundant mechanisms, which incorporate an external drive connection that can be accessed by a rescue tool handled by a second vehicle manipulator. The rescue tool then connects to the redundant, healthy actuator and drives it, thereby bypassing the damaged mechanism of the vehicle manipulator.

2.9.3.4 Maintenance Time Estimation

A staged procurement is assumed for the IVT systems. During the first ten years of operation, an 80/100°, or if proven necessary, a 180° system will be used for in-vessel component maintenance. To speed the replacement of blanket modules by a breeding blanket, an additional 180° system may be procured. Estimated maintenance time estimates are shown in Table 2.9.3-4. Single module replacement is expected to be possible within one month, whereas for replacement of a toroidal row of modules approximately 2.5 months, or 1 month are required respectively, depending on whether a 180° or 360° IVT system is deployed.

Table 2.9.3-4 Time Estimates for Blanket Maintenance

Maintenance	80/100° system	180° system	360° system (full system)
One blanket module replacement	25 days	(same as 80/100° system)	(same as 80/100° system)
One toroidal row replacement	No use (151 days)	74 days	32 days
All blanket modules replacement	No use (916 days)	487 days	276 days

2.9.3.5 Assessment/Future Work

An overall RH procedure for replacement of blanket modules has been established. A large in-vessel transporter with telescopic manipulator has been designed. The design has been fully optimised with respect to payload and size. Design concepts of additional equipment and tools are progressing. The main requirements of welding and cutting tools have been confirmed through R&D. The basic scenario and procedure of blanket maintenance using an approximately full scale prototype IVT system have been demonstrated in the large R&D project L6.

The emphasis of present R&D is on developing position and force feedback control for the accurate positioning of blanket modules onto the VV wall, which requires the insertion of keys into keyways with very small gap clearances (fraction of a mm). This has been demonstrated in 2001. Important characteristic data of blanket RH system operation, using a teach-and-playback technique, has been obtained. Furthermore, the remote connection/disconnection of adjacent rail links is being developed in bench tests.

Typical rescue situation were simulated to verify the feasibility of the postulated rescue operations and demonstrate the fail safe behaviour of the remote handling equipment under off-normal conditions. As a result, the respective rescue operations have been successfully performed under the simulated conditions. The respective maximum torque in the rescue tests are 19 Nm for screwing the redundant mechanism to drive the faulty axis, and negligible for disconnecting the jamming mechanism.

After mid-2001 continued development of detailed designs has to be carried out and detailed maintenance procedures, as well as rescue scenarios, have to be demonstrated. This should include:

- demonstration of all module attachment and replacement procedures, including module handling, bolting, welding/cutting, testing;
- demonstration of module transfer procedures (manipulator to receiver, module transporter through port, receiver to rack, rack to receiver, receiver to hot cell receiver);
- optimisation of man-machine interfaces, development of automatic sequences.

To achieve the above demonstrations, relevant full-scale prototype equipment has to be procured.

The above demonstrations must include rescue from upset and failure conditions.

2.9.4 Cask Transfer System

2.9.4.1 System Description

The ITER cask transfer system (Figure 2.9.4-1) consists of a container for the transport of in-vessel components, capable of remotely docking to the vacuum vessel and to the hot cell ports, and travelling by means of a remotely controlled transfer system. Each cask has three main sub-systems: a cask enclosure, a cask transfer system, and remotely operated equipment inside the cask. The cask enclosure shape and dimensions vary, depending on the size of the component to be transported and on the design of the vacuum vessel flange. The cask transfer system, which allows the cask to travel independently through the building, is designed to be a separate and exchangeable unit. Its design is universal in the sense that it can be used in conjunction with any of the cask envelopes without modification. This approach helps reduce the total inventory of cask system components by allowing total system interchangeability.

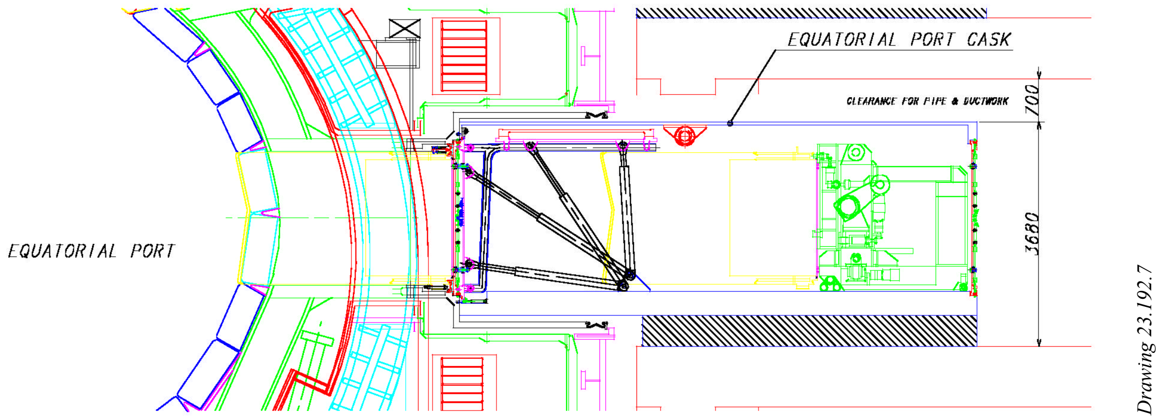

Figure 2.9.4-1 Cask Transfer System

The cask equipment consists of a handling tractor (for the lifting and positioning/removal of the payload), and a manipulator (for the execution of tasks such as bolting and unbolting, seal cutting, welding inspection, etc.). The largest cask size (with the exception of the single, neutral beam injector cask) is 2.6 m wide, 3.7 m high and 8.5 m long, and the maximum weight (unladen/laden) is 40/80 t. In more detail, the transfer cask system includes the components itemised below.

1) Cask platform and enclosure, i.e. the cask load-bearing and envelope structure required for supporting and containing the payload. The load-bearing structure acts also as gamma shielding to prevent radiation damage to the cask transfer system underneath. The envelope is of light construction but strong enough to withstand a maximum internal pressure of 1.05 bar (following air temperature increase caused by the nuclear heating caused by the radioactive payload) and a minimum internal pressure of 0.90 bar. Six different cask envelopes are required to satisfy the need to transfer different sized components while docking simultaneously to four different machine ports.

2) Cask double-seal door system (see Figure 2.9.4-2), fitted to the front end of the cask, allows the component transfer in and out of the cask under contamination-controlled conditions. The function of the double door is to allow connection and disconnection of the cask without the risk of a spread of contamination. The double-seal door is operated

by a combination of hydraulic cylinders and by a set of bayonet type mechanisms (for the selective connection and disconnection of the cask door to/from the maintenance door). Where possible, the door actuators are fitted to the fixed part of the cask, thus simplifying cable routing and increasing the overall system safety. The double-seal door opens by tilting upwards and backwards inside the cask, where it is stored near the cask ceiling. A single-seal door is fitted at the rear end of the cask, becoming a full double-seal door system when a rescue cask is docked to the rear end of the cask.

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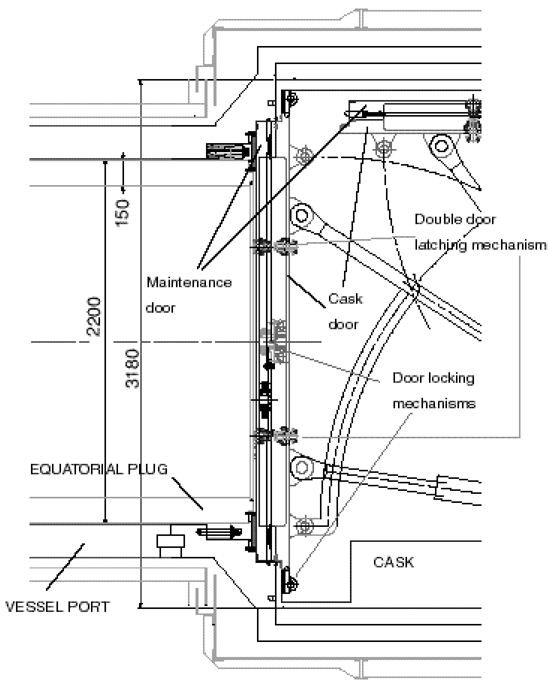

Figure 2.9.4-2 Double-Seal Door System

3) Cask transfer system, allows the cask to be suspended on a virtually frictionless thin air film which acts as a compact, high load capacity, flexible interface between the cask and the floor. Air to the bearings is supplied by a set of on-board compressors. Cask motion (multi-directional) is achieved by a double set of drive wheels powered by electric motors, fed (like other cask onboard electrical components) by a set of onboard batteries. The transfer system design is such that one single transfer unit type can be shared among five different-sized casks.

4) Cask docking and alignment system. The docking system allows all the necessary movements and forces required to adjust the cask position in front of the vessel or hot cell port and keep it there throughout the component transfer operation. This is achieved by means of a jacking system (vertical, tilt and yaw adjustment) and pushing devices reacting on the building floor (providing horizontal adjustment and compression of the docking flange seals).

5) In-cask handling equipment (mainly a combined tractor/manipulator system, remotely controlled) for the disconnection, reconnection, loading, and unloading of the components. For specific operations, the in-cask equipment can be rather complex, as in the case of blanket module replacement.

6) Control system, for the remote control of the cask and of the handling equipment.

2.9.4.2 Rescue Scenario

The issue of rescue in the case of cask failure (such as cask double-seal door failure, or in-cask handling equipment failure) has been addressed. In these cases a rescue cask is delivered and docked to the rear of the failed cask. The front door of the rescue cask is connected to the main cask rear door. The two doors are then opened inside the rescue cask. At this point two rescue actions are possible:

- if the main cask handling equipment (manipulator, gripper, etc.) is faulty, this is retrieved inside the rescue cask and later replaced with new equipment (i.e. requiring the rescue cask to travel to a free hot cell port and then return to the main cask);
- if the main cask front double seal door is faulty, the rescue cask equipment removes (if present) any component and equipment inside the main cask (plug, manipulator, etc.) returning them to the hot cell; in a second phase, the rescue cask equipment enters the main cask again and, by-passing the double seal door actuator mechanism, closes the double seal door, leaving a maintenance door fitted onto the machine (or hot cell) port and closing the failed cask; the two casks are then removed and a new cask is sent to continue the operation.

The cask transfer system is designed such that in case of failure it can be removed from under the cask (while using temporary jacks) and replaced with a new unit. Redundancy for the main cask transfer components (air bearing units, air compressors and batteries) is included in the design.

2.9.4 3 Maintenance Time Estimation

Maintenance time varies depending on the operation to be performed. In general, the duration of the intrinsic cask operations has to be compatible with the specified overall maintenance time for the components to be replaced. This varies greatly depending on the extent of the replacement operation.

However, there is a minimum time, which must be accounted for to allow the execution of the intrinsic cask functions. These are given in Table 2.9.4-1.

Table 2.9.4-1 Estimated Times for Certain Cask Operations

Operation	Estimated Time
Docking at the vacuum vessel port interface	*h*
Cask alignment	0.75
Cask docking and external power connections	1
Docking surfaces double seal leak check	0.5
Cask door /maintenance door reconnection (1)	0.25
Double-seal door opening	0.25
Double-seal door closing	0.25
Cask/maintenance door disconnection	0.25
Maintenance door leak checking	0.5
Cask undocking and external power disconnection	0.5
TOTAL EST. TIME at VV port	**4.00 ~ 4.25**

Table 2.9.4-1 Estimated Times for Certain Cask Operations (contd.)

Operation	Estimated Time
Docking at the hot cell interface (*)	*h*
Cask alignment	0.75
Cask docking and external power connections	1
Docking surfaces double seal leak check	0.5
Cask/hot cell maintenance door connection	0.25
Double-seal door opening	0.25
Double-seal door closing	0.25
Double door interspace leak checking	0.5
Cask/hot cell maintenance door disconnection	0.25
Cask undocking and external power disconnection	0.5
TOTAL EST. TIME at hot cell interface	**4.25**
Hot cell docking port adapter exchange	*h*
Adapter n.1 double seal leak checking	0.5
Adapter n.1 disconnection	1
Adapter n.2 reconnection	1
Adapter n.2 double seal leak checking	0.5
TOTAL EST. TIME for adapter exchange	**3**

(1) If returning from the hot cell

(*) Assumes that the correct hot cell docking port adapter is already installed, otherwise, in case of adapter exchange, add the time below

2.9.4 4 Assessment and Future Work

Cask docking and double-seal door operation were demonstrated for the 1998 ITER design[1]. However, docking at the vacuum vessel ports for the current design requires that the cask is extended from its support into the cryostat port, and is connected to the vessel port. Moreover, the upper ports are inclined and require more complex handling operations. While good design progress has been made for the current configuration during the period 2000-2001, future R&D needs to address the development and qualification of individual operations.

The transfer cask design and the general port handling using a cask system is now established, but certain areas need further R&D, in particular cask alignment and positioning/docking, double-seal door operation, and the handling tractor development.

2.9.5 Viewing and Metrology

The need for regular viewing inside the vacuum vessel is anticipated for inspection of the inner walls, especially after plasma operations have indicated possible damage to components. Insertion of viewing probes with adequate resolution should allow surveying of the inner walls within a reasonable time, e.g., several hours. A sufficient number of probes should be deployed at toroidal positions to achieve an adequate viewing coverage.

[1] "Technical Basis for the ITER Final Design Report, Cost Review and Safety Analysis (FDR)", ITER EDA documentation series n.16

Metrology may be required to assess the degree of damage after off-normal events and will also be needed to confirm accurate positioning of in-vessel components after replacement. Moreover, metrology may be needed for plasma erosion measurement.

As a result of optimisation considerations, divertor ports were selected for in-vessel viewing (IVV) probe insertion into the vacuum chamber. Deployment of a probe, between the lower outboard module and the divertor cassette, from six, equi-spaced ports, allows nearly 100% viewing of the blanket and divertor first walls. Viewing activity was assumed to be under full vacuum, with the in-vessel components at dwell temperature.

The plug-type system (Figure 2.9.5-1) is permanently parked on the rails inside the port. Due to the configuration of the port and the components permanently mounted inside the port, a curved deployment trajectory is necessary. A cask is required for maintenance.

Such an arrangement requires the use of motors, actuators, sensors, support systems, etc., all operating in vacuum. The technical basis for their radiation hardness also needs to be demonstrated by further R&D, as does the development of viewing and metrology probes. The results so far indicate that the ITER requirements regarding accuracy, resolution and radiation hardness are likely to be met.

The requirements specified for the system are also being scrutinised, e.g., the need for deployment under vacuum and at dwell temperature.

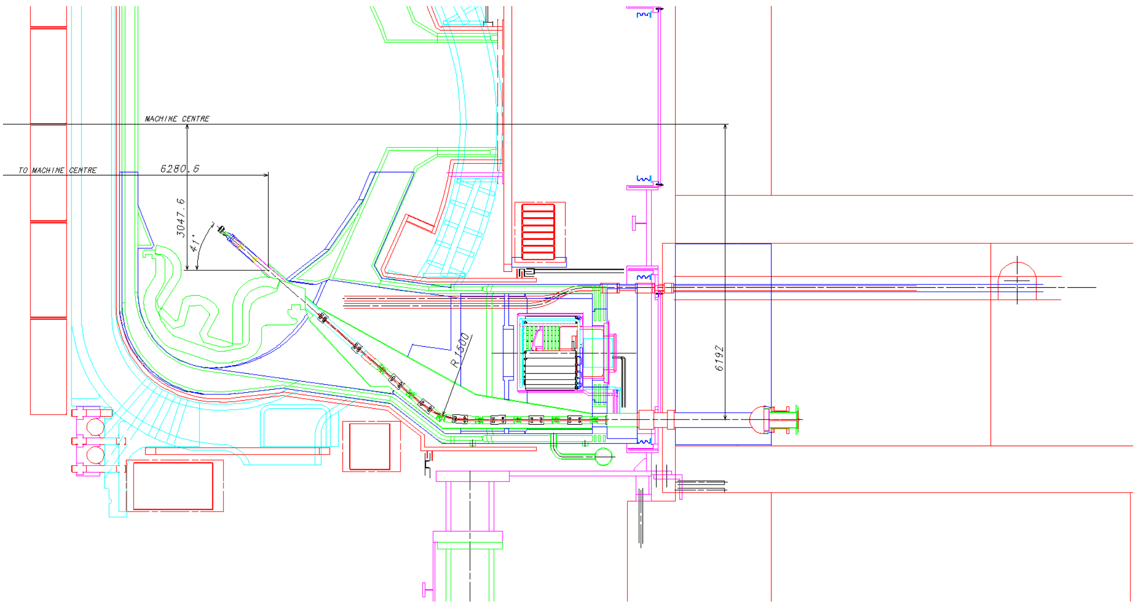

Figure 2.9.5-1 Concept of Plug-type IVV System

2.9.6 Neutral Beam (NB) Injector Maintenance

2.9.6.1 Introduction

Routine remote maintenance of the NB injectors is needed only for the replacement of the ion source filaments, replenishment of the cesium oven and the removal of cesium from the accelerator grids and insulators. Replacement of the source filaments, and replacement of the cesium oven, can be achieved "in-situ", and R&D on removing cesium from the insulators shows the feasibility of in-situ cesium cleaning, i.e., without removing the ion source. Should in-situ cesium cleaning not ultimately prove feasible, as a back-up solution the beam source from the beam-line can be taken to the hot cell for detailed maintenance. The maintenance sequence of cask travel, docking and ion source removal is shown in Figure 2.9.6-1. The remote handling disconnection and reconnection of the ion sources, while being a complex and time-consuming operation, is nevertheless feasible.

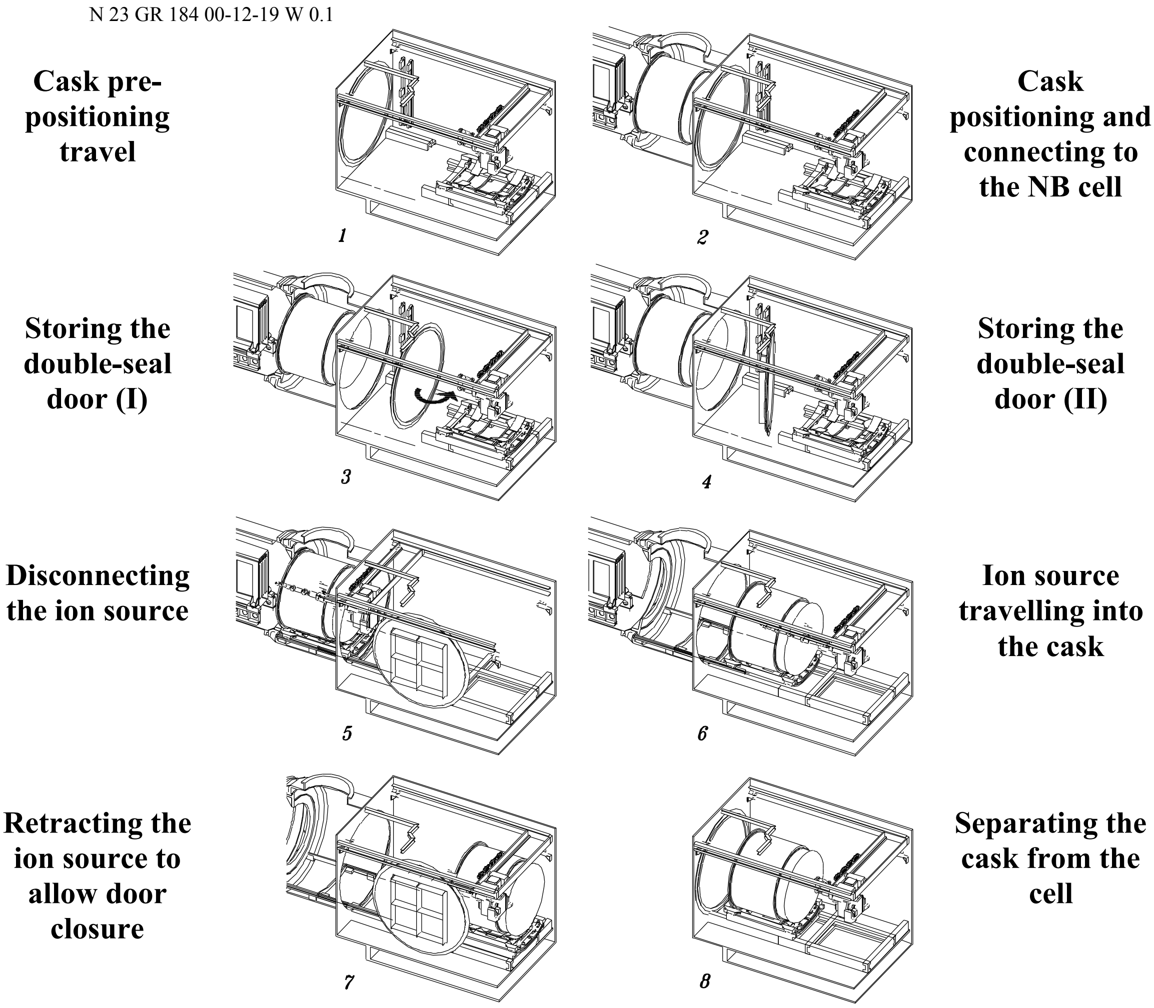

Figure 2.9.6-1 Maintenance Cask Travel, Docking and Ion Source Removal

2.9.6.2 Maintenance Processes

1) Installation of the maintenance cask

The NB injector transfer cask is a dedicated cask used only for maintaining the NB injectors. The ion source pressure vessel has a "race track" shaped dome to which the maintenance cask can be docked. The cask is similar to the other transfer casks operating at the equatorial port level and contains all the remote handling equipment required to carry out a maintenance operation. The installation therefore proceeds as follows.

a) Remove the biological and magnetic shield doors from the required NB cell and re-configure them as temporary gallery shielding.
b) Position the transfer cask at the NB cell using the air bearing support system and the cask driving wheels.
c) Align the transfer cask with the back of the ion source dome, and dock to it.
d) Attach the NB injector ion source dome to the transfer cask door and remove the whole assembly to the back of the cask.

2) Maintenance of ion source filaments

The ion source has 72 filaments arranged radially and longitudinally along the plasma generator, which is in the form of a partial cylinder. The ion source and filament are grouped into sets of six. To ease assembly, the filament housing is provided with a tapered profile. The plasma source chamber is provided with hinge pivots to guide and correctly position a tool installed specifically for assembling the filaments. This tool (Figure 2.9.6-2), engages the hinges on the ion source plasma chamber and automatically aligns the filaments when they are swung into position.

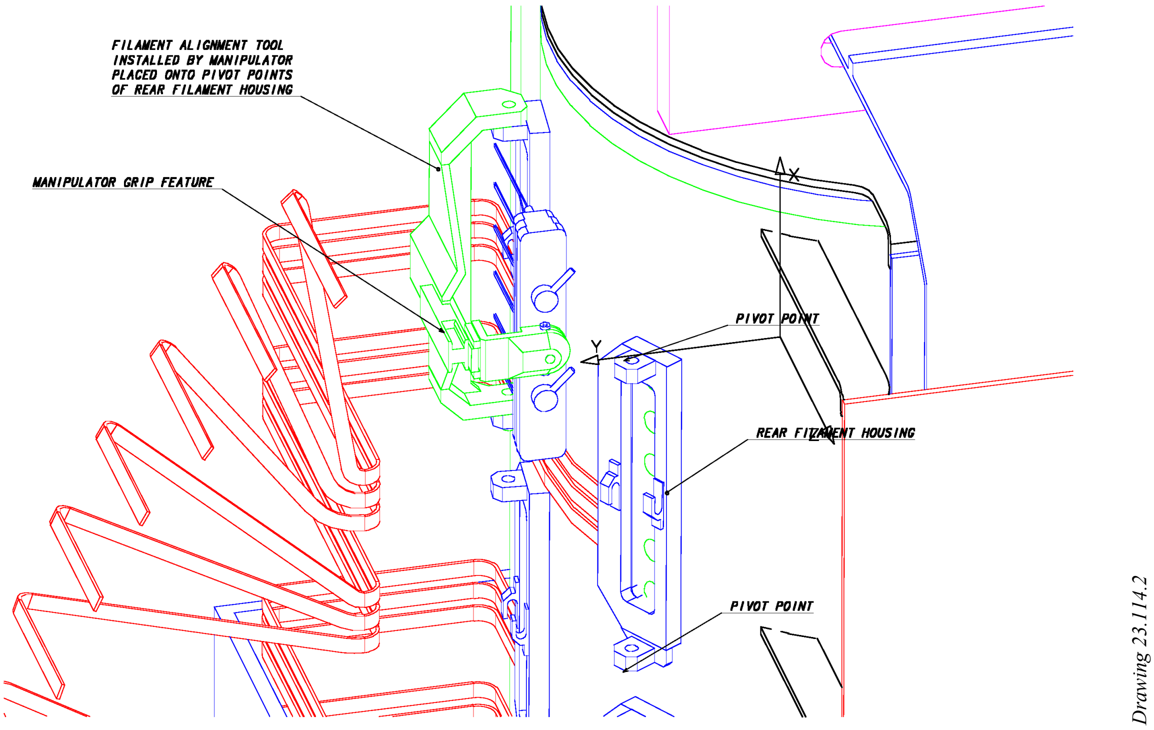

Figure 2.9.6-2 Filament Alignment Tool

3) Replacement of the cesium oven (Figure 2.9.6-3)

There are two cesium ovens per NB injector and they are located at the rear of the ion source. To replenish the cesium source it is necessary to replace the cesium oven. The cesium ovens will be replaced each time the ion source filaments are replaced.

The oven is a self-contained unit and is attached to the ion source plasma generator by a single captive fastener. The ovens are aligned horizontally during assembly by means of a tapered collar and positioned axially by three datum pins attached to the plasma generator housing. An insulated guide pin ensures alignment of the fasteners during assembly.

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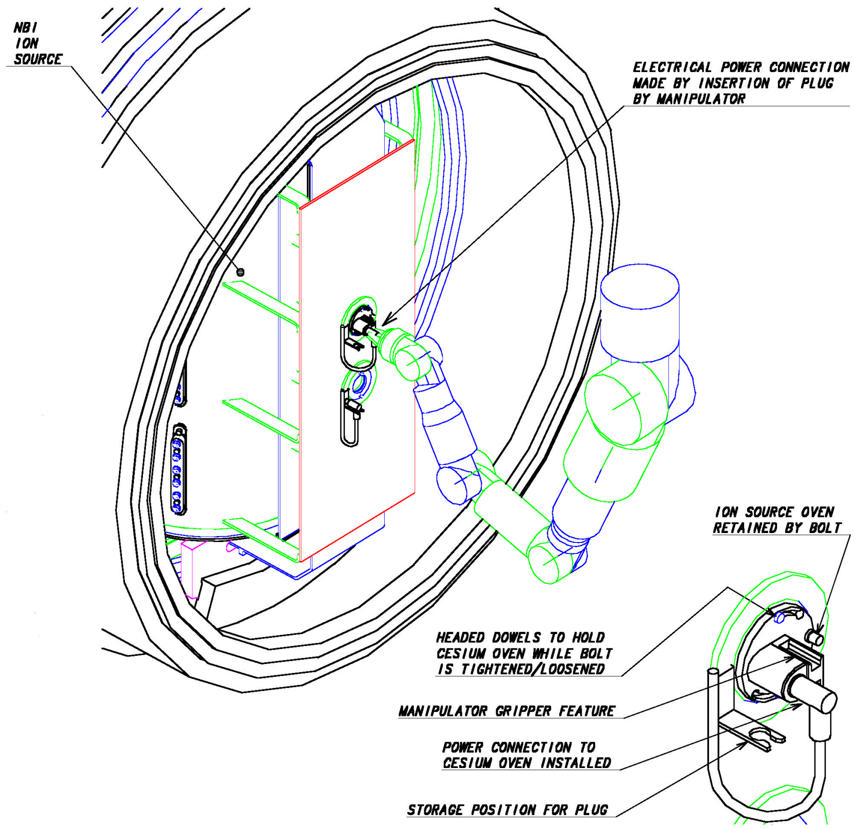


From Drawing 23.153.2

Figure 2.9.6-3 Replacement of a Cesium Oven

4) In-situ cesium cleaning of ion sources (if applicable)

The manipulator delivers cesium cleaning tools to the grids and insulator, where the tools perform laser cesium cleaning.

5) Maintenance of NB injector beam-line components

The beam-line components are generally RH class 3. However, in the event that a beam line component may need replacement, they can be replaced in a manner similar to that described above for the ion source. In this case, the ion source transporter is replaced by a second transporter, which has an upper and a lower set of rails. The lower set aligns with the beam source transporter rails at the bottom of the pressure vessel. The upper set aligns with the beam-line component support rails. Using these rails, beam-line components can be pulled into the transfer cask and subsequently transported to the hot cell.

a) *Neutraliser, Residual Ion Dump (RID), Calorimeter, and Cryopump*
To facilitate remote cutting and welding of coolant pipes, all welded connections are located on the "service flange" at the entrance of the beam-line vessel. The rear flange of the beam line features a reduction ring that can be removed (unbolting followed by cutting of the lip weld. This increases the free passage dimensions so that the largest component (the cryopump panels) can slide out. Prior to cryopump removal, dismantling of all other beam-line components is required.

b) *Fast Shutter*
Two components of the fast shutter are considered for infrequent maintenance. They are the "soft" seal and the pneumatic actuator. The actuator is mounted externally and may be accessed from within the NB cell. The seal is removed after first removing the bellows. The fast shutters on the NB injector systems incorporate the inboard rupture discs of the vacuum vessel pressure suppression system. Maintenance access to the rupture discs is established by removing the bellows.

c) *NB Bellows*
To remove the bellows, whilst at the same time maintaining confinement, the secondary containment surrounding the bellows is provided with a double-door system to which may be attached a maintenance cask. All the equipment required to perform maintenance is inside the cask. After cutting the bellows welded lip seal, the bellows are compressed and raised into the maintenance cask. The cask is transported by an overhead monorail to a hatch in the floor, and hence to the hot cell.

d) *NB Duct Components*
The NB injector duct liner replacement will be carried out from within the vacuum vessel using the remote handling in-vessel transporter.

2.9.6.3 Assessment and Future Work

Maintenance concepts have been developed, partly in detail, for the ITER NB injector system. The handling principles are based to a large extent on similar procedures used for the maintenance of other components. Specific procedures are required for cesium cleaning and these are now being addressed in R&D. To qualify the procedures for NB injector maintenance, prototype tools and equipment will need to be tested in mock-ups.

2.9.7 In-Cryostat Repair

2.9.7.1 Design and Interfaces Description

Because of the congested nature within the cryostat and the difficulty of achieving direct access to components located between the outside of the machine and the inside of the cryostat, in-cryostat maintenance is, as far as possible, eliminated by design. Components inside the cryostat are conservatively designed with factors of reliability high enough to render failure very unlikely. All components are designed to last the life of the machine and no components require planned routine maintenance. In the unlikely event that a repair is required, the strategy for repair within the cryostat is based on human access with hands-on repair. Machine shielding thicknesses are such that any radiation received by operators during maintenance (see 2.14) is below 100 µSv/h 2 weeks after shutdown, and is as low as reasonably achievable (ALARA).

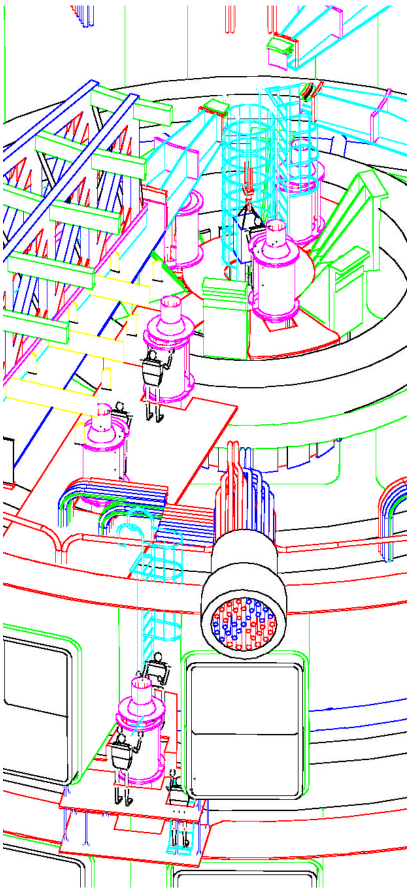
The specific objectives for in-cryostat repair are as follows.

- To inspect and repair components within the cryostat and located between the cryostat wall and outer surface of the machine, which include the following items:
  - magnet termination joints (current and helium);
  - intercoil structure bolted connections;
  - thermal shields;
  - vacuum or cryogenic leaks;
  - electrical or thermal shorts.
- A less likely objective of in-cryostat operations involves extensive work, mainly related to the replacement of large components, i.e. a PF coil, a TF coil and associated vacuum vessel sector, etc.

Access to the interior of the cryostat for repair is provided at three levels:

- the top of the cryostat which has
  - a central access hatch
  - four perimeter hatches;
- the four equatorial remote handling ports;
- four radial access hatches at the basemat level.

Typical access conditions for the upper CS and PF coils are shown in Figure 2.9.7-1.



Excerpt from N 23 GR 188 00-12-19 W 0.1

Figure 2.9.7-1
Overview of Upper CS and PF Coil Access

Below each of the hatches at the top of the cryostat is a series of landings, walkways and stairs that allow maintenance personnel to travel to the various sites where repair or inspection may need to be carried out. The equatorial level remote handling ports are provided with hatches in the roof and floor. Ladders, from the remote handling ports, will permit access to the interspaces between the upper and equatorial ports and the divertor and equatorial ports. From the basemat level, stairs and ladders provide access to the overhead repair and inspection sites.

Installed lifting points and rigid set down areas (to protect the delicate thermal shield, etc.) will be provided to assist in the transfer of heavy components and maintenance equipment.

2.9.7.2 Maintenance Scenarios

During maintenance within the cryostat, the magnets will be turned off, warmed to room temperature and the cryostat opened. Only a small residual magnetic field is assumed to remain. Pressure inside the cryostat will be ambient and the atmosphere, normal air. The interior of the cryostat is assumed to be free of radioactive contamination, and maintenance workers will not normally be required to wear plastic suits or be provided with a supply of breathing air.

A typical repair procedure involves the following items.

- Planning to ensure that the estimated radiation dose uptake by personnel entering the cryostat is ALARA. A minimum of two people is assumed, including a maintenance worker and health physics monitor.
- Gaining access to the interior of the cryostat by removing the access hatch by releasing fasteners and cutting the welded lip seal joint, and likewise removing the demountable access panel in the underlying thermal shield.
- Installing walkways and platforms as required (if appropriate) and travelling to the work site along walkways and platforms.
- Assembling equipment.
- Carrying out repairs, reassembly and testing.
- Dismantling equipment, cleaning up and monitoring.
- Retiring from the cryostat.
- Closing the cryostat and checking for leaks.

To access the PF1 coil terminations, a ladder is used to get to the in-cryostat platform via the central access dome in the cryostat lid. Stairs allow access from the pumping platform to the PF2 and PF3 coil terminations. The lower PF coils (PF4, PF5, and PF6) are accessible through a cryostat access port at basemat level. The PF4 coil has the option of being accessed from above. The PF5 coil terminations are mounted on the TF coil clamps and are accessible by ladder and landing from the basemat level. Access to bypass joints or to the PF3 or PF4 coils may also be made via access hatch from the equatorial remote handling ports. A maintenance worker then has access to the area between the equatorial ports and is able to climb up to the PF3 coil or down to the PF4 coil.

The TF coil feed joint can be reached by a maintenance worker on a mobile platform erected on the inside of the cryostat.

Access to the three CS termination joints at the top of the machine is through the upper central dome and onto the vacuum pumping platform. Access to the three at the bottom is via an access port at the basemat level and a walkway through the TF coil support structure. At the top of the machine there is a platform supported off the PF1 coil and the feed joint can be reached from this platform. At the bottom of the machine there is a ladder to an elevated platform from where the lower feed joint can be reached.

2.9.7.3 Rescue Scenario

Two means of access will be provided during personnel entry to the cryostat. The primary access will allow for the transport of personnel and materials, and the second access will provide an escape route in the event of an accident.

2.9.7.4 Assessment and Future Work

Means to access the cryostat for hands-on repair have been established. Critical repair procedures have been developed and the needs for specific access, working space, tools and fixtures have been identified.

Following the detailed layout of components inside the cryostat and a detailed analysis of the radiation levels expected during the operating schedule, there is additional work required to develop the following for in-cryostat repair.
- Devices for deployment of repair equipment.
- Tools for disassembly and assembly of termination and cryogenic isolation joints.
- Repair times and compliance with ALARA and ITER radiation protection program.
- Remote back-up procedures should current estimates of radiation levels prove too optimistic.

2.9.8 Hot Cell Repair and Maintenance

2.9.8.1 Introduction

The hot cell provides space and handling facilities for the reception, dispatch, decontamination, storage, repair, refurbishment and testing of highly radioactive and, or contaminated in-vessel components and materials (divertor cassettes, blanket modules, and other in-vessel component such as diagnostics and port plugs). Facilities are also provided for the maintenance of remote handling tools and for radioactive waste processing and storage prior to disposal by the ITER host.

2.9.8.2 Engineering Description

An overview of hot cell building is shown in Figure 2.9.8-1. The functions performed by the hot cell repair/maintenance equipment are summarised in Table 2.9.8-1 and the system description is as follows.

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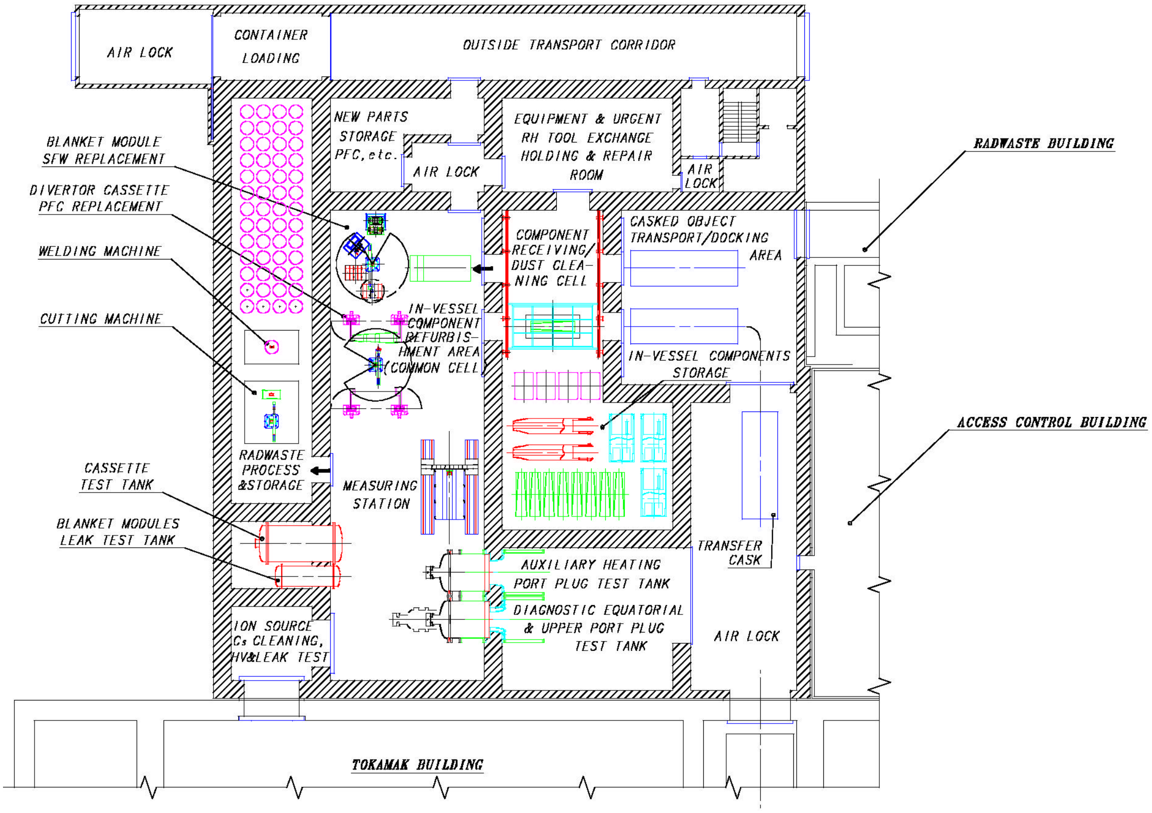

Figure 2.9.8-1 Overview of the Hot Cell (Ground Floor Layout)

Table 2.9.8-1 Hot Cell Repair/Maintenance Equipment

No	Items	Description
1	Dust cleaning system	This facility has two lines to avoid congestion, and consists of the following equipment. • Port number for cask docking system: 2 • Cleaning method: vacuum brush or CO_2 pellet blast • Handling robots: one overhead type arm robot for each line (two robots) • End-effectors/tools: dust cleaning arm, inspecting arm • Overhead crane: 50 t capacity crane with gripper, one rescue crane
2	Blanket module first wall (FW) replacement workstation	This facility has one workstation in the common refurbishment cell, and consists of the following equipment. • Blanket module supporting stand for refurbishment: 1 line (i) Handling robot: column-type arm robot • End-effectors/tools: - Bolting tool: torque wrench - Cutting tool: with laser cutting head - Welding tool: with TIG welding head - Weld inspection tool: ultrasonic transducer or electro-magnetic acoustic transducer • End-effector and tool storage: all end-effectors and tools are parked in a tool storage rack

Table 2.9.8-1 Hot Cell Repair/Maintenance Equipment (cont'd)

No	Items	Description
3	Divertor cassette plasma-facing component (PFC) replacement workstation	This facility 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
4	Pressure and leak test tank for blanket module and divertor cassette	Divertor cassettes and blanket modules must be pressure and leak tested in this facility after exchanging a PFC. • Number of vacuum test tanks: 1 each for blanket module and divertor cassette • Pressure testing line (water) for cooling pipes • Leak testing line (helium gas) for cooling pipes
5	Transporter	For the transport of components in the common refurbishment cell, the following equipment is used. • Floor mobile transporter • Overhead crane: 50 t capacity crane with gripper, 1 rescue crane
6	In-vessel components storage system	Components are stored on the floor. The storage capacity of the storage cell is as follows: • 16 divertor cassettes (12 t each) • 20 blanket modules (4 t each) • 4 port plugs (3 equatorial RH/limiter/diagnostics plugs + 1 dummy plug, or 3 divertor diagnostics racks) • 2-4 upper port plugs (13 t ea.)
7	Equipment measuring station	Repaired components are brought on their carrying trolleys under the measuring station gantry and examined by the following equipment: • 3D measuring: non-touch method • 3D-examination device: touch sensor • Visual inspection device: CCD camera • Welding inspection : ultra-sonic inspection
8	Radwaste processing and storage facility	The equipment in the radwaste processing and storage cell comprises the following, together with storage drums. • Laser cutter for cutting thin structures. • Diamond blade saw for cutting elements of small pieces. • Canning machine to weld the lids of drums by TIG welding • Overhead crane: 50 t capacity crane with gripper, 1 rescue crane

Table 2.9.8-1 Hot Cell Repair/Maintenance Equipment (cont'd)

No	Items	Description
9	Port plug equipment testing facility	The equipment in the port plug equipment testing facility comprises the following. • Diagnostic, equatorial and upper port plug test tank. • Auxiliary heating port plug test tank
10	Remote handling equipment test stand	The configuration of the maintenance cell is 10.4 m inner length and 100° sector angle with isolation wall of 200 mm concrete. The equipment in the RH equipment test stand is as follows. • Dummy docking port structure (1 dummy upper port, 3 dummy equatorial ports, and 1 dummy divertor port) • Part mock-up vacuum vessel (20° sector) and the support structure • Dummy in-vessel component (1 dummy divertor cassette, and 1 dummy blanket module)

2.9.8.2.1 Description of Hot Cell Areas

The main areas are shown in Figure 2.9.8-1

a) Dust cleaning area, where components withdrawn from the vacuum vessel (VV) are received and offloaded into a component receiving cell to remove activated dust. After refurbishment and any testing, the components are brought back into the receiving cell and loaded into transfer casks for return to the VV.
b) Common refurbishment area. This area houses dedicated and general workstations, where the layout of the processing area provides flexibility to modify the internal locations of the workstations.
c) Common storage area to store components before repair, after repair, or to await processing for disposal as waste.
d) Radwaste processing and storage area, where the waste is treated for tritium recovery, if required, and segmented and packaged for final disposal.
e) Port plug equipment testing area, where the ex-vessel side of port plugs is accessible for hands-on maintenance and testing, whereas the plasma-facing side is accessible with remote handling equipment from within the hot cell.

Above the hot cell, there is a remote handling (RH) equipment test stand, as shown in Figure 2.9.8-2, designated for the maintenance and repair of RH equipment. Additionally, the test stand is used for operator training, and commissioning of equipment prior to maintenance or rescue interventions in the vessel.

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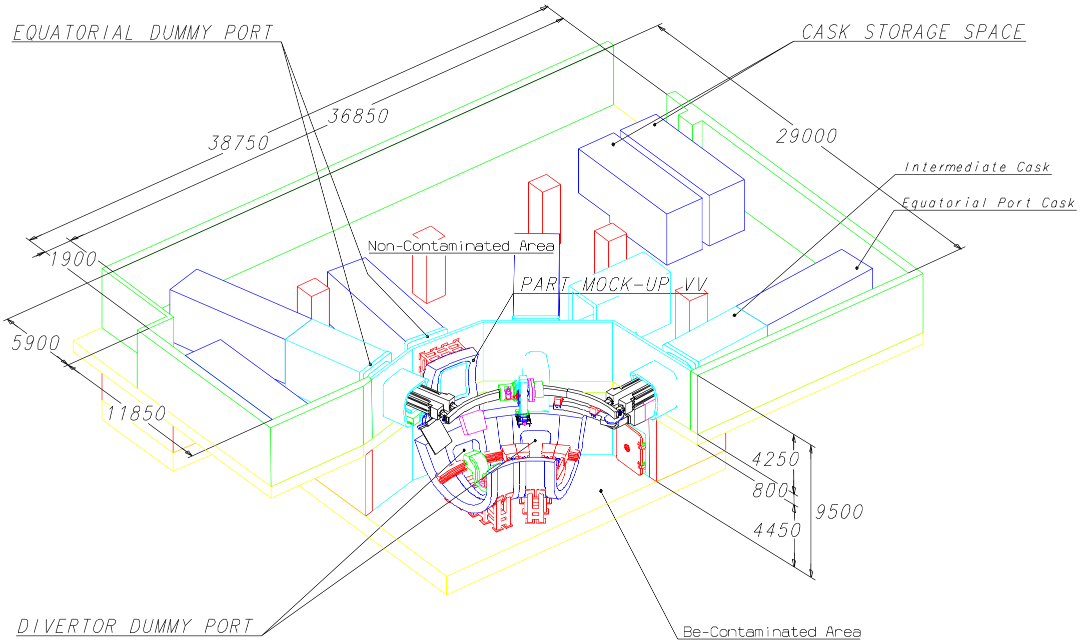

Figure 2.9.8-2 Overview of the Remote Handling Equipment Test Stand

2.9.8.2.2 Layout of the Hot Cell Building

The hot cell building (HCB) is a rectangular reinforced concrete building with a 53.7 x 44.5 m footprint. The HCB is organized on two main levels. Ground level functions include in-vessel component docking, dust cleaning, storage, repair and testing, RH tool exchange and maintenance, waste processing, waste storage and shipping, and the reception and storage of new parts and components. The upper level (+10.56 m) includes space allocation for RH equipment testing, transfer casks storage, and houses equipment for atmosphere confinement control and atmosphere detritiation.

Additionally, the HCB is available, during the initial installation phase of the tokamak in-vessel components, to provide a pre-assembly, beryllium-controlled area, and a facility for loading components into transfer casks.

2.9.8.3 Maintenance Scenario

The basic block diagram for hot cell repair operations is shown in Figure 2.9.8-3. 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. The repaired components are stored in the combined storage facility after dust cleaning. For layout flexibility and transfer simplicity, the common refurbishment cell is an open and rectangular space in which are installed the internal work-stations for various repair and refurbishment operations. As in the case of activated and contaminated components of systems such as diagnostics and EC H&CD, some hands-on maintenance will be performed at the port plug test tank area.

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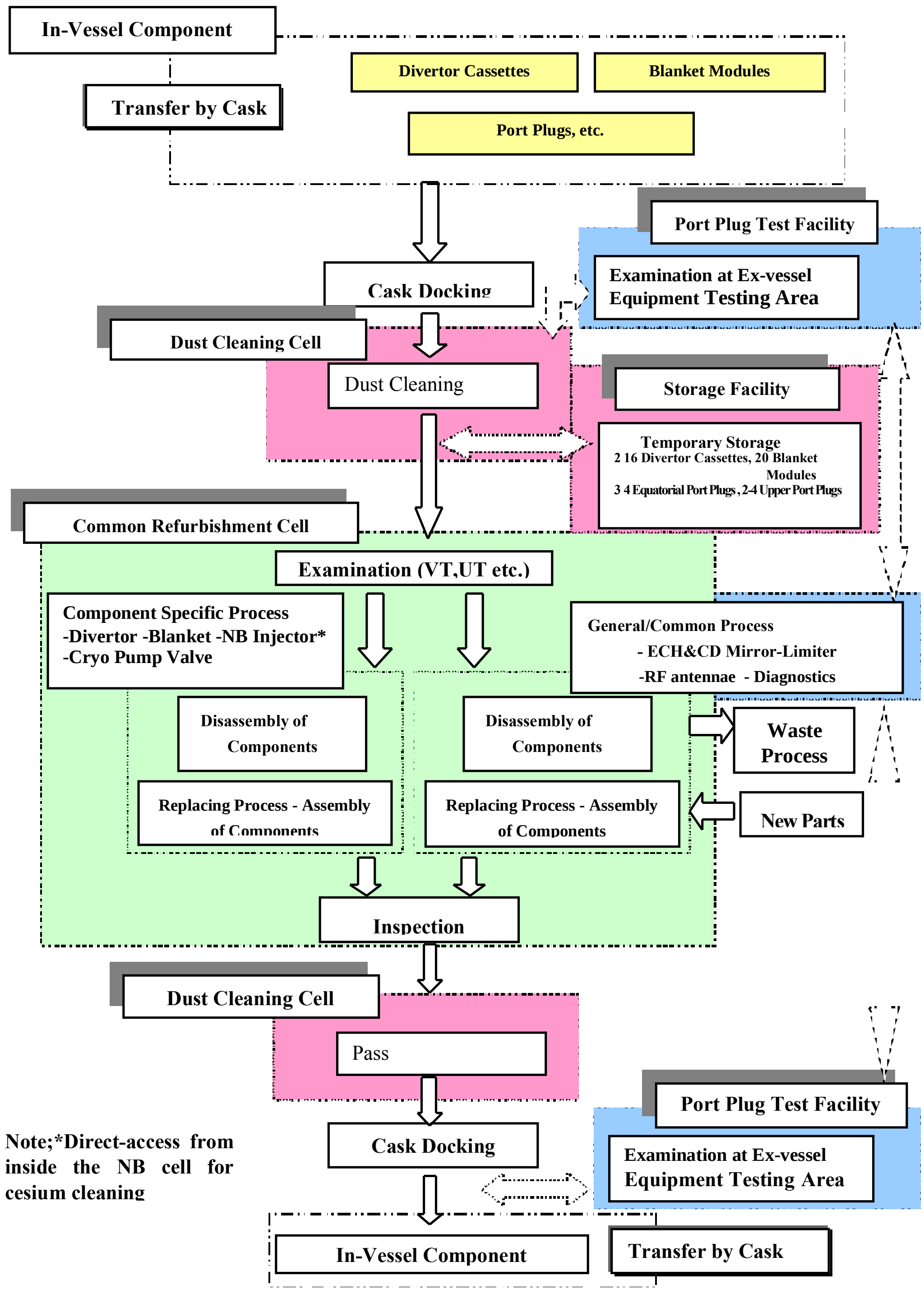

Figure 2.9.8-3 Block Diagram for Hot Cell Repair Operations

2.9.8.4 Assessment

The design of the hot cell is now established and studies done to date confirm that it will meet the design requirements. The work remaining to be done consists chiefly of the detailed design of specialised tools and equipment (including specification and selection of proprietary items) for use in the hot cell, and for further studies to verify the hot cell capacity, both in terms of component throughput and also adequacy of space provision.

2.9.9 Machine Disassembly and Re-assembly

2.9.9.1 Interface Description

The feasibility of disassembly and re-assembly of the magnets or vessel is a basic requirement that affects the machine layout and building design. In particular, during disassembly of a machine 40° sector, (a VV 40° sector with its thermal shield together with its two associated TF coils, the weight to be handled exceeds 1,200 t. Moreover, lifting such a large element out of the cryostat requires that the cryostat lid and bioshield be fully or partly removed, which they are designed to be. Provision also has to be made for the requisite space and facilities.

2.9.9.2 Maintenance Scenarios

2.9.9.2.1 Central Solenoid (CS) Disassembly and Re-assembly

The CS can be repaired in-situ in the event of local failures such as electrical insulator faults or helium leaks. Other, more extensive faults may require that the coil be removed from the machine. For this operation, a lifting device is inserted from the top, after removing the central flange from the cryostat head, and the CS is lifted by the overhead crane without any additional shielding, because the dose rates around the CS are low. A set-down space is reserved to receive the CS in the laydown area of the laydown, assembly and RF heating building.

2.9.9.2.2 Poloidal Field Coils Disassembly and Re-assembly

The PF coils can be repaired in-situ in the event of localised faults such as a helium leak, an electric short circuit, or a ground insulation fault. In the event of failures too extensive to repair in-situ, the faulted PF coil has to be removed. In the case of the upper, untrapped PF coils (PF1 and PF2), these can be removed directly, following the establishment of an appropriately sized aperture in the cryostat upper head and bioshield,, and the removal of coolant pipe and vacuum pumping upper headers, as well as coil feeders, etc.. However, coils PF3 and PF4 are trapped between the VV equatorial and the upper and lower ports respectively. Their replacement would require a very large amount of preparatory work, including cutting off parts of the VV ports. To minimise the failure probability, these coils incorporate in-built redundancy. The lower coils PF5 and 6 are trapped beneath the VV. Replacement of either of these lower PF coils requires that a new coil is fabricated in-situ. The layout inside the cryostat has been configured such that this can be done.

2.9.9.2.3 *Toroidal Field Coils and Vacuum Vessel Disassembly and Re-assembly*

In the event of TF coil failure, replacement of a machine 40° sector will be required. This operation follows the assembly procedure in reverse. This complex operation entails the prior dismantling and removal of a large number of the components inside the cryostat using manned interventions, and remote removal of the relevant in-vessel components, followed by cutting out of the affected VV sector. The machine 40° sector is then lifted out of the cryostat by the overhead cranes. The damaged TF coil is replaced by the spare one, and the assembly procedure is started again, using the same vessel sector (there is no spare vessel sector).

While schemes can be devised for this repair operation to be carried out at any time, once the vessel has become heavily activated, their level of difficulty is considerably multiplied. The vessel and coils would have to be accommodated in a shielded cask. Therefore the crane capacity limits the amount of shielding that can be provided. Also the level of neutron and gamma radiation in the hall at the time of replacement due to the open torus provides another limit. This calls into question the feasibility of such a repair for the machine operating programme. Such a procedure will anyway last many months (depending on activation levels). The more likely situation is that failure will occur in the early years of operation, when the vessel is not heavily activated. Should the failure occur after significant activation, the decision whether to repair the device can be taken at the time based on the information to be gained by a repaired machine, versus what has been achieved thus far and the time for repair. The procedures to be used can also be finalised and implemented then.

2.9.9.3 Maintenance Time Estimation

2.9.9.3.1 *CS or PF Coils Disassembly and Re-assembly*

In comparison to the repair time, the disassembly/re-assembly time for the CS or PF coils is not significant, the repair time of the coils being dominant.

2.9.9.3.2 *Machine 40° Sector Disassembly and Re-assembly*

When the radiation level is low, the procedure for TFC/VV removal without a shielding cask is as follows.

i) The bioshield lid is removed, transferred to the parking location outside the laydown area.
ii) The cryostat lid is removed to outside the laydown area.
iii) PF1, PF2 coils are removed to the north side floor of the tokamak building.
iv) The machine 40° sector is removed to the laydown area through the west side of the tokamak building. By lifting in this way, it is possible to perform repair and maintenance operations on the laydown area.

The total intervention time for this case is estimated at several months.

2.9.9.4 Assessment and Future Work

The feasibility of TFC/VV disassembly and re-assembly using remote procedures has been studied conceptually and solutions for handling and shielding are proposed.

Further studies and developments are required to verify the feasibility of the disassembly and re-assembly of large components, to a level appropriate to such highly unlikely operations.