11 Cryostat

11.1 Functions, Basic Configuration and System Boundaries

11.1.1 Functions

The cryostat shall be designed to perform the functions described in the DRG1.

The vacuum vessel pressure suppression system (VVPSS) shall be designed to limit the vacuum vessel internal pressure, in the case of loss of coolant from the in-vessel components, to 0.2 MPa.

11.1.2 Basic Configuration

The cryostat is a cylindrical pressure vessel, with its axis vertical, and with flat bottom and top ends. The cryostat envelops the tokamak basic machine, and has penetrations to allow passage of all the components and systems required to operate and maintain the tokamak and the cryostat itself. The cryostat bottom end is just above the pit floor level.
The VVPSS consists of a large linear tank of circular cross section, containing enough room temperature water to condense the steam resulting from the most adverse in-vessel loss of coolant accident. The tank is connected to the vacuum vessel by three main pressure relief pipes incorporating double rupture disc assemblies which constitute the vacuum boundary between the vacuum vessel and the room temperature suppression water during normal operation. The VVPSS includes a bypass system for the rupture discs, consisting of bypass pipes containing isolation valves, which are designed to open during a small in-vessel loss of coolant event, when the vacuum vessel pressure is greater than atmospheric, but less than the opening pressure of the rupture discs. During an in-vessel loss of coolant event, the VVPSS acts in concert with the VV drainage system, the former routing evolved steam to the suppression tank where it is condensed, while the latter facilitates timely drainage of water from the VV to limit the amount of steam that the suppression tank has to condense. The VV drainage system is brought into play automatically by the opening of rupture discs in the VV drainage lines, for a large loss of coolant event, and by the opening of drainage valves for a small loss of coolant event. These drainage rupture discs and valves are part of the VVPSS. Additionally, the VVPSS is connected to the radioactive gaseous processing system, the low level waste processing system, the liquid and gas distribution system and the leak detection system.

11.1.3 Cryostat System Boundary

The cryostat has many penetrations to allow the passage of the components and systems needed to operate and maintain the tokamak. The boundaries between the cryostat and other components and systems are as follows.

(1) *Connections between cryostat penetrations and vacuum vessel port extensions*
The connections between cryostat penetrations and the vacuum vessel port extensions incorporate bellows to accommodate mutual thermal expansion. The connection structures, including the bellows and associated cryostat penetration, shall be considered part of the cryostat, but the cryostat penetration cover plates, together with associated penetrating components and systems, are outside the cryostat system boundary (except where otherwise specified in this document). The cryostat system boundary is at the

junction with the penetration cover plate.

(2) `*H&CD and diagnostic neutral beam penetrations*

H&CD and diagnostic neutral beam ducts penetrate the cryostat and are connected to the cryostat and to the bioshield through bellows. These bellows and associated structure are part of the cryostat. The neutron shielding around the H&CD and diagnostic neutral beam ducts is part of the cryostat.

(3) *Primary heat transfer systems (PHTSs) penetrations*

The ex-cryostat guard pipes enveloping the PHTSs pipes penetrate the cryostat. The ex-cryostat guard pipes, together with their associated bellows and cryostat penetration cover plates forming the vacuum barrier, are part of the cryostat. The cryostat system boundary is at the joint between the ex-cryostat and in-cryostat PHTSs and guard pipes, outside the penetration cover plates.

(4) *Magnet system current, instrumentation and coolant penetrations*

The vacuum jacket pipes of the magnet coolant pipes and current feeds penetrate the cryostat. The system boundary between the cryostat and magnet system is at the all-welded joint between the cryostat penetration and the vacuum jacket outside the bioshield wall.

(5) *Thermal shield coolant and instrumentation penetrations*

The vacuum jackets enveloping the thermal shield cooling pipes penetrate the cryostat. The vacuum jacket pipes with associated bellows are part of the cryostat. The cryostat system boundary is at the all-welded joint between the cryostat and the ex-cryostat thermal shield vacuum jacket pipes, outside the cryostat.

(6) *Vacuum pumping penetrations*

Vacuum pumping penetrations for the rough pumping system and the high vacuum system penetrate the cryostat. The vacuum pumping feedthroughs are part of the cryostat. The cryostat system boundary is at the joint between the pumping feedthrough and the ex-cryostat vacuum system pipework.

(7) *Remote handling access penetration cover plates*

The remote handling access penetration cover plates are part of the cryostat.

(8) *Gravity support pedestal*

The gravity support ring pedestal is connected to the tokamak gravity supports by stud bolts. The gravity support pedestal is part of the cryostat, but the connecting stud bolts to the gravity support are part of the gravity support. The cryostat system boundary is at the joint between the gravity support ring pedestal and the tokamak gravity supports.

11.1.4 VVPSS System Boundary

The suppression tank is connected to various systems to allow handling of liquid and gaseous streams arising from its operation. The boundaries between the systems are as follows.

(1) *The main pressure relief pipes*

Three main pressure relief pipes connect the suppression tank with the vacuum enclosures of two H&CD and one diagnostic neutral beam. These pipes are part of the VVPSS system. The main inboard rupture discs (plasma side) are part of the H&CD and diagnostic neutral beam fast shutters. The outboard main rupture discs are part of the VVPSS. The boundary between the VVPSS and the H&CD neutral beam vacuum enclosure is at the welded connection between the relief pipes and the enclosures.

(2) *VV drainage line rupture discs*

The VV drainage lines are part of the cooling water system (CWS), but incorporate double rupture disc assemblies that open during a large in-vessel loss of coolant event to rapidly drain residual water from the VV, thereby limiting the quantity of steam that the suppression tank has to condense. The rupture discs are part of the VVPSS and the boundary with the VV drainage part of the CWS is at the welded connection between the rupture discs and the drainage lines.

(3) *Bypass valves and lines*
The bypass valves and lines used for venting steam to the suppression tank during small in-vessel loss of coolant events bypass the main rupture discs. These bypass valves and lines are part of VVPSS and the system boundary is where the pipelines are welded to the requisite VV ports. Corresponding valves and lines bypass the rupture discs in the VV drainage system lines, to allow drainage of residual water from the VV following a small in-vessel loss of coolant event. The bypass valves and lines are part of the VVPSS and the system boundary is the welded connections where these bypass lines branch from the VV drainage part of the CWS.

(4) *Radioactive gaseous processing system*
The tank ullage has a pipe connection to the radioactive gaseous processing system to allow purging as part of post-event clean-up. The boundary between the VVPSS and the radioactive gaseous processing system is at the welded joint where the pipe joining the systems connects with the ullage of the suppression tank.

(5) *Liquid and gas distribution system*
The VVPSS is connected to the liquid and gas distribution system so that nitrogen gas can be supplied to the suppression tank ullage to purge it through to the radioactive gaseous processing system as part of post-event clean-up. The boundary between the VVPSS and the liquid and gas distribution system is at the welded joint where the pipe joining the systems connects with the ullage of the suppression tank.

Demineralised make-up water is supplied to the suppression tank from the liquid and gas distribution system. The boundary between the systems is at the welded joint between the make-up water supply pipe and the suppression tank.

(6) *Low level waste processing system*
The suppression tank water space is connected to the low level waste processing system to allow post-event clean-up of the suppression water. The boundary between the VVPSS and the low level waste processing system is at the welded joint where the pipe joining the systems connects with the water space of the suppression tank.

(7) *Leak detection system*
The leak tightness of the interspaces between the rupture discs in the steam relief pipes and the drainage system pipes are monitored by the leak detection system (part of the machine vacuum system). The interspaces of the bypass valves are likewise monitored. The boundary between the leak detection system and the VVPSS is at the welded joints between the interconnecting pipes and the bypass valve and rupture disc interspaces.

(8) *VVPSS tank vacuum system*
The VVPSS tank vacuum system, which maintains a vacuum in the suppression tank ullage, is entirely part of the VVPSS.

11.2 Specific System-Internal Requirements

11.2.1 Vacuum

Level 1 vacuum requirements for the cryostat are described in DRG1. Additional specific requirements for the cryostat and its pressure relief, and the VVPSS, are as follows:

(1) All elements of the cryostat which have a vacuum interface (that is, which face the cryostat vacuum, maintain it, or have the potential for outgassing into it) shall be vacuum

class 2 as specified in the ITER vacuum design handbook, and shall be designed in accordance with the requirements of the handbook.

(2) The room temperature areas of the cryostat internals will constitute the majority of the outgassing load into the cryostat high vacuum during normal operation (magnet structures and thermal shields cold). The water outgassing component can cryocondense on thermal shield reflective surfaces, and only a few hundred monolayers of water ice deposition can result in an unacceptable increase in apparent emissivity. There is thus a requirement for all vacuum-facing elements to be designed for outgassing minimisation.

(3) Air leaks in the cryostat vacuum boundary will impinge on the thermal shields, where atmospheric moisture will cryocondense on the reflection surfaces, with potential degradation of apparent emissivity. To minimise the likelihood of this eventuality, potential leak sites such as feedthroughs shall be provided with guard vacuum with provision for differential pumping, where this is practical. For electric power feedthroughs with a potential for Paschen breakdown, pressure measuring instrumentation shall be provided to give an alarm when the pressure is in the breakdown range.

(4) The cryostat and all internal components (and the cryostat helium pumping system) shall be designed such that the total pressure (mainly helium) is less than 10^{-4} Pa during normal operation (magnet structures cold) to limit residual gas conduction from warm to cold structures to a reasonable value.

(5) The maximum helium leak rate into the cryostat through its overpressure protection device shall be 10^{-10} Pa m^3/s.

(6) The maximum helium leak rate through each of the VVPSS rupture discs (leak tested independently) shall be 10^{-10} Pa m^3/s.

(7) The pressure suppression tank ullage shall be capable of being evacuated to tank water vapour pressure, with the evacuation maintained during normal tokamak operation.

(8) All parts of the VVPSS facing primary (torus) vacuum shall be bakeable to 240°C.

11.2.2 Structural

(1) All parts of the cryostat, the VVPSS and the ancillaries shall be designed to withstand the design basis loads as specified herein and in accordance with rules laid down by the appropriate design codes as specified in the SDC.

(2) All penetrations connecting permanent links between inside and outside equipment (magnet feeders, water pipes, etc.) shall penetrate only through the permanent part of the cryostat pressure boundary (i.e. that which does not have to be removed for maintenance).

(3) The cryostat shall withstand all loads applied during the normal and off-normal operational regimes, and at specified accidental and fault conditions. Specific loads are:
- external pressure during normal operation: 0.1 MPa
- maximum internal gas pressure (absolute) at accident conditions (magnet and PHTS loss of coolant event into the cryostat) shall be limited to 0.20 MPa, with provision for a pressure relief system vented to the stack.

(4) The cryostat shall be designed as a safety importance class component, as specified in the PSR.

(5) The cryostat and the VVPSS shall be designed to withstand seismic loads, as defined in the PSR.

(6) The VVPSS tank shall be of circular cross section and have the same design pressure as the vacuum vessel. The design shall account for the large transient loads that are imposed during in-vessel loss of coolant events.

(7) The rupture discs of the VVPSS shall be designed to open at as low a pressure as feasible so that impulsive loading of the vacuum vessel pressure suppression tank structure

following disc opening is minimised. The opening pressure shall be selected in accordance with that commercially available for the size of rupture disc required, in order to utilize equipment of known characteristics and to minimize the cost.

(8) The components of the cryostat overpressure protection system shall have the same design pressure as the cryostat pressure boundary.

(9) The cryostat support ring pedestal shall withstand all loads transferred from the tokamak.

The cryostat load cases and combinations are tabulated in Table 11.2-1

Table 11.2-1 Design Load Combination, Number of Cycles and Their Categories for the Cryostat

Load Regime	Load Category	Pressure	Seismic	Plasma	Magnet	Number of Cycles
Tests	I					-
Operation	I			pulses		30,000
Operation	I			VDE I		150
Operation	I			Disr. I		3,000
Operation	I			Disr. I	F.Disch	50
VV baking at 200°C, magnets warm	I					100
Magnet cool-down and warm-up	I					100
VV baking, magnets at 4K	I					100
Operation	II	CLE II		Disr. I		50
Operation	II	CLE II		Disr. II		300
Operation	II	CLE II		VDE II		15
Operation	II		SL-1	VDE I		10
Operation	II		SL-1	Disr. I		10
Magnets at 4K	II		SL-1			10
Operation	III	CLE III		VDE II		1
Operation	III	CLE III		Disr. II		1
Operation	III			Disr. II	F.Disch	1
Operation	III		SL-1	VDE II	F.Disch	1
Operation	III		SL-1	Disr. II	F.Disch	1
Operation	III	CLE III		VDE III		1
Cryostat air ingress, magnets & VV at normal operation temperature	III					1
Operation	IV	CLE IV		Disr. I		1
Operation	IV	CLE IV		VDE III		1
Operation	IV	CLE IV		VDE III		1
PHTS & helium LOCAs, magnets & VV at normal operating temperature	IV					1
PHTS LOCA, magnets, VV at operation	IV					1
Cryostat air ingress, VV baking, magnets at 4K	IV		SL-1			1
Operation	IV		SL-2	VDE I		1
Operation	IV		SL-2	Disr. I		1

Note: The term CLE, as used in this document, refers to a coolant leakage event into either the vacuum vessel or cryostat vacuum envelopes (see the DRG1 annex "Load Specification and Combination", section 4.4).

The VVPSS load cases and combinations are tabulated in Table 11.2-2

Table 11.2-2 Design Load Combination, Number of Cycles and Their Categories for the VVPSS

Load Regime	Load Category	Pressure	Seismic	Plasma	Magnet	Number of Cycles
Tests	I					-
Operation	I			pulses		30,000
Operation	I			VDE I		150
Operation	I			Disr. I		3,000
Operation	I			Disr. I	F.Disch	50
Operation	II	CLE II		Disr. I		50
Operation	II	CLE II		Disr. II		300
Operation	II	CLE II		VDE II		15
Operation	II		SL-1	VDE I		10
Operation	II		SL-1	Disr. I		10
Operation	III	CLE III		VDE II		1
Operation	III	CLE III		Disr. II		1
Operation	III			Disr. II	F.Disch	1
Operation	III		SL-1	VDE II	F.Disch	1
Operation	III		SL-1	Disr. II	F.Disch	1
Operation	III	CLE III		VDE III		1
Operation	IV	CLE IV		Disr. I		1
Operation	IV	CLE IV		VDE III		1
Operation	IV	CLE IV		VDE III		1
Operation	IV		SL-2	VDE I		1
Operation	IV		SL-2	Disr. I		1

Notes: 1. The term CLE, as used in this document, refers to a coolant leakage event into either the vacuum vessel or cryostat vacuum envelopes (see the DRG1 annex "Load Specification and Combination", section 4.4).
2. The damage limits for loading conditions for the cryostat and VVPSS are as laid down by the appropriate design codes as specified in the SDC. Seismic requirements and safety importance classification are as specified in the PSR.

11.2.3 Electromagnetic

(1) The toroidal electrical resistance of the cryostat cylindrical section shall be greater than 10 μΩ to preclude adverse affects on plasma breakdown.
(2) Primary cooling pipes and manifolds shall not require electrical insulation from the cryostat wall.
(3) The cryostat shall not cause a substantial damping of variable control magnetic fields or a related increase of power requirement for the plasma control system. It shall not cause a significant increase in the volt-second requirements for the PF coil system or unduly increase the stray magnetic field in the plasma during startup.
(4) The cryostat must be able to withstand imposed electromagnetic pressures applied during plasma start up and quench of the poloidal field coils.

11.2.4 Thermohydraulic

(1) The pressure/flow and relief device opening characteristics of the cryostat pressure relief system, including stack effects, shall be designed such that the maximum pressure in the

cryostat during overpressure events stays below the design value of 0.2 MPa.

(2) The pressure/flow characteristics of the VVPSS shall be designed to keep the peak vacuum vessel pressure following a design basis in-vacuum CLE IV below the design value of 0.2 MPa by an adequate margin to encompass uncertainties both in the total amount and flow rate of the lost coolant.

(3) The amount of room temperature suppression water initially held in the suppression tank shall be adequate to condense the steam evolved during an in-vessel CLE IV event, while keeping the final average temperature below 80°C, including an appropriate margin against uncertainties in the heat and mass transfer predictions.
The suppression tank volumetric capacity shall be large enough to maintain a vapour ullage under conditions of transient steam voidage in the tank water, and to contain the maximum design basis amount of spillage water (CLE IV), while still retaining a final vapor ullage.

(4) Each of the rupture disc relief devices shall have a small bore bypass line connecting the vacuum vessel to the suppression tank by way of vacuum valves that can be opened during small in-vessel loss of coolant events in which the resulting steam pressure in the vacuum vessel is not large enough to open the rupture discs. This provision is needed to prevent a release of radioactive materials if an aggravating failure, such as a breached vacuum window, occurred at the same time as the small in-vessel water leak.

11.2.5 Mechanical

The cryostat top and bottom ends shall be designed such that the requisite parts of the pressure boundary can be cut away to give access for replacement of the PF and TF coils, and re-welded and tested following completion of these maintenance operations.

11.2.6 Electrical

(1) The cryostat shall be electrically grounded directly through the structural supports without the use of electrically insulating breaks and grounding resistors.

(2) The VVPSS shall be electrically grounded directly through the structural supports without the use of electrically insulating breaks and grounding resistors.

(3) The in-cryostat ice detector system, if of a calorimetric type, will require electric energisation.

(4) The bakeout heaters on the high vacuum parts of the VVPSS pipework, if of the ohmic type, will require an electrical supply.

11.2.7 Nuclear

(1) The neutron shielding around the H&CD and diagnostic neutral beam ducts is required to prevent excessive neutron streaming into the adjacent cryostat zone, which if unmitigated, would inhibit personnel access to this region on account of excessive activation of the cryostat. Apart from this, the cryostat provides no ionizing radiation shielding function.

(2) The VVPSS shall be designed to condense and retain all the radioactive water resulting from a design basis loss of coolant event into the vacuum vessel, together with all associated activated particulate and activated/tritiated non-condensable gas.

11.2.8 Repair

(1) Part of the cryostat may become activated and will require remote access, both external as

well as internal. Adequate internal access to components located inside the cryostat shall be provided by access ports in the upper head and the cylinder.

(2) As much maintenance as feasible must be done within the cryostat hands-on, in particular the more likely RH Class 3 tasks such as repairs to magnet feeder breaks boxes.

(3) The design of the access port penetrations in the cryostat shall be such as to allow the deployment of shielding equipment used to enable personnel maintenance access inside the cryostat to designated components such as the magnet feeder breaks boxes.

(4) The pressure relief devices of the cryostat pressure relief system shall be located outside the biological shield to obviate the need for remote handling.

(5) The inboard rupture disc of the VVPSS (reference location in the fast shutters of the H&CD and diagnostic neutral beam lines) shall be designed for replacement using remote handling techniques. The outboard rupture disc (located outside the bioshield) shall be designed for hands-on maintenance.

(6) The cryostat shall be designed such that the following maintenance operations can be conducted without breaking cryostat vacuum;
   - Remote handling of divertor cassettes through the dedicated divertor remote handling ports.
   - Remote cutting and welding of the first wall and blanket coolant pipes with access from outside the cryostat.
   - Remote access to all equipment located in the vacuum vessel ports outside the port plate.

11.2.9 Chemical

(1) There is a potential for the radiochemical formation of ozone, with a consequent explosive decomposition hazard, if air leaks are allowed to accumulate on the cold mass in regions of high neutron and gamma flux. Mitigation shall be provided by an in-cryostat ice detector system.

(2) The inner surface of the cryostat wall (and all internal components) shall be thoroughly cleaned in accordance with the requirements of the ITER vacuum design handbook prior to initial pump down.

11.2.10 Manufacturing

(1) The design shall allow maximum pre-fabrication and testing at the supplier's shop.

(2) The design shall be such that parts of the cryostat can be pre-assembled at the ITER site in pieces of maximum weight and size compatible with arrangements for transport and lifting into the pit.

(3) The segmentation of the cryostat will be made using steel plates as large as possible in order to minimize the length of the weld joints.

(4) The surface of the components shall be protected from damage and contact with foreign materials throughout the manufacturing activities and the transportation to the ITER site.

(5) The cryostat and VVPSS components shall be leak tested to the maximum extent possible in the supplier’s shop to minimise on-site re-work caused by leaks resulting from manufacture.

11.2.11 Assembly

(1) The cryostat and VVPSS shall be designed to have minimum impact on the overall ITER construction schedule. This shall be realized by designing for maximum shop

manufacture and leak testing, and pre-assembly at grade on the ITER site, thereby minimizing critical path assembly activities in the tokamak pit.

(2) The cryostat initial assembly and testing shall be integrated into the overall machine assembly schedule.

(3) Provisions shall be made for in-situ repair of leaks on all assembly joints and for replacement or repair of all bellows.

11.2.12 Testing

(1) The cryostat pressure boundary shall not be designed to allow structural pressure testing of sub-assemblies fabricated either at the supplier's shop or on the ITER site, but shall be designed to facilitate vacuum leak testing of sub-assemblies at the supplier's shop, to the greatest extent practicable. The design shall allow for a global structural pressure and leak test following complete assembly of the cryostat and all elements penetrating the pressure boundary. For penetrating systems which cannot be fully installed prior to the cryostat global pressure and leak tests, the design shall be such that any interface welds or joints subsequently installed can be pressure and leak tested. The design shall be such as to facilitate localisation of any leaks detected during global leak testing following assembly of the cryostat and all penetrating elements in the pit.

(2) The VVPSS design shall allow it to be pressure tested after installation in the tokamak building, in conjunction with the pressure testing of the vacuum vessel. The design shall allow the suppression tank and VVPSS bypass lines and valves to be vacuum tested alone, for early detection and repair of leaks, and in conjunction with the VV for testing the closing welds.

11.2.13 Instrumentation and Control

Instrumentation and control is required for the cryostat as follows;

(1) Temperature measurement of the cryostat wall at the PF4 coil elevation to monitor ohmic heating.

(2) Temperature measurement at the cryostat bottom end to monitor cryogenic spillage.

(3) Energisation and output from the in-cryostat ice detection system.

(4) If calculations confirm that, during non-operational periods when the cryostat thermal shield is at 80K, the cryostat wall temperature drops below the prevailing dewpoint, heaters with some instrumentation and control will be required.

(5) Position monitoring of the cryostat pressure relief valve.

Instrumentation and control is required for the VVPSS as follows;

(1) Suppression tank water temperature and level.

(2) Suppression tank water leak detection.

(3) Open/close monitoring for the VVPSS rupture discs.

(4) Safety grade pressure instrumentation to measure the pressure rise in the VV during CLE II and associated control equipment to open the bypass valves and the drainage line valves.

(5) Position monitoring for the VVPSS bypass valves.

(6) Temperature measurement and control for the bakeout heaters on the high vacuum portions of the VVPSS pipework and bypass lines.

(7) Additional process variables that will have to be monitored in the secondary containment cell to alert plant operators in the event of a water leak from the suppression tank.

11.2.14 Decommissioning

The cryostat will consist of activated stainless steel at end-of-life and may therefore require cutting-up and packaging for shipment to a disposal site. The VVPSS shall be designed to facilitate decontamination, to the greatest extent practicable.

11.2.15 Materials

(1) The cryostat shall be made of conventional stainless steel type 304L and 304 plate as allowed in ASME section VIII, division 2. Bellows will be austenitic stainless steel or elastomeric. Flexible seal materials will be compatible with tritium and the prevailing neutron and gamma radiation fluences.
(2) The materials used for the VVPSS shall be carbon steel for the main tank, the tank support structure, inner structure and relief pipe between the outboard rupture disc and the main tank. Other parts of relief pipes will be made of conventional stainless steel type 304L.
(3) The relief pipe rupture discs shall be made of stainless steel type 316L.

11.2.16 Operation

In view of the intimate relationship between the quality of the cryostat vacuum and the magnet thermal insulation, it is foreseen that, with the exception of a limited number of commissioning activities, cryostat operation will be part of an integrated control system together with the tokamak. All actions essential to safety and accident mitigation will be implemented automatically through a control and interlock system of appropriate quality.

To prevent the build up of ice on the cold mass, with consequent ozone formation hazard, the air in-leakage rate into the cryostat shall be measured by the cryostat leak detection system, and measures implemented to ensure that the total air in-leakage rate does not exceed the threshold for ozone hazard, as defined in the PSR. As an additional safeguard, ice detectors will be installed inside the cryostat vacuum envelope, to alert operators of the formation of cryocondensate layers on the cold mass.

In order to preclude excessive cryocondensation of water on the thermal shield reflective surfaces, the cryostat internals will be sufficiently out-gassed prior to thermal shield cool-down by sequential pumping and venting with super-dry gas. Additionally, the magnets will be sub-cooled relative to the thermal shields during the initial phase of magnet cool-down so that water will be preferentially pumped by the magnet system cold surfaces.

The cryostat and magnet system start-up will be, in outline;
(1) Rough pump the cryostat and dehydrate it by repeatedly pumping and venting with super-dry nitrogen until water partial pressure is stationary (target terminal water pressure 10^{-7} Pa)
(2) High vacuum pump the cryostat to a total pressure of 10^{-4} Pa. If the water partial pressure $> 10^{-7}$ Pa, repeatedly vent and pump down with super-dry nitrogen until the target value attained.
(3) Raise vacuum vessel temperature to baking value. Heat vacuum VVTS to maximum allowable value (safe thermal expansion limit). High vacuum pump the cryostat to outgas the vacuum vessel exterior and cryostat internals.
(4) Cool magnets to liquid nitrogen temperature, keeping magnets 50°C colder than the

thermal shields in order to preferentially pump water onto the magnets.
(5) Cool magnets to liquid helium temperature.

11.2.17 Maintenance

11.2.17.1 Hands-on Maintenance

As much maintenance as practical outside the bioshield will be done hands-on, minimising remote handling. The layout of equipment outside the bioshield shall be designed to facilitate cryostat maintenance.

11.2.17.2 Remote Handling Maintenance

Remote maintenance of in-vessel components shall be performed without having to break cryostat vacuum. To allow remote maintenance within the interspace between the cryostat and the tokamak, adequate access corridors shall be provided for the remote handling equipment to get to and work on the component to be maintained. As much maintenance as feasible inside the cryostat shall be done hands-on and the cryostat penetrations shall allow for the installation of shielded access ways to enable personnel to access the maintenance zones.

11.2.18 Testing

The pressure boundary of the cryostat and VVPSS may require periodic testing to meet statutory requirements. Following any modification work on the pressure boundaries, validation testing will be required, which remains to be specified.

11.2.19 In-service Inspection

Internal inspection of the cryostat and VVPSS may be required following an accident. To the greatest extent possible, such inspections will be done hands-on, using specially installed shielded access ways to allow personnel access from outside the bioshield to the location to be inspected.

11.2.20 Quality Assurance (QA)

The cryostat and VVPSS shall be designed, manufactured, tested, commissioned, operated, maintained and decommissioned in compliance with the ITER QA programme and with the ASME boiler and pressure vessel code section VIII, division 2, and the applicable codes ASME section I, II, III subsections NC, V, IX, and XI.

The QA activities at all stages of material procurement, shop fabrication, site installation, examination, testing and commissioning, etc. for the components shall be performed under the control of the QA programme. Appropriate QA measures shall be implemented by manufacturers and other service providers prior to the commencement of manufacturing and other deliverable activities. Additionally, all activities (assembly, testing, commissioning etc.) shall be performed in accordance with approved procedures incorporated in the QA programme.

Materials, including welding materials, to be used for the main components shall be purchased with certified material test reports and be traceable throughout the manufacturing operations. Some forming procedures such as pressing and bending will require qualification. Welding procedures will be qualified prior to the welding operations, and welding shall be performed in accordance with detailed written procedures and performed by qualified welders and welding operators. Nondestructive examinations such as radiographic, ultrasonic, thermographic, visual and liquid penetrant shall be performed for welded joints in accordance with detailed written procedures. Likewise all leak testing will come within the ambit of the QA programme.

11.3 Codes and Standards

The cryostat and VVPSS structural design shall be in accordance with ASME VIII division 2 and the design criteria specified in ITER structural design criteria. The cryostat and VVPSS vacuum design shall be in accordance with the ITER vacuum design handbook.