

9 Vacuum Pumping and Fuelling

9.1 Functions, Basic Configuration and System Boundaries

The vacuum pumping and fuelling system, which covers also leak detection and wall conditioning functions, comprises the following systems and equipment, to the boundaries indicated.

9.1.1 Vacuum Pumping Systems (VPS)

- Roughing system
- Torus vacuum pumping system
This includes the vacuum vessel divertor port closure plates on which the pumps are mounted.
- Cryostat vacuum pumping system
This includes the mounting bolts to support pads on the cryostat for high vacuum and helium pumps, and roughing lines.
- NB and DNB, IC H&CD, EC H&CD and LHH&CD pumping systems
For these three RF systems the VPS provides pumps located in the port plugs, transmission lines and RF conditionings units, and all exhaust lines. The VPS includes bolts and fittings to fixtures on the port plug, and connectors to feedthroughs of the various cover plates.
- Guard and service vacuum systems
These include the mounting bolts and connection flanges for connection to each individual services user.
- Diagnostic pumping systems
The VPS provides pumps for individual diagnostics and connections to the guard and service vacuum systems and all exhaust lines. The VPS includes bolts and fittings to fixtures on the port plug, and connectors to feedthroughs of the various cover plates.
- Venting systems
The venting systems are either integral parts of particular vacuum systems or connected to each individual services user through the vent supply system. The connection to each unit includes the mounting bolts and connection flanges.
- Maintenance detritiation re-circulation piping
The roughing system line and the torus vacuum pumping system cryopump foreline will be used in conjunction with the S-ADS for torus maintenance detritiation. (The S-ADS is part of the tritium plant.)

Exhaust gas from all vacuum pumping systems is routed to the tritium plant for processing via exhaust manifolds provided, including connectors to the intake pipe stubs of the tritium plant, and support connections to surrounding equipment and the buildings, as part of the roughing system. Provision for controlled discharge of the cryostat vacuum directly to the environment will also be made.

Certain VPS equipment is located in glove boxes in the vacuum pumping room within the tritium building and this equipment is part of the VPS. The tritium plant glove box detritiation recirculation system connects to these.

The VPS connects to local load centres in the tritium building for building services: electrical

power, cooling water, pneumatic supplies and gas supplies for venting the torus and cryostat and other vacuum systems and equipment.

The VPS connects to local distribution points in the torus pit for cryogenics to cool the torus primary pumps, and the cryostat high vacuum pumps.

Local controllers for each of the above systems connect to the CODAC service centre in the tritium building.

VPS equipment and piping located throughout the pit and galleries are connected to other systems and the buildings using connectors provided by the VPS.

9.1.2 Fuelling Systems (FS)

- Gas distribution and supply system
Includes the connections to the tritium plant distribution centre in the tritium building for hydrogen and impurities. Includes the gas distribution piping from the tritium plant and the connections to the valve boxes of the fuelling and gas delivery systems.
- Gas fuelling system
Includes the connections of the fuel lines to the vessel and to feedthroughs on the upper and divertor port vessel and cryostat cover plates, as well as the gas valve boxes located in the upper port and divertor pit level galleries.
- Pellet injection system
Includes connections of flight tube to the vacuum vessel and connections to feedthroughs of the divertor port vessel and cryostat cover plates. Also includes connections to cryogen distribution points in the torus pit.
- Fusion power shutdown system.
The fusion power shutdown system is incorporated in the gas fuelling system valve boxes located at the upper port level with hardwire connection to the fusion power shutdown control system.

The above systems include also the support connections of each system to the buildings or other systems.

The FS connects to local load centres in the tritium building for building services: electrical power, cooling water, and pneumatic supplies.

Local controllers for each of the above systems connect to the CODAC service centre in the pit.

9.1.3 Leak Detection Systems (LDS)

- torus global leak detection system,
- cryostat global leak detection system,
- service leak detection system.

These systems include connections to covers or shrouds around the items to be tested as well as all lines, pumps and analysis stations including connection to the VPS exhaust gas manifolds. This includes connections to local electrical power load centres, and connections of local controllers to the CODAC service centre.

9.1.4 Wall Conditioning Systems

- Glow discharge cleaning system (GDC)
The glow discharge electrodes are introduced by the in-vessel viewing system (IVVS). The GDC includes the electrodes to their gripping point by the IVVS, its cooling system including the heat radiation system mounted on the inside of the IVVS cask, its power supply system including the connector to the cask power supply, and control system circuitry including local controller to the service point of CODAC in the cask.

9.2 Requirements

9.2.1 General

1. The design shall minimise tritium inventory to the maximum extent possible and segregate/isolate tritium inventories to minimise the quantity releasable by any single event.
2. On-site testing shall be reduced to the maximum possible extent.
3. The capability shall be provided to allow the in-situ leak testing of all systems.
4. The use of standard components, materials, and processes is required wherever reasonable. Exceptions to this rule can be taken for appropriate technical or economic reasons, but these exceptions must be fully documented.

9.2.2 Vacuum Pumping Systems

General

1. All permanently installed mechanical pumps and leak detection systems shall be located in the tritium building.
2. The design and construction of the all systems shall be consistent with providing a high quality vacuum.
3. All tritium-bearing vacuum lines shall be doubly contained and both primary and secondary boundaries actively monitored for vacuum integrity.
4. Filters shall be installed on all vacuum connections to the torus to prevent the transport of dust into external vacuum systems.

Roughing system

1. The roughing system(s) used for pumping the torus shall be dry and not exhaust oil (hydrocarbons) under normal or failure conditions to the oil-sensitive parts of the tritium plant. In cases where oil is used in a component, double sealing shall be provided to separate the oil side from the vacuum side. Interspace monitoring shall be provided to detect seal leakage or failure and the pump immediately isolated and shut down.
2. The torus roughing pump(s) shall provide a pumping speed that is sufficient to evacuate the torus cryopumps in the prescribed time during regeneration when operating in the long pulse mode with on-line regeneration.
3. The NB and DNB injector roughing pump(s) shall provide a pumping speed that is sufficient to evacuate each injector cryopump in turn during regeneration within the specified period.
4. The roughing system shall evacuate the torus from atmosphere to the cross-over pressure of the torus primary pumps.

5. The roughing system shall evacuate the cryostat from atmosphere to the cross-over pressure of the cryostat high vacuum cryopumps.
6. The torus and cryostat roughing pumps shall have a blank-off pressure < 1 Pa for all gases, when measured at the pump inlet.
7. The roughing pumping shall be capable of long-term operation at high inlet pressures without overheating.
8. The use of oil-sealed pumps shall be limited to applications that do not need to be exhausted to the tritium plant during normal operations. The backstreaming of oil and oil vapours from the exhaust of these pumps during off-normal events shall be mitigated by design to the maximum extent possible to prevent irrecoverable contamination of other systems.
9. The torus roughing pump(s) shall be used for the pumping of activated gases used in conditioning. This includes GDC, ECR/ICR discharge and reactive cleaning modes.
10. The roughing pumps shall be purged on shut-down to minimise the retention of activated gases within the system.
11. The torus and NB/DNB injector roughing systems shall be compatible with tritium service.

Torus high vacuum pumping system

1. Batch regenerating cryopumps shall be used for high vacuum pumping of the torus.
2. All cryopumps shall be independently controlled to allow individual pumps to be shut down in the event of failure or to regulate the pumping speed provided at the torus.
3. The cryopumps shall be installed in the cryopump ports located at the divertor level.
4. The regeneration schedule shall be consistent with minimising the inventory within the cryopumps to the maximum extent possible.
5. The crossover pressure from the torus roughing pumps during evacuation of the torus will be < 10 Pa.
6. The inventory of individual cryopumps shall be controlled to limit deflagration pressures to < 500 kPa during off-normal events. This deflagration limit shall include an allowance for residual inventory and the loss of one (1) pump.
7. During long-pulse operation the incremental cycle time shall be optimised to limit pump inventory, cryogenic demands for fast cool-down and the roughing pumping speed needed for regeneration.
8. The capability of operating the cryopumps at elevated temperatures to suppress the pumping of helium during leak testing while retaining the pumping speed for other gases shall be provided.
9. The cryopumps shall be capable of pumping water vapour at a rate commensurate with the global leak rate in order to prevent the accumulation of unacceptable levels in the torus that would result in contamination of the plasma due to oxygen.
10. The system shall be capable of pumping both impurity gases generated during conditioning and the excess conditioning gases throughout the duration of the condition cycle. This includes GDC, ECR/ICR discharge and reactive cleaning modes.
11. The pumping of gases for reactive conditioning is not required. This requirement will be fulfilled using the torus roughing system.
12. The design of the system shall be compatible with tritium service.

Cryostat vacuum pumping systems

1. Cryostat pressure shall be measured at a position at which the conductance loss between the measurement point and the pumping system is not significant.
2. The cryostat pumping system shall provide a vacuum environment to limit the thermal

loads applied to the superconducting magnet system by gas conduction and convection during cool down of the magnets, when suitably designed thermal shields are installed.

3. The cryostat pumping system shall be compatible with tritium service to the extent necessary to maintain the vacuum integrity of the cryostat boundary following exposure to tritium under upset conditions. Subsequent maintenance intervention is acceptable to replace components the life of which is limited following exposure to tritium.
4. Components exposed to the interior of the cryostat shall be designed to withstand transient contact with fluids in the range of 4.5 - 500K during design basis accidents.

NB and DNB pumping system.

1. Evacuation of the NB and DNB injectors from atmospheric pressure shall be undertaken in conjunction with the torus (NB and DNB injectors shutters open).
2. The capacity of the NB and DNB injectors cryogenic pumping panels shall be sufficient such that regeneration of the cryopanel will not be required during the longest design pulse.

IC H&CD pumping system

1. The IC H&CD pumping system shall provide pumping of the transmission line between the torus and primary vacuum window, and the interspace between the primary windows and the secondary window assembly, which form the primary and secondary containment boundaries. The pumping speed shall be sufficient to maintain the specified pressure.

EC H&CD pumping system

1. The EC H&CD pumping system shall provide pumping of the transmission lines between the torus vacuum window and the RF conditioning units and the pumping of individual RF conditioning units. The pumping speed shall be sufficient to maintain the specified pressure.

LH H&CD pumping system

The waveguide volume of the LH H&CD situated between the primary and secondary windows shall be pumped via the port interspace vacuum and sufficient pumping speed shall be provided to maintain the specified pressure.

Guard and service vacuum systems

1. Guard and service ring manifolds shall be provided at the divertor, equatorial and top port levels.
2. The service roughing system shall be pumped by the roughing system.
3. The guard vacuum pumping systems shall provide the capability to actively pump all guard vacuum interspaces as may be required.
4. Each port interspace shall be pumped separately to prevent cross contamination between ports.
5. Each port interspace shall be connected to the service ring manifold of the service roughing system, guard vacuum system and services leak detection system.
6. The secondary containment pumping system shall be connected to the service roughing system.
7. It shall be possible to isolate the secondary containment pumping system from the service roughing system following evacuation to operating pressure.
8. Each individual secondary containment shall be actively monitored for leaks.

Diagnostic pumping systems

For non-tritiated diagnostics; consideration shall be given to the use of the service vacuum system for performing this function.

For tritiated diagnostics; vacuum pumping systems, which are compatible with the requirements of the various diagnostics, shall be provided.

These systems shall provide the capability to evacuate and actively pump all diagnostics as required.

9.2.3 Venting Systems

General

1. The vent gas supply pressure control system shall be of fail-safe design to prevent inadvertent venting of any system, or pressurising of any component or system above the design operating pressure of the component being vented, under any postulated failure condition.
2. The vent gas shall be filtered.

Torus venting system

1. A venting system shall be provided to allow controlled venting of the torus to any pressure not exceeding the local atmospheric pressure at the time of venting.
2. The capability to vent to intermediate torus pressures shall be provided.
3. The venting time shall be fully adjustable from 2 to 10 hours.
4. The design of the torus venting system shall limit the agitation of dust.

Cryostat venting system

1. A venting system shall be provided to allow controlled venting of the cryostat to any pressure not exceeding the local atmospheric pressure at the time of venting.
2. The capability to vent to intermediate cryostat pressures shall be provided.
3. The venting system will also be used to allow beyond design basis decay heat removal by filling the cryostat with warm helium to thermally couple the VV with the magnets to allow them to be a heat sink for the decay heat.
4. A venting time shall be fully adjustable from 2 to 10 hours.

NB and DNB venting system

1. The NB and DNB injectors will be vented with the torus (NB and DNB injectors shutters open).

IC H&CD venting system

1. The window assembly will be vented by the service venting system.

EC H&CD venting system

1. The transmission lines and RF conditioning units will be vented by the service venting system.

Service venting system

1. Service vent ring manifolds shall be provided at the divertor, equatorial and top port levels.
2. The service venting systems shall vent all port interspace and miscellaneous vacuum volumes as may be required.
3. The system shall allow the controlled venting of the IC H&CD window assemblies with

dry air or nitrogen.

4. The system shall allow the controlled venting of the EC H&CD transmission lines and RF conditioning units with dry air or nitrogen.

Maintenance detritiation re-circulation piping

1. Use shall be made of existing lines (torus roughing line and foreline) to the maximum extent possible.
2. During maintenance detritiation operation the torus shall be maintained at a slight depression ~ 2 kPa below the local atmospheric pressure.
3. During tokamak maintenance operations the entire loop connected to the S-ADS shall be slightly depressed below the local atmospheric pressure.

9.2.4 Fuelling Systems

Gas distribution and supply system

1. The gas distribution system shall deliver gases from the tritium plant to the various fuel delivery systems, gas injection, pellet injection, and fusion power shut-down during all modes of operation, including wall conditioning.
2. The gas distribution system shall deliver the gases (H_2 and D_2) to the NB/DNB injector system valve box by a dedicated set of lines designed specifically for the pressure rating of the system. This valve box shall be equipped with dedicated positive shut-off valves, for each of the NB and DNB injectors. The capability for flow measurement shall not be provided.
3. The gas distribution system shall include a pump and purge line to evacuate and purge gases for the various delivery systems. This purge line shall be connected to the tritium plant.
4. The lines shall be contained and actively monitored for both internal and external leaks.
5. The lines shall be sized for the maximum specified flow rates and tritium-bearing lines shall be of minimum volume to limit inventory.
6. A dedicated valve box, connected to the gas distribution system, shall be used to supply gas to the pellet injector(s).
7. Additional connection points shall be provided at alternate pellet injector locations.
8. The pellet injection valve box(es) shall be located adjacent to the pellet cask.

Gas injection (fuelling) system (GIS)

1. Gas injectors shall be located at the top of the machine and at the divertor level to provide the delivery of gases for fuelling, radiative cooling of the divertor, fusion power shut-down and conditioning.
2. Gas injection valve boxes (top port GIS) shall be installed at the top of the machine to deliver gases via individual gas delivery tubes routed through the top port. Each tube shall deliver the gas to behind the blanket allowing the gas to distribute into the torus through the gaps between blanket modules.
3. Gas injection valve boxes (divertor port GIS) shall be installed at the divertor level port to deliver fuelling gases via individual gas delivery tubes routed through the divertor port, under the divertor to the private region of the divertor.
4. The GIS valve boxes located at each level shall be uniformly distributed toriodally.
5. The gas delivery tubes shall be sized and routed to meet the fuelling gas delivery rates and response times.

Pellet injection system

1. The pellet injection system shall be configured for high field side (HFS) pellet launch.
2. A single operational pellet injection point shall be provided, equipped with two injectors.
3. The loss of pellet mass due to erosion during extrusion and acceleration shall be less than 30% (target value is 20%).
4. The pellet injector cask will be located at the divertor port level.
5. The routing of the pellet flight tubes shall minimise the number of bends and maximise their radius to limit pellet damage.
6. A spare flight tube shall be installed for redundancy.
7. The pellet injection system shall have protective interlocks that will prevent the firing of pellets in the absence of a plasma. This interlock shall be provided by the plasma control system.

Fusion power shutdown system (FPSS)

1. The FPSS shall deliver impurity gases to initiate a fusion power shutdown from multiple delivery points for redundancy.
2. The FPSS shall be hardwired and initiated by a signal received from the fusion power shutdown control system.

9.2.5 Leak Detection Systems

Torus global leak detection system

1. The torus global leak detection system(s) shall be capable of detecting leaks in individual components with the torus under vacuum and the individual component configured for leak testing:
 - During commissioning, with all water cooled components dry $< 1 \times 10^{-10}$ Pam³/s
 - Following the start of plasma operations, with a component which operates dry, dry or a water-cooled component drained and dried, $< 1 \times 10^{-8}$ Pam³/s.
 - Following the suspension of plasma operations due to degraded plasma performance, with a water-cooled component bearing water, $< 1 \times 10^{-6}$ Pam³/s.
2. Means shall be provided to measure the total in-leakage into the torus both during commissioning and plasma operations.

Cryostat global leak detection system

1. The cryostat global leak detection system(s) shall be capable of detecting leaks in individual components with the cryostat under vacuum and individual components configured for leak testing:
 - During commissioning, with all components dry and purged of helium, $< 1 \times 10^{-8}$ Pam³/s.
 - Following the start of plasma operations, with individual water-cooled or helium-filled component drained and dried of water or purged of helium, $< 1 \times 10^{-6}$ Pam³/s.
2. Means shall be provided to measure the total in-leakage into the cryostat both with the magnets at room temperature or cooled to operating temperature.

Services leak detection system

1. The services leak detection system shall verify the vacuum integrity of the non-tritiated primary and cryostat interfacing system and components including:
 - Guard vacuum systems.
 - Service vacuum systems.
 - Non-tritiated diagnostics systems.

- Port interspaces.

9.2.6 Wall Conditioning Systems

Glow discharge cleaning system (GDC)

1. The GDC systems shall operate with the magnets de-energised.
2. The GDC systems shall have the capability of steady state operation.
3. The conditioning gases shall be delivered by the gas fuelling system.
4. Conditioning gases shall be exhausted from the torus by either the torus roughing or torus cryopumping system.

IC H&CD and EC H&CD discharge cleaning (RFDC)

1. RFDC shall be carried out with the magnets energised.
2. RFDC shall be capable of being operated during the dwell between pulses.
3. RFDC shall have the capability of steady-state operation.
4. The conditioning gases shall be delivered by the gas fuelling system.
5. Conditioning gases shall be exhausted from the torus by the torus cryopumping system.

Reactive cleaning

1. The conditioning gases shall be delivered by the gas fuelling system.
2. Reactive gases shall be exhausted from the torus by the torus roughing system.

9.2.7 Structural

1. The loading conditions for component design and the corresponding damage limit frequencies for individual components shall be assessed to determine if fatigue analysis is necessary. If fatigue analysis is not required, the most demanding design basis loading event should be identified.
2. The components of each system shall be designed to withstand and operate in and under the operating loads applicable to the location of that system or component.

9.2.8 Mechanical

1. Each system must be designed to withstand and operate in the ambient magnetic fields applicable to the location of that system or component.
2. All systems shall be designed to retain their function after both normal and off-normal events.
3. Systems shall be isolated as necessary from the torus and cryostat to protect the component parts of systems during off-normal events by closing valves to limit the propagation of an unplanned pressure rise.
4. Materials used in the design shall have well-characterised mechanical and structural properties for their respective service conditions (temperature, stress, nuclear, etc.) in order to obtain a high degree of confidence in their performance.

9.2.9 Electrical

1. The use of class I and class II uninterruptible supplies shall be limited to the maximum possible extent consistent with providing the necessary safeguards for equipment and the prevention of safety hazards arising from power failure.

9.2.10 Grounding and Isolation

1. The design operating pressure within interspaces and guard vacuum system shall take full account of electrical installations to ensure that voltage breakdown shall not occur during normal operating conditions.

9.2.11 Nuclear

1. The components of each system must be designed to withstand and operate at the nuclear heating loads and the integrated doses applicable to the location of that component.
2. The design shall mitigate the effects of neutron streaming to the maximum extent possible.

9.2.12 Chemical

1. The design shall preclude self-sustaining chemical reactions (such as steam reactions with plasma-facing components).
2. The components requiring water cooling shall be compatible with water coolant chemistry. Specific requirements to limit corrosion, electrochemical, and other effects to acceptable levels over the life of the system shall be observed.

9.2.13 Remote Handling

1. Remote maintenance capability shall be provided such that personnel exposure during maintenance operations does not exceed the specified limits.
2. All systems located in an area where hands-on operation is not permitted shall be able to be installed, maintained and/or replaced by using remote maintenance equipment.
3. All equipment and components which requires remote handling (RH) intervention shall be designed to be compatible with the RH tools which are being developed.
4. Sufficient space for the insertion and removal of tools must be assured.
5. All equipment and components that require RH intervention shall be capable of being leak tested, by remote means.

9.2.14 Reliability and Maintainability

1. The general reliability principles adopted for each system shall be consistent with performing the safety function necessary to protect site personnel and the public.
2. The levels of reliability of each system shall be consistent with achieving the required levels of availability of the complete machine throughout all operation phases.
3. Maintenance and/or replacement operations shall be undertaken without significant interruption of operations.
4. Each system shall be designed for the full number of pulses of the nominal reference discharges expected in the plant life.
5. After failure the torus cryopump inlet valve assembly shall be replaceable in less than two weeks during the next planned maintenance session after establishing access to the pump mounting plug.
6. Redundancy shall be provided for the torus pumps so that no maintenance intervention will be required following an individual failure or an individual component out of service.
7. The torus and NB roughing, cryostat pumping, leak detection and miscellaneous vacuum systems shall be designed to maximise hands-on maintenance operations outside the

bioshield.

9.2.15 Manufacturing Requirements

1. To the maximum extent possible:
 - all components are to be purchased from standard catalogues,
 - all system critical components shall undergo a reliability demonstration as part of their qualification,
 - the reliability of all first-of-a-kind components shall be demonstrated under simulated operational conditions using as a minimum a suitably-sized prototype before procurement.

9.2.16 Testing

1. Acceptance testing procedures shall be developed to ensure rapid commissioning of each subsystem.
2. Each system shall be designed to permit the functional testing of all systems on a routine basis to confirm performance and vacuum integrity.

9.2.17 Decommissioning and Waste Management

1. The design shall consider the following to facilitate the decommissioning and reduce occupational exposures by:
 - segregating radioactive systems or components,
 - designing to avoid contamination or allow easy decontamination,
 - selection of construction materials to reduce activation products in materials subject to irradiation.
2. The design of these systems shall minimise, to the maximum extent possible, the generation of and the storage and disposal requirements of radioactive and mixed waste.