

6 Divertor

6.1 Functions, Basic Configuration and System Boundaries

6.1.1 Functions

The divertor shall be segmented into cassettes sized to allow installation via the divertor level handling ports. The divertor cassettes shall provide a structure on which differently shaped plasma-facing components (PFCs) can be mounted prior to installation in the machine.

6.1.2 Basic Configuration

The main components of the divertor system are:

- (1) a reusable divertor cassette body which provides a mechanical support for different possible arrangements of plasma interfaces;
- (2) inner and outer vertical targets, which at their lower ends are the high heat flux components interacting directly with the SOL plasma and at their upper act as inner and outer baffles for neutral particles;
- (3) semi-transparent liners to both protect the stainless steel (SS) cassette body from radiated heat flux and to provide a path through which the He reaction product is exhausted;
- (4) the dome, located below the separatrix X-point, seeing mainly radiation and charge exchange (CX) neutrals, and baffling neutrals which are pumped through the semi-transparent liner beneath the dome;
- (5) support pads to provide locking and alignment of the divertor cassettes on the toroidal rails;
- (6) divertor to VV gas seals, to prevent backstreaming of gas from the divertor into the main plasma chamber;
- (7) cooling pipe interfaces connecting the divertor cassettes to the radial cooling pipes at each divertor port.

6.1.3 System Boundaries

The divertor system boundaries are as follows:

- the support rails and their attachment to the vacuum vessel.
- remote handling gripping points for radial and toroidal movers.
- diagnostic mounting supports within and on the side of the cassette and within the divertor ports.

- connectors to the water cooling system: for cooling and baking of the divertor cassette and PFCs.

6.2 Requirements

6.2.1 General

- (1) The divertor cassettes shall be designed for the entire lifetime of the machine, however, the PFCs shall be designed for a reduced lifetime. Up to 8 exchanges of PFCs are foreseen over the lifetime of the machine.
- (2) The divertor PFCs shall withstand at least 1000 pulses of 400 s duration (with a goal of > 3000) at nominal parameters including 100 full power disruptions (goal > 300) and 100 slow transients (goal > 300). The design lifetime of the PFCs shall be suitable in terms of both erosion lifetime from ion and charge exchange (CX) bombardment, and component fatigue lifetime due to thermal and mechanical load combinations.
- (3) During normal operational conditions the lower divertor target geometry shall be designed to limit the surface heat flux to $\sim 10 \text{ MW/m}^2$ (strike point region) and to $< 5 \text{ MW/m}^2$ on the upper vertical target (baffle region).
- (4) Slow transient thermal loading conditions - the lower divertor target geometry should be designed to limit the surface heat flux to 20 MW/m^2 for sub-pulses $< 10 \text{ s}$.
- (5) Should plasma-facing material (PFM) loss occur locally the heat sink has to withstand all possible loading conditions for up to 10 events (disruptions, slow transients, steady-state power load) without producing a water leak.
- (6) The divertor design shall include methods and procedures to detect and evaluate the in-vessel tritium inventory and efficiently remove it from codeposited layers when it approaches the mobilisable inventory limit defined in the PSR.
- (7) The divertor shall be designed to achieve an impurity retention factor (shielding efficiency) of > 100 (> 1000 desirable). The retention factor is defined as the ratio of the flux of impurity neutrals entering the divertor plasma to the impurity ion flux entering the main plasma.
- (8) The design shall minimise the amount of dust that can be retained on the hot surfaces of the PFCs, and potentially react with steam to produce hydrogen in the case of an air or water ingress into the VV.
- (9) The divertor design shall include dust removal and monitoring methods to maintain and confirm that the levels are below those specified.

6.2.2 Vacuum

- (1) The permissible helium leak rate of each cassette should be $< 10^{-9} \text{ Pam}^3\text{s}^{-1}$ after the pre-baking (prior to assembly). The total integrated leak rate for the assembled divertor shall be $< 10^{-8} \text{ Pam}^3\text{s}^{-1}$.
- (2) Automatic leak detection shall be foreseen at the primary T confinement boundary at vulnerable locations (i.e. RH welds, flanges, bellows, etc.)
- (3) After pre-baking prior to assembly, permissible out-gassing rates at room temperature are less than $10^{-10} \text{ Pam}^3\text{s}^{-1}\text{m}^{-2}$ for all impurities except for hydrogen species and $10^{-8} \text{ Pam}^3\text{s}^{-1}\text{m}^{-2}$ for hydrogen species. Temperatures and durations will be determined as a result of tests performed on prototypical components.
- (4) Where penetrations of the VV are involved, (for the divertor coolant pipes and instrumentation feedthroughs) the design must preserve primary confinement boundary conditions. For example, tritium confinement requires a double vacuum boundary with leak test capability at all vulnerable boundaries, including windows.
- (5) The design must be capable of draining and drying for leak detection.

6.2.3 Mechanical Loads & Load Combinations

- (1) Operation shall be able to be restored after events in categories I & II without maintenance intervention, and after one category III event after a maintenance intervention.
- (2) The divertor shall be designed to withstand, within stress and deflection allowables, external forces due to the relative movement of the vessel and other in-vessel components.
- (3) The divertor should be designed to withstand the various normal and off-normal combinations of loads:
 - for the cassette body for the entire lifetime of ITER
 - for the PFCs a reduced lifetime is acceptable in line with the goals defined in 6.2.1.
- (4) After a category IV event, loss of integrity of the pressure boundary of the divertor system is accepted, but the overall deformation of the cassette should be such as not to damage other SIC-2 or SIC-3 components.

6.2.4 Thermohydraulic

- (1) The hydraulic system within the PFCs shall be capable of sustaining 20 MWm^{-2} in the region of the strike point of the SOL with sufficient margin on critical heat flux (CHF). The margin on CHF under any circumstances shall be >1.4 .

- (2) The divertor shall be designed to allow draining of the majority of the water from the cassettes prior to any remote maintenance activity involving the removal of cassettes.
- (3) The components and all circuits must be compatible with the water coolant chemistry. The uniform corrosion and corrosion mass transfer shall be minimised. Materials and environment chemistry shall not cause local corrosion damage such as pitting, stress corrosion cracking, or significant galvanic corrosion. The structural integrity and required lifetime of components including circuits shall be maintained.

6.2.5 Mechanical

- (1) The supports shall be designed to accommodate maximum distortions of the rail and cassette caused by thermal bowing, neutron-induced swelling, and application of vacuum .
- (2) The support system of the cassette to the vacuum vessel (rails) must:
 - a. withstand the expected range of electromagnetic loads (see above);
 - b. withstand the maximum range of temperatures between the divertor and vessel;
 - c. provide positive fixing (without allowing gaps to grow) during the entire life-time;
 - d. provide plasma-facing surface alignment;
 - e. be concentric with the magnetic centre of the machine.
- (3) The supply lines shall be routed through the lower vacuum vessel ports (maintenance and cryopump ports).
- (4) The high heat flux (HHF) components shall at least withstand a neutron dose corresponding to 0.05 MWam^{-2} at the outboard first wall.
- (5) All components installed as part of the divertor (including diagnostics) shall be able to withstand nuclear heating during operation and nuclear afterheat during maintenance and downtime.
- (6) The level of decay heating during cassette handling (no water cooling) shall be $< 1 \text{ kW/cassette}$ 1 month after shutdown.
- (7) The armour materials and armour design of the divertor components will be chosen according to the erosion lifetime, thermal shock and fatigue crack resistance, neutron irradiation resistance, tritium retention, and vacuum compatibility and outgassing requirements, in conjunction with the physics requirements to limit the level of impurities inside the machine.
- (8) Materials shall be used with well characterised mechanical and structural properties for their respective service conditions (temperature, stress, neutron damage dose, etc.) in order to obtain a high degree of confidence in their performance.

6.2.6 Electrical

- (1) To prevent arcs within the divertor structures and between the divertor and other structures (blanket or vacuum vessel), as well as unipolar arcs probable because of the presence of ionised plasma, the voltage between adjacent structures has to be reduced by using controlled electrical connections. The cassette must be electrically connected to the vacuum vessel. The connections must be designed to carry the maximum current in case of VDE's (~160 kA per cassette). These connections should be compatible with remote installation and disassembly during divertor maintenance. Electrical connection between cassettes is not envisaged.
- (2) In order not to make a significant contribution to the toroidal resistance of the machine, the toroidal resistance of the divertor shall be higher than $100 \mu \Omega$.

6.2.7 Remote Handling

- (1) The divertor is to be designed for relatively frequent (3 to 8 times during the nominal life) fully remote assembly and disassembly. The detailed requirements for its maintenance are described in detail in DRG 2 chapter 8.
- (2) Remote replacement of eroded/damaged PFC's, which are irradiated, shall be performed ex-vessel in a hot cell. The divertor cassette shall be built in a modular manner in order to allow exchange of the HHF components in the hot cell.
- (3) Structural supports, coolant lines joints, instrumentation, and all other interfaces necessary for (dis)assembly must be compatible with the capability of the remotely operated tools. If possible, these interfaces shall connect and disconnect automatically without the necessity of special RH operations. e.g. electrical connectors can couple when the cassette is pushed into its final location, gas lines will automatically connect through the support rails.
- (4) Sufficient space for the insertion and removal of tools must be assured.
- (5) All liquid and gas pressure bearing joints must be capable of being leak tested by remote means.
- (6) The maintenance or replacement of diagnostic equipment integrated in the cassette or diagnostic plug should be less frequent than the planned maintenance of the HHF components.
- (7) The divertor design shall facilitate repair and decommissioning (including tritium reclamation), and reduce occupational exposures:
 - using modular components for easy dismantling;
 - segregating radioactive systems or components ;
 - designing to avoid contamination or allow easy decontamination;

- selecting construction materials to reduce activation products in materials subject to irradiation.

6.2.8 Manufacturing

- (1) The surface finish shall be N8 (3.2 μm) or finer.
- (2) Joints should be designed where possible to allow the use of NDT inspection.
- (3) Where practical all welds should be full penetration butt welds.

6.2.9 Assembly

- (1) Each support and cassette shall have a unique identifier. The supports shall be finally machined before installation from 3D surveys of the cassettes and toroidal rails.
- (2) The supports locking system shall be pre-loaded or designed to avoid any dynamic effect during off-normal events.
- (3) If used, bolts should be secured (lock welding).
- (4) Absolute positioning tolerance of in-vessel ends of radial feeding pipes: ± 5 mm.
- (5) Adjustment capacity of pipe supports located inside divertor port: ± 3 mm.

6.2.10 Instrumentation and Control

- (1) Information about the divertor performance shall be inferred from the diagnostic cassettes at the 3 RH ports (ports 3, 9 & 15), and two other ports (ports 12 & 18) and from 10 instrumented cassettes. Diagnostic cassettes incorporate optical and microwave diagnostics and need to be positioned directly in front of a port, whereas instrumented cassettes are limited to diagnostics using signals transmitted via cables, and can be positioned elsewhere. The diagnostics for the divertor have parts in the divertor cassette and in the case of diagnostic cassettes, other parts in the diagnostic block located inside the divertor maintenance ports.
- (2) Magnetic pick-up coils, pressure gauges, bolometers, Langmuir probes, and micro-fission chambers which form part of the plasma diagnostics shall be pre-assembled onto separate plates (strong-backs) that are attached to the sides of the instrumented cassettes in the hot cell.
- (3) Deformation sensors and thermocouples shall be attached to the instrumented cassette body in order to monitor its performance.

- (4) Halo current sensors (Rogowski coils) shall be incorporated into the instrumented cassettes cassette to vessel attachments.
- (5) The effects of radiation streaming must be mitigated, whenever a penetration is required for a diagnostic access through the divertor cassette, by compensating shielding behind the diagnostic element or introduction of labyrinths.