16 Ion Cyclotron Heating and Current Drive System

16.1 Functions, Basic Configuration and System Boundaries

The Ion Cyclotron Heating and Current Drive (IC H&CD) system consists of:

- launching array(s), composed of:
  - a Faraday shield;
  - eight resonant double loop (RDL) launching structures, with tuners and vacuum transmission lines;
  - one neutron shield and 1 support structure;
- main transmission lines;
- RF power sources;
- electrical power supply sets;
- decoupling units;
- monitoring and controls;
- auxiliaries and services.

The IC H&CD system boundaries are as follows:

- bolted attachment flange of the RF plug to the vacuum vessel port flange not including the primary vacuum seal;
- bolted connection of the IC main transmission lines to the cryostat cover plate, including the seal for the secondary vacuum;
- coolant connection to the blanket and vessel cooling systems at a flange at the cryostat cover plate;
- attachments for getter pumps and vacuum monitoring equipment;
- attachments of transmission lines to the buildings between the cryostat port cover plate and the power supply area;
- connection to the additional heating power supplies at the high voltage terminal of the RF power source;
- location of the RF power sources supplies in a dedicated heated, ventilated and air conditioned area within the building complex;
- connection to the RF power supply cooling system in the RF power sources hall;
- connection of the local plant controller to the site CODAC control system.

16.2 Requirements

16.2.1 General

The ICH&CD system shall provide ion and electron heating in 50–50 % DT plasma for a volume averaged plasma density of 2 to 20 × 10^{19} m^{-3}, and in the plasma temperature range $2.5 \leq T_e \leq 12$ (keV). The system shall be capable of driving a continuous an on–axis-current density of at least 200 kA/m^2 and/or a total current of greater than 1 MA within $r/a < 0.7$, with a line average density of 5×10^{19} m^{-3} or greater.

The system can assist in establishing breakdown and in minimising the poloidal flux during the current initiation phase. It can be used for wall conditioning with H and other gases, with and without full toroidal field.

All IC system components shall use technology currently available or whose reliability can demonstrated before being installed in ITER.

The ICH&CD system shall be designed to operate at discrete bands of 2 MHz, within the desired frequency range. In-band electronic modulation shall be provided from each mid band frequency, up to ±1 MHz deviation, with a frequency resolution of 1kHz.

The system shall be equipped with instrumentation for the automatic control of RF power, frequency, phase and voltage standing wave ratio (VSWR). Automatic protection against voltage breakdown in load, transmission and power source shall be included in the design.

16.2.2 Vacuum

Ceramic feed-through(s), located at the VV closure plate in each vacuum transmission line are to be used for primary vacuum containment. Similar feed-through(s) shall be used for secondary vacuum containment at the cryostat closure plate.

A rupture disk, exhausting in a vault de-tritiation system (VDS) shall protect the vacuum window on secondary vacuum against over pressure.

16.2.3 Mechanical

Ex-vessel transmission lines and vacuum windows shall withstand a continuous pressure up to 0.2 MPa.

Thin, low resistance (50 μm) metallic coatings (Cu, Be, Ni) may be required to reduce RF losses in some in-vessel components.

16.2.4 Thermohydraulic

In-vessel Components

In addition to plasma radiation and volumetric nuclear heat loads, the in-vessel components of the IC array shall withstand a surface heat load due to RF losses up to 2% of the transmitted power.

The plasma-facing component shall not be designed to withstand thermal conduction loads from the plasma, (e.g. during the start-up phase), from which they shall be protected by the adjacent shielding blanket modules or by suitable protections integrated in the blanket.

In addition to the standard baking procedures, baking of the IC in-vessel components is to be provided by the controlled application of continuous or pulsed RF power at reduced coolant flow.

All IC components must be compatible with water coolant chemistry. Corrosion, electrochemical, and other effects are to be limited to acceptable levels over the life of the system.

In-vessel components sufficiently shielded from neutron flux may be cooled using the Vacuum Vessel coolant loop

All in-vessel components shall be designed to be drained of water in-situ.

Ex-vessel Components

RF test and matched loads present in the systems may use, for power dissipation, liquid resistors, circulated in a closed loop and cooled by heat exchange by water from the component cooling water supply (CCWS) system

16.2.5 Electrical

The reliability of the IC system operation depends on the maximum RF electric field reached in the system. The following maximum RF electric field and current limits are not to be exceeded anywhere in the system:

- Max. (peak) RF electric field on plasma:	2.0 kV/mm
- Max. (peak) RF electric field in vacuum:	4.0 kV/mm
- Max. (peak) RF current:	3.5 kA

Effort should be made in the design, to further lower the above values, in particular the on-plasma voltage.

Allocation of electrically isolated gaps and inserts in or between structural in-vessel components shall restrict values of local and global disruption induced currents below safe levels. The design should avoid the use of double or multiple grounding points, as they can create large loops for RF or low frequency induced currents.

Design and routing of grounding connections (busbars, cooling conduits, resistors jumpers, etc.) shall be chosen so as to limit RF voltages below the specified values. The grounding scheme should minimise the possibility of propagation of electrical breakdown, including modes with diffuse discharges and arcs in vacuum volumes for a wide range of gas pressure, in presence of water or steam.

In addition to the above low frequency ground, a high frequency (capacitive) ground connection to the VV may be provided as necessary, in order to avoid RF resonance excited in the port inter-spaces and to prevent that EM interference affects monitoring equipment located in these areas.

All RF and DC Power generation equipment shall be contained in sealed enclosures against electromagnetic interference (EMI). All power transmitter components (including DC supplies) shall be further enclosed in a second overall EMI sealed enclosure. Any input and output signal cable or cooling line crossing this boundary shall be individually (low pass) filtered or configured as an RF choke.

Continuously operated radiation monitors shall be part of the interlock system of the IC System, and shall prevent high power operation at any level of EMI above the specified threshold.

All power transmission lines shall be shielded and preferably of the coaxial type. No transmission of base-band low-level signals shall take place in the system. The RF signals detected at the monitoring points shall be down-converted, before transmission, to an intermediate frequency (IF) much lower than the operating frequency, to improve noise immunity. All signal exchanges between different IC subsystems and between IC and other systems shall be via fibre optic links.

16.2.6 Remote Handling

The IC array shall be removable from the equatorial port by remote handling. Any interruption of the ITER operation, due to this removal should be minimised by appropriate design. It should be possible to maintain vacuum windows and tuning components without disassembly of the IC array.

The structural supports, coolant lines joints, instrumentation leads, and all other interfaces shall be compatible with the capability of the remotely operated tools. Gripping points capable of supporting the full weight over the full range of motion required at installation or removal must be provided on all remotely maintained components. The design must ensure sufficient space for the insertion and removal of all required tools.

All liquid and gas pressure bearing joints must be capable of being leak detected by remote means.

Mechanical guides should be provided to aid the transporter for final positioning and alignment and to protect adjacent components from damage due to collisions.

Renewal of low Z (beryllium) coatings of the plasma-facing components may be performed in the hot-cell.

16.2.7 Manufacturing

Manufacturing tolerances shall be consistent with achieving the overall installation tolerances, taking into account inaccuracies resulting from installation and tolerances of mating components.

The in-vessel components of the IC system shall be fabricated as a set of modular components and sub-assemblies capable of being assembled by a contractor at the construction site. The system shall be assembled using a plan that is compatible with the project's general assembly plan. The assembly plan will be developed considering facility restrictions on size and handled weight.

Any special tools and fixtures for use in on-site assembly and installation shall be provided as part of the IC system.

All inner and outer surfaces of the vessel port plug are to be cleaned with a solvent (acetone, alcohol, or equivalent) and then air-dried.

16.2.8 Instrumentation & Control

The control of the plasma position (gap) in front of the IC H&CD array shall be automatically performed by using the antenna radiative loss (coupling) as feedback signal

All RF components exposed to high RF voltage shall be continuously monitored by fast arc detection monitors. The pressure in the main transmission line shall be continuously monitored and controlled above the threshold value. No high power RF operation shall be possible without these two monitors operative.