14 The Cooling Water System

14.1 Functions, Basic Configuration and System Boundaries

14.1.1 Functions

The main functions of the cooling water system (CWS), which consists of the tokamak cooling water system (TCWS), the component cooling water system (CCWS), the chilled water system (CHWS) and the heat rejection system (HRS) are described in DRG1. Essentially, the CWS removes heat from various heat sources in the tokamak and some associated systems and components, under controlled flow rate, temperature and pressure conditions, and releases the transferred heat into the environment.

14.1.2 Basic Configuration and System Boundaries

The CWS consists of:

(i) the tokamak cooling water system (TCWS); which consists of primary heat transfer systems (PHTSs), chemical and volume control systems (CVCSs), draining and refilling systems, and a drying system

(ii) the component cooling water system (CCWS)

(iii) the chilled water system (CHWS)

(iv) the heat rejection system (HRS) based on cooling towers.

The main clients of each system are as follows.

(i) PHTSs: PHTSs are assigned to components inside the vacuum vessel and the vacuum vessel itself. These components are blanket modules, port-limiters, divertor cassettes, vacuum vessel, the in-port components of the ICH&CD and ECH&CD (RFH&CD) systems, and the diagnostics inside the vacuum vessel. There is also a PHTS for the NB injectors (low and high voltage) and the diagnostic NB injector. The in-vessel PHTSs are the PFW/BLK, DIV/LIM and NB injector PHTSs. The interfaces with the clients are at VV ports except for the NB injector, where the interface is at the NB injector cell.

(ii) CVCSs: these systems are purification systems for the in-vessel PHTSs loops, and the clients are all the PHTSs loops except the VV PHTS. The interfaces with the clients are at the clients components.

(iii) the draining and refilling systems: these systems are assigned for the inventory control in all PHTSs loops during operation and maintenance, and the clients are all the PHTSs loops. The interfaces with the clients are at the clients components.

(iv) the drying system: this system is considered to dry out the PHTSs loops of the blanket modules, port-limiters, divertor cassettes, and vacuum vessel after their drainage. The interfaces with the clients are at the clients components.

(v) CCWS: this system serves the power supply components, the RFH&CD generators components, pumps in the TCWS, and components in the site services building. The interfaces with the clients are at the clients components.

(vi) CHWS: this system serves the HVAC for various buildings, NB injector (high voltage), tritium process components, and some of the CCWS for the power supply components. The interfaces with the clients are at the clients components.

(vii) HRS: this system assigned for the entire heat load of all other parts of the CWS, and it has the interfaces with heat exchangers in the TCWS, the cryoplant compressor, test blanket module PHTSs (designed by the home teams), the CCWS, and the CHWS. The interfaces with the clients are at the clients components.

14.2 Specific System – Internal Requirements

14.2.1 Design

14.2.1.1 Site Conditions

The following site conditions shall be considered for the design of components of the CWS which are located outdoors.

- Maximum steady, horizontal wind ≤ 140 km/h
- Maximum air temperature ≤ 35°C (24 h average ≤ 30°C)
- Minimum air temperature ≥ -25°C (24 h average ≥ -15°C)
- Maximum relative humidity (24 h average) ≤ 95 %
  (corresponding vapor pressure ≤ 22 mbar)
- Maximum relative humidity (30 day average) ≤ 90 %
  (corresponding vapor pressure ≤ 18 mbar)
- Barometric pressure - sea level to 500 m
- Maximum snow load - 150 kg/m^2
- Maximum icing - 10 mm
- Maximum 24 h rainfall - 20 cm
- Maximum 1 h rainfall - 5 cm
- Heavy air pollution (level 3 according to IEC 71-2)

14.2.1.2 Tokamak Cooling Water System (TCWS)

(1) Primary Heat Transfer Systems (PHTSs)
Guidelines for the cooling assignment and number of loops for each PHTS of the in-vessel components and the vacuum vessel, and design requirements for the associated systems are summarised below. All loops of the PHTSs shall be pressurised. The thermohydraulic design requirement for each PHTS is shown in Table 14-1.

Table 14-1 Thermohydraulic Requirements for the PHTSs

PHTS	H-Operation Phase		DT-Operation Phase	
Blanket (PFW/BLK)				
• Pulse				
Thermal load (MW)	55		690	
Flow rate (kg/s)	(TBD) [1]		3,390 [2]	
Inlet temperature (°C)	100		100	
Inlet pressure (MPa)	3.0		3.0	
• Baking				
Inlet temperature (°C)	240		240	
Inlet pressure (MPa)	4.4		4.4	
Divertor & Limiter (DIV/LIM)				
• Pulse				
Thermal load (MW)	50		202	
Flow rate (kg/s)	(TBD)[1]		1,000[2]	
Inlet temperature (°C)	100		100	
Inlet pressure (MPa)	4.2		4.2	
• Baking				
Inlet temperature (°C)	240		240	
Inlet pressure (MPa)	4.4		4.4	
NB Injectors (NB)				
• Low voltage				
Thermal load (MW)	65.6[3]		86.9[3]	
Flow rate (kg/s)	463		591.7	
Inlet temperature (°C)	≤ 80		≤ 80	
• High voltage	(ion source)	(the others)	(ion source)	(the others)
Thermal load (MW)	3.6[3]	7.6[3]	4.8[3]	10.5[3]
Flow rate (kg/s)	36.6	47.3	48.8	65.6
Inlet temperature (°C)	≤ 20	≤ 60	≤ 20	≤ 60
Vacuum Vessel (VV)				
• Pulse				
Thermal load (MW)	~ 0		10	
Flow rate (kg/s)	trickle flow		950	
Inlet temperature (°C)	100		100	
Inlet pressure (MPa)	~ 1.1		1.1	
• Baking				
Inlet temperature (°C)	200		200	
Inlet pressure (MPa)	~ 2.4		2.4	
• Decay heat removal				
Heat load to VV (MW)			0.83 (peak)	

1) TBD items are under discussion
2) Corresponding to ~ 50°C temperature rise in the blanket, the port limiter, and the divertor
3) 33 MW heating by the NB injector with 1 DNB injector and 1 calorie meter for the H-operation phase, and 50 MW heating for DT-operation phase are considered.

The primary first wall and blanket modules (PFW/BLK) PHTS is located in the tokamak cooling water system (TCWS) vault. The inlet and the outlet locations on the vacuum vessel are at the top of every upper port for the blanket modules and at the equatorial ports for the in-port components. The cooling pipes between the loops and the VV will be installed inside the upper pipe chases and the vertical shafts which connect the upper and lower chases and are formed outside of the bioshield. A 3-loop concept is chosen for cost reduction.

The divertor cassettes and port limiters (DIV/LIM) PHTS is located in the TCWS vault. The inlet and outlet locations on the vacuum vessel are at every divertor port edge for the divertor cassettes and at two of the equatorial ports edges for the port-limiters. The cooling pipes outside the VV will be installed inside the pipe chases and the vertical shafts. A 1-loop concept is chosen for cost reduction.

The vacuum vessel (VV) PHTS is designed for pulsed loads during normal operation and is able to remove at least 0.83 MW of decay heat in a fully passive mode, i.e. by natural convection under category III and IV events. To promote natural convection it is important to have sufficient height difference between the heat source (vacuum vessel) and sink (heat exchanger). The air-cooled heat exchangers will be located on top of the tokamak building at the east and west sides of the tokamak pit. The inlet and outlet locations are located at the bottom of the divertor ports and at the top of the upper ports, respectively. All closure plates at VV port edges are cooled in parallel with the main VV, and a pair of inlets and outlets are on the VV port edges. Part of the piping, such as the distributing/collecting manifolds, will be installed inside the pipe chases and the vertical shafts. A 2-loop concept is chosen for redundancy.

The NB injector PHTS serves the neutral beam injector systems which consists of the low voltage systems and the high voltage systems. The PHTS will be located in the TCWS vault and connected to the NB injector components located in the NB cell which has communication with the TCWS vault through the vertical shafts. A 1-loop concept is chosen for cost reduction.

No dedicated PHTS is considered for the in-port components of the RFH&CD systems. The thermal loads of the ICH&CD system, the ECH&CD system, and LHH&CD system, the components of which are located in the equatorial and/or upper ports, are removed as follows. The heat load from the plasma-facing portion (inner portion) of the components is removed by the PFW/BLK PHTS, and the heat load from the rear portion (outside portion) which forms the vacuum boundary of the VV port is removed by the vacuum vessel PHTS.

No dedicated PHTS is considered for the diagnostics and the wall-conditioning system. The thermal loads from specific diagnostics that are contained inside the vacuum vessel are treated in the same way as the in-port components in the RFH&CD systems.

Heat exchangers of PHTSs except those of the VV PHTS are cooled with the heat rejection system including cooling towers. The heat exchangers of the VV PHTS are cooled with air as the ultimate heat sink.

(2) Chemical and Volume Control Systems (CVCSs)
The CVCSs units are located inside the TCWS vault under the mezzanine floor on which the PHTSs components are located. Sufficient water polishing capacity shall be provided to satisfy the requirements for activated corrosion products (ACPs) concentration and water chemistry in the loops of the PHTSs. Three CVCS units, one each for the PFW/BLK PHTS, the DIV/LIM PHTS and the NB injection PHTS will operate continuously with a high degree of reliability. The CVCS for the PFW/BLK PHTS serves its 3 loops, and the connections and

valves between each loop and the CVCS allow each loop to be connected in turn, so that the CVCS serves one loop at a time. Following the experience of CVCS operation in nuclear power plants, the CVCS reference design shall employ redundancy for components that require routine maintenance to allow continuous operation without performance degradation.

(3) Draining and Refilling Systems
Sufficient storage capacity shall be provided to accept the drained inventory from the loops of the PHTSs to allow maintenance and/or component replacement. Separate drainage of cooling loops shall be possible. Draining of some selected components for maintenance/repair/inspection shall be feasible without the need to drain the entire loop. Some of the drain tanks for the PHTSs except the VV PHTS shall be designed to accept the residual water during an in-vessel LOCA, and the drain tanks for the VV PHTS shall have enough capacity to accept the residual water from a damaged VV PHTS.

The position of the main components of these systems will be in the galleries at the basemat level in the tokamak building.

(4) Drying System
Sufficient gas flow above saturation temperature and moisture separation capability shall be provided to allow removal of residual humidity after draining the tokamak components. Common use of a drying unit is under consideration for the blanket modules, the divertor cassettes and VV closure plate. The position of this system will be the vault annex in the tritium building.

14.2.1.3 Component Cooling Water System (CCWS)

The CCWS shall be designed considering the following zoning of client systems. The heat load for each zone is summarised in Table 14-2.

(i) tokamak building zone; the main clients are RFH&CD generators components and RFH&CD power supply system inside the assembly hall, and components such as pumps inside the tokamak building. The loop for the RFH&CD power supply system is served by the CHWS (see 14.2.1.4) due to the low temperature condition, and the other loops are served by the HRS (see 14.2.1.5).

(2) power supply zone; the clients are components of the power supply systems including busbars. Some of the loops are served by the CHWS (see 14.2.1.4) and the remaining loops are served by the HRS (see 14.2.1.5).

(iii) site service zone; the clients are components inside the site services building. The loop is served by the HRS (see 14.2.1.5).

Elements of the CCWS will be installed at an appropriate position in each zone, and the individual CCWS circuits shall be designed with a reliability determined by the requirements of the client system.

The locations of the main components of the CCWS are; at the basemat level of the tritium building for the tokamak building zone, at the ground level of the MPSSNB (magnet power supply switching network building) for the power supply zone, and at the ground level of the site services building for the site services zone.

Table 14-2 Heat Loads (MW) in Clients of the CCWS

CCWS Zone and Client Systems	H-Operation Phase	DT-Operation Phase
Tokamak Zone	~ 48	~ 91
RF H&CD generators components	(40.8) [1]	(81.6) [1]
RF H&CD power supply	(3.0) [2]	(5.9) [2]
Pump cooling & anti-coil in NB cell	(3.3)	(3.3)
Condenser (2) in drying system	(0.5)	(0.5)
Power Supply Zone	~ 27	~ 28
Power supply components (1)	(18.8)	(18.8)
Power supply components (2)	(8.1) [2, 3]	(9.1) [2, 3]
Site Service Zone	1.0	1.0
Total	~ 76	~ 120

Notes:

[1] As for additional heating, 20 MW of ECH&CD and 20 MW of ICH&CD for the H-operation phase, and 40 MW of ECH&CD and 40 MW of ICH&CD for the DT-operation phase.

[2] The heat load is transferred to the CHWS (see 14.2.1.4)

[3] 33 MW heating by the NB injectors for the H-operation phase, and 50 MW heating for the DT-operation phase are considered.

14.2.1.4 Chilled Water System (CHWS)

The CHWS shall be designed considering the following clients zoning. The heat load for each zone is summarised in Tables 14-3 and 14-4.

(i) tokamak building zone; the clients are the air conditioning systems for the tokamak building except the vault cooler for the TCWS vault and non-safety components and the air conditioning system for the tritium building.

(ii) power supply zone; the clients are the air conditioning systems for the power supply building and part of the CCWS for power supply components which require an inlet temperature < 35°C.

(iii) site services zone; the clients are the air conditioning systems for the site services building.

(iv) safety-related; the clients are the vault cooler (post-LOCA cooling system), tritium process components and the air ventilation systems for the hot cell.

Individual CCWS system will be installed at appropriate positions in each zone, and the individual CHWS circuits shall be designed for unique reliability requirements as determined by the required reliability of the client system.

The locations of the main components of the CHWS are the same as those of the CCWS.

The safety-related elements of the CHWS shall have full redundancy for confinement purposes. The location of the safety-related elements of the CHWS is at the basemat level of the tritium building.

Table 14-3 Heat Loads (MW) in Clients of the CHWS (Non-safety-related Elements)

CHWS Zone and Client Systems	H-Operation Phase	DT-Operation Phase
Tokamak Zone	~ 18.7	~ 23.0
Building HVAC and condenser (2) in drying system	(10.3)	(10.3)
HX (2) in NB injector PHTS	(5.4)	(6.7)
RF H&CD power supply	(3.0)	(5.9)
Power Supply Zone	~ 11.0	~ 12.1
Building HVAC	(2.9)	(2.9)
Power supply components (2)	(8.1)	(9.1)
Site Service Zone	~ 5.5	~ 5.5
Building HVAC	(5.5)	(5.5)
Total	~ 35.5	~ 41

Notes: A 0.7 scaling factor compared with 1998 ITER is assumed for all HVAC systems.

Table 14-4 Heat Loads (MW) for the Safety-related Elements of the CHWS

Heat Source	H-Operation Phase	DT-Operation Phase
TCWS vault cooler	1.1	1.1
Air ventilation in hot cell	0	0.9
Tritium process component	0	2.0
Total	1.1	4.0 x 2

14.2.1.5 Heat Rejection System (HRS)

The HRS shall be designed to deal with heat loads under various plasma scenarios including steady-state operation. The heat loads from the following systems shall be considered. The heat load for each client is summarised in Tables 14-5 and 14-6.

(i) heat exchangers in the loops of the PHTSs except for the VV PHTS.
(ii) Test blanket modules PHTSs designed by each party. Proposals are under consideration for test modules that are helium cooled, lithium cooled and a lithium lead design using water cooling. It is expected that six dedicated primary cooling loops (2 loops/test blanket module PHTS) will be clients of the HRS.
(iii) miscellaneous; compressor in the cryoplant and heat exchangers in the CVCS.
(iv) CCWS elements in each zone.
(v) CHWS elements in each zone.
(vi) Safety-related CHWS elements

The HRS for the safety-related CHWS elements shall have full redundancy for confinement purposes.

The reference HRS consists of cooling towers with associated basins and water circulation pumps. The location of the water circulation pumps will be close to, but outside, the client buildings; the tritium building, the cryoplant compressor building and the MPSSNB, and a feed and return penstock connects the pump stations and basins.

Table 14-5 Heat Loads (MW) in Clients of the Heat Rejection System

Heat Source	**H** [1]	**DT** [1]
Total heat dissipated to in-vessel components and to vacuum vessel;	~ 75	~ 812
PFW/BLK PHTS	(~ 55)	(~ 690)
DIV/LIM PHTS	(~ 50)	(~ 202)
VV PHTS	(~ 0) [2]	(~ 10) [2]
NB injectors PHTS;	~ 74 [3]	~ 97 [3]
Main HX	(~ 67)	(87.7)
Pre-cooler	(~ 7.0) [4]	(~ 9.2) [4]
CVCS;	~ 3.7	~ 9.5
PFW/BLK PHTS	(2.5)	(2.5)
DIV/LIM PHTS	(0.9)	(0.9)
NB injector PHTS	(0.3)	(0.3)
Test blanket PHTS	(0)	(~ 5.5)
Cryoplant Compressor	~ 25	~ 25
CCWS	~ 79	~ 120
Tokamak zone	(~ 51)	(~ 91) [5]
Power supply zone	(~27)	(~ 28)
Site services zone	(~ 1.0)	(~ 1.0)
CHWS	~ 45 [6]	~ 52 [6]
Tokamak zone chiller	(~ 23.5)	(~ 29.1)
Power supply zone chiller	(~ 14.2)	(~ 15.5)
Site services zone chiller	(~ 6.9)	(~ 6.9)
Total	~ 300	~ 1,120

Notes:

[1] The heat loads include the heat dissipated in the cooling water system (pump heat etc.).

[2] The heat load from the vacuum vessel is dissipated to air through air-cooled HXs.

[3] 33 MW heating by NB injector for the H-operation phase, and 50 MW heating for the DT-operation phase are considered.

[4] The heat load of the HX (2) in the NB injector HV line is included in the tokamak chilled water system load.

[5] For additional heating (in addition to NBH&CD), 20 MW of ECH&CD and 20 MW of ICH&CD for the H-operation phase, and 40 MW of ECH&CD and 40 MW of ICH&CD for the DT-operation phase.

[6] The heat load for the CHWS, and the heat load for the HRS from the chiller units is 1.25 times the heat load.

Table 14-6 Heat Loads (MW) for Safety-related Systems

Heat Source	H	DT
Safety-related chilled water system	~1.4	5.0 x 2
TCWS vault cooler	(~1.4)	(1.4)
Air ventilation in hot cell	(0)	(1.1)
Tritium plant	(0)	(2.5)
Total	~1.4	~ 5.0 x 2

14.2.2 Operation

14.2.2.1 Thermohydraulic

(1) TCWS

The thermohydraulic parameters of the PHTSs for the in-vessel components and the vacuum vessel to be controlled during each operation mode are listed in Table 14-7.

The coolant inlet temperature for the low voltage system in the NB injector must be controlled to ≤ 80°C. The coolant inlet temperatures for the ion source and the other components in the high voltage system of the NB injector must be controlled to ≤ 20°C and ≤ 60°C, respectively. The temperature differences between the inlet and outlet of the ion source and the other components in the high voltage system must be kept to less than 20°C and 40°C, respectively. The flow rate for the NB injector shall be controlled within + 10%/- 10%. Baking of the neutral beam systems is not needed, however a trickle flow to avoid freezing when the beam is off is needed. Reduced flow is preferred to reduce erosion for the main systems.

Table 14-7 Thermohydraulic Parameters to be controlled

PHTS	PFW/BLK	DIV/LIM	VV
Flat top			
Inlet temp. (°C)	100 +5/-10	100 +5/-10	100 +10/-10
Inlet pressure (MPa)	3.0 +/- 0.2	4.2 +/- 0.2	1.1 +/- 0.2
Flow rate (kg/s)	3,390 +/- 5%	1,000 +/- 5%	950 +/- 6%
Ramp-up/down			
Inlet temp. (°C)	100 +15/-15	100 +5/-10	100 +10/-10
Inlet pressure (MPa)	3.0 +/- 0.2	4.2 +/- 0.2	1.1 +/- 0.2
Flow rate (kg/s)	3,390 +/- 10%	1,000 +/- 5%	950 +/- 6%
Plasma disruption			
Inlet temp. (°C)	100 +15/-30	100 +15/-30	100 +10/-10
Inlet pressure (MPa)	3.0 +/- 0.2	4.2 +/- 0.2	1.1 +/- 0.2
Flow rate (kg/s)	3,390 +/- 10%	1,000 +/- 10 %	950 +/- 6%
Short term standby			
Inlet temp. (°C)	~ 100	~ 100	~ 100
Inlet pressure (MPa)	no requirement	no requirement	no requirement
Flow rate (kg/s)	DHR*	DHR	DHR
Baking			
Inlet temp. (°C)	240 +10/-10	240 +10/-10	200 +0/-10
Inlet pressure (MPa)	4.4 +/- 0.2	4.4 +/- 0.2	2.4 +/- 0.2
Flow rate (kg/s)	no requirement	no requirement	no requirement
Temp. increase (°C /h)	< 15	< 15	< 5

* DHR - Sufficient for decay heat removal

(2) CCWS

The CCWS supply temperature shall be a maximum of 40°C during all operation modes except for power supply components which use semiconductors. The supply temperature for the semiconductor devices shall be a maximum of 35°C. In addition, power supply components require a certain flow rate to get a required heat transfer coefficient on the component. The major requirements are summarised in Table 14 -8.

Table 14-8 Major Thermohydraulic Requirement on Components Cooling

Component	Temperature		Flow Rate (kg/s)
	Inlet (°C)	Outlet (°C)	
Power Supply			
Reactors	< 45	-	94.4
Busbars	< 45	-	111.4
Switching network	< 45	-	8.3
Fast discharge	< 45	-	13.9
RPCs	< 35	-	38.9
Coil converters	< 35	-	252.8
NB injector power supply	< 35	-	183.3*
ECH&CD power supply	< 35	-	222.2*
ICH&CD power supply	< 35	-	100.0*
RFH&CD components			
ECH&CD	≤ 40	≤ 70	-
ICH&CD	≤ 40	≤ 70	-

Note)*: 50 MW heating by NB injector and 40 MW of ECH&CD and 40 MW of ICH&CD

(3) CHWS
The CHWS supply temperature shall be 6 ± 1°C at the outlet of the chiller units. At the interface points, it shall be 6 ± 1.5 °C. The return temperature shall be 12 ± 1 °C at the inlet of the chiller units. The supply and return temperature on the HRS side of the chiller unit shall be 35°C and 40°C, respectively.

(4) HRS
The HRS shall provide cooled water at a maximum of 35°C and a minimum of 5°C during all operating modes. The maximum return temperature from the client system shall be less than 75°C during normal operation. Provisions for increasing the minimum value of the range shall be included in the design should these be determined to be necessary at a later date.

14.2.2.2 Chemical

(1) TCWS
The water chemistry of all loops of the PHTSs except the VV PHTS shall be controlled by the CVCSs within specified limits for all modes of operation including extended shutdown, and/or extended loss of electrical power. Loop materials must be compatible with the coolant chemistry under all operational conditions. The coolant water chemistry specifications are given in Table 14-9.

Table 14-9 Water Chemistry Specifications

Parameter	Specification			
PHTS	PFW/BLK	DIV/LIM	VV	NB injector
Material in contact with water	SS304L SS316 L(N) IG*	SS304L CuCrZr/ SS316 L(N) IG*	SS304L SS316 L(N) IG* SS30467* SS430*	SS304L SS316 L(N) IG* Swirl: Cu Ni Be*
pH @ 20°C	7.0 ± 0.5	7.0 ± 0.5	7.0 ± 0.5	7.0 ± 0.5
Hydrogen, cm^3/kg	25	25	- **	25
Oxygen, mg/kg	< 10	< 10	< 100	< 10
Chlorine (and fluorine) ions, mg/kg	< 5	< 5	< 5	< 5
Hardness (Ca, Mg, etc.), mg-equivalent/kg	< 5	< 5	< 5	< 5
Sulfate content, mg/kg	< 5	< 5	< 5	< 5
Iron content, mg/kg	< 5	< 5	< 5	< 5
Copper content, mg/kg	< 5	< 5	< 5	< 5
Conductivity, mSiemens/cm @ 25°C	< 0.3	< 0.3	< 0.3	< 0.2
Oil product conc., organics, mg/kg	< 100	< 100	< 100	< 100

* To be applied for the cooling channels of the in-vessel components, the vessel, and the additional heating systems themselves.

** Validity for no control of the hydrogen concentration of the VV PHTS coolant needs to be confirmed by further study.

(2) CCWS

The fluid circulated by the CCWS shall contain suitable corrosion-inhibition additives, if necessary. The CCWS shall include appropriate equipment to remove suspended material, maintain chemical specifications, and maintain fluid inventory. Such equipment shall not be shared between the loops of the CCWS unless compelling cost or operational requirements dictate otherwise. The high voltage components such as the pulsed power supply converters require very low conductivity, de-mineralised water. Therefore, de-mineraliser (ion exchange resin units) will be installed in some sub-systems in accordance with component requirements.

(3) CHWS

The fluid circulated by the CHWS shall contain suitable corrosion-inhibition additives. The CHWS shall include appropriate equipment to remove suspended material, maintain chemical specifications, and maintain fluid inventory. Such equipment shall not be shared between the loops of the CHWS unless compelling cost or operational requirements dictate otherwise.

(4) HRS

For the cooling towers in the HRS, anti-corrosives chemicals, pH control and biocides may be added to prevent corrosion and biological growth. However, chemical use shall be compatible with sewer discharge restrictions. The cooling water total dissolved solids (TDS) shall be maintained below 2,000 ppm by the use of a blowdown system, unless local sewer regulations limit TDS to lower values.

14.2.2.3 Electromagnetic

(1) TCWS
The TCWS vault and the pipe chases are subject to magnetic fields (0.1 T - 0.03 T) during plasma operation. PHTS components must either be magnetically shielded or able to operate in the prevailing fields.

(2) CCWS, CHWS, and HRS
None.

14.2.2.4 Layout

(1) TCWS
Components inside the TCWS vault and the pipe chases shall be arranged to minimise cost and maximise inspection and maintenance access, taking into account the magnetic fields and the radiological hazards associated with inspection and maintenance.

The layout of the PHTS piping must provide appropriate separation from the electrical feeds for the magnets such that magnet deformation or arcing will not simultaneously damage the PHTSs in a manner likely to lead to an unacceptable break of confinement.

Human access to the TCWS vault and the pipe chases will be limited due to radiation from the tokamak and activated corrosion products in the loops, and by tritium permeated and/or leaked from loops into the atmosphere. Careful design in combination with gamma shielding and with pre-maintenance cleaning procedures should allow the possibility of hands-on maintenance and repair 24 hrs after the most recent plasma pulse. (The degree of accessibility after 24 hours, and the waiting period for extended access are under review; a decision will be made after new analysis.)

(2) CCWS, CHWS, and HRS
Components of the other systems inside various buildings shall be arranged to minimise cost and maximise inspection and maintenance access.

14.2.3 Other

14.2.3.1 Mechanical

The pipework of the TCWS forms electrical connections between the vacuum vessel and the cryostat, and it connects both electrically with the other TCWS components located inside the TCWS vault. The design of the pipework will consider any induced electromagnetic loads and effects due to the normal pulsed operation of the magnets.

The following items shall be also considered.

(1) Displacements
Operational displacements caused by thermal contractions and expansions as well as plasma operation conditions including off-normal conditions and seismic conditions, will produce relative motion between the pipework boundaries, vessel and cryostat. These shall be compensated for by designing the pipework to be sufficiently flexible or by incorporating

flexible elements in the design. The design values to be used as the maximum displacement for SL-2 are summarised in Tables 14-10 and 14-11.

Table 14-10 Design Values for Maximum Displacement of Ports (in mm)

	Horizontal Port		**Equatorial Port**		**Divertor Port**		**NB Injector Port**	
	Therm.	**Seis.**	**Therm.**	**Seis.**	**Therm.**	**Seis.**	**Therm.**	**Seis.**
R-direction	+55.4/0	± 25	+55.4/0	± 25	+55.4/0	± 25	+55.4/0	± 25
Z-direction	0/-11.5	± 10	0/-26.8	± 10	0/-47.5	± 10	0/-26.8	± 10
Toroidal direction	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

Note: Base on G 10 RI 2 00-10-04 W 0.1. TBD items shall be analysed by the VV group and/or DI unit

Table 14-11 Design Value for Maximum Displacement between the TCWS Vault and Ground

R-direction	± 80 mm
Z-direction	± 30 mm

(2) Seismic
The cooling water systems shall be designed to withstand SL-0/SL-1 earthquakes with 0.05 g peak horizontal and vertical ground acceleration, and SL-2 earthquakes with 0.2 g peak acceleration without seismic isolation depending on the seismic importance classification described in the PSR.

(3) Flanges and Valves
Demountable flanged connections shall be used only where necessary for inspection and maintenance of the TCWS.

(4) Penetrations of the TCWS Vault
A fully welded design is mandatory in view of the required leak tightness (10% volume/day at 0.2 MPa) for the penetrations of the TCWS vault and pipe chases.

14.2.3.2 Electrical

A safety emergency power (class-III power) should be connected to the safety-related systems. Non-safety emergency power requirements apply to decay heat removal systems in CAT-II events. The low flow pumps, corresponding motor-operated valves, and circulation pumps in the HRS are therefore connected to class-III power.

All electrical equipment shall conform to the appropriate IEC standards, i.e. 11 kV, 3.3 kV, 480 V, 240 V and 120 V.

14.2.3.3 Nuclear

(1) TCWS
All loop components inside the cryostat will be all-metallic and hence should not be subject to damage due to neutron or gamma irradiation. Water will become activated and will contain activated corrosion products as well as tritium.

All loop components inside the vaults will be subject to gamma radiation from activated corrosion products and N-16, and contain tritium in the loop inventory. Instrumentation and components must therefore be designed for the expected lifetime ionising radiation dose.

(2) CCWS, CHWS, and HRS
The pipeworks shall be designed to avoid the circulation of any component cooling fluid into areas where significant neutron fields may exist. This requirement is designed to prevent the activation of corrosion inhibitors or corrosion products within the each system.

The radionuclide concentration of the blowdown system discharge in the cooling towers of the HRS shall be regularly measured. System operation shall be suspended if the concentration approaches host country discharge limits.

14.2.3.4 Assembly

The final assembly of the TCWS in the cryostat shall be under clean conditions. The design shall be based on modular units allowing maximum pre-assembly and testing in the "manufacturer's shop" thereby minimising assembly and testing time at the ITER site.

14.2.3.5 Testing

In addition to the code-prescribed tests described in section 14.3, the design shall allow the testing of flow rates to individual blanket module manifolds as well as to the divertor cassettes. Drying and leak testing/localisation of individual cassettes or module manifolds may, however, be feasible only after opening the flow and/or return pipes to these items. This avoids the use of a very large number of valves.

A CVCS serves multiple loops and the flow rates for each loop shall be confirmed by testing. The flow distribution behaviour during the switchover between loops shall be established.

14.2.3.6 Instrumentation and Control

Instrumentation shall include pressure, temperature and flow sensors to allow independent control of each separate loop and/or component for the whole cooling water system (CWS). Further, instruments shall be installed to monitor component integrity, water chemistry and activity. Modern design practice shall be applied ensuring that a high degree of in-situ calibration can be achieved.

14.2.3.7 Decommissioning

Loop components inside the cryostat will become activated by neutrons, and all loop components wetted by the coolant will become contaminated by activated corrosion products, tritium, and activated coolant. The design shall make provision for chemical cleaning of the PHTSs components and CVCSs components prior to disassembly.

14.2.3.8 Grounding/Insulation

The grounding shall be in accordance with that implemented for the tokamak and interconnecting systems. No electrical isolation is to be provided between the vacuum vessel and the PHTSs or between the cryostat and the PHTSs.

The heat dissipation of the TCWS pipework and components into the TCWS vault and the pipe chases shall be minimised by thermal insulation for heat loss reduction.

The CCWS shall be well-connected to the building grounding system. Special requirements apply to the grounding and insulation for cooling of the high voltage equipment such as the pulse power supply system and ECH&CD gyrotrons. These systems require the ability to isolate portions of the piping system from the ground grid in order to test for leakage current.

Some of the HRS branch lines into the tokamak building will require electrical isolation devices such as insulation flanges to avoid closed circuit.

14.2.3.9 Materials

The reference material for the TCWS is type 304 L stainless steel for components wetted by coolant except for sections of the in-vessel components, the vacuum vessel, the additional heating systems, the test blanket modules, and the guard pipes etc.

The elements of the CCWS and CHWS shall be carbon steel and/or stainless steel unless compelling cost or operational requirements dictate otherwise. For the high voltage cooling in the CCWS, fiber-reinforced plastic (FRP), polyvinyl chloride (PVC) and/or ceramics shall be used for insulation purposes.

The materials of construction selected for the HRS shall be compatible with the use of appropriate biocides which may be added to the working fluid.

14.2.3.10 Air Conditioning

The secondary envelope around the PHTSs and CVCSs, i.e. the TCWS vaults and the pipe chases through which the pipework will be routed to the cryostat, shall be connected to a detritiation system. The room for the drain tanks in the drain and refilling systems which are used for the drainage from the vacuum vessel after an in-vessel LOCA shall also be connected to a detritiation system. On the other hand, an air supply to allow human access into the TCWS vault is required during maintenance.

The heat dissipation of the PHTSs pipework and components into the vaults shall be minimised by thermal insulation. Nevertheless, large coolers will be required for the TCWS vault and pipe chases to keep the ambient temperature in the area to approximately 40°C.

14.2.4 Maintenance Considerations

Maintenance of the cooling water system pipework and loop components is classified for remote maintenance as RH class 3. Pipework connections to in-vessel components are defined for maintenance as part of the component.

14.2.4.1 Major Maintenance

The major maintenance requirements are;
(i) access to the TCWS vault at 24 hours after shutdown

(ii) capability for drainage, refilling and drying of in-vessel components and the vacuum vessel
(iii) shielding of high dose rate components inside the TCWS vault and pipe chases to reduce the worker's dose
(iv) emergency exits from the TCWS vault
(v) pathway for transferring parts of components
(vi) lifting devices

14.2.5 Surveillance and In-Vessel Testing

The design shall be based as far as possible on in-situ calibration of instrumentation. Routine sampling shall be required to monitor the condition of the coolant during operation. Sampling lines shall be routed to a central sampling station (see chapter 24), or allow local withdrawal.

14.2.5.1 Major Surveillance

The major surveillance requirements are;
(i) deposit in the loop
(ii) leakage from the loop
(iii) water chemistry in the loop
(iv) radioactivity in the loops of the TCWS (activated corrosion products and tritium)
(v) dose rate around the component
(vi) grounding and insulation

14.2.5.2 Major In-Service Inspection (ISI)

The major ISI functions are;
(i) integrity of the confinement,
(ii) integrity of the support system for the confinement,
(iii) degradation of cooling water system performance.

14.2.6 Quality Assurance (QA)

The PHTSs and CVCSs shall be designed, manufactured, tested, commissioned, operated, maintained and decommissioned in compliance with the ITER QA programme.

The design of the cooling water system shall be based to the largest extent possible on proven technology, and components should have a high standard of reliability with significant operation and maintenance experience. Features requiring significant R&D must be minimised or avoided. The applicable codes and standards are provided in section 14.3. Standardisation among PHTSs should be considered as much as practical.

14.2.7 Reliability Assurance

The single failure criterion shall be applied to active safety importance class items.

14.3 Codes and Standards

14.3.1 Design Code

The whole CWS shall be designed, fabricated and installed according to the codes and standards shown in Table 14-12. Some items in the table are site dependent, and must be determined considering safety importance and functions.

Table 14-12 Design Codes and Standards for ITER PHTS

Component	**Design, Manufacture, Inspect, QA, Test (1) (2) (3) (4)**	**In-service Inspection**
Vessels	VIII	API-510
Piping	B 31.3	API-570
Pumps	B73.1M / B73.2M (5)	TBD
Valves	B16.34 (6)	TBD
Supports	ASME III-NF-2	TBD
Secondary Confinement	VIII / B 31.3 / B16.34	TBD

Notes:
1. The intent is to use industry standard codes to the maximum extent possible and to supplement them as necessary with additional ITER-specific requirements that do not result in a degradation of safety. These additional requirements are to be documented and justified as part of licensing, and they will be an addition to the procurement specifications. Some examples of additional requirements are listed in notes 2-4 below.
2. Engineering analysis is needed for overpressure protection, to ensure that the dynamics of pressure/temperature/flow transients are accounted for. ASME section III-NC may be used as a guideline for developing additional requirements.
3. Quality assurance requirements or acceptance inspections may be increased in some cases, yet to be determined. An example could be the specification of cobalt content in steel, which is not a part of a section VIII material specification.
4. The loading cases analysed should be consistent with the loading categories used in ITER - categories I, II, III, and IV. Categories I and III correspond to normal and accident conditions in ASME section VIII. Higher stress allowables need to be proposed and justified for loading category IV, an extremely unlikely event, in a manner consistent with ASME section III-NC. Additional inspections may be needed to justify the higher allowables.
5. The pump standards B73.1M and B73.2M are examples that apply to particular types of centrifugal pumps. If pumps not of these types are used, other consistent requirements will be employed.
6. The valve standard B16.34 is a standard for generic flanged, threaded or welded valves. If special valves not of these types are used, other consistent requirements will be employed.

Abbreviations for Codes and Standards:
VIII: ANSI/ASME Boiler and Pressure Vessel Code, section VIII (Pressure Vessels).
B31.3: ANSI/ASME Code for Pressure Piping, Chemical Plant and Petroleum Refinery Piping , 1995 Edition.
B73.1M: ANSI/ASME Specification for Horizontal End Suction Centrifugal Pumps for Chemical Processes, 1991 Edition.
B73.2M: ANSI/ASME Specification, Vertical In-Line Centrifugal Pumps for Chemical

Processes, 1991 Edition.
B16.34: ANSI/ASME Standard, Valves - Flanged, Threaded, and Welding End, 1988 Edition.
AISC: AISC (American Institute of Steel Construction), Steel Construction Manual.
API-510: ANSI/API (American Petroleum Institute) 510, Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair and Alteration, 1989 Edition.
API-570: ANSI/API (American Petroleum Institute) 570, Piping Inspection Code: Inspection, Repair, Alterations and Rerating of In-Service Piping Systems, 1993 Edition.
III-NC: ANSI/ASME Boiler and Pressure Vessel Code, Section III Division 1 (Rules for Construction of Nuclear Power Plant Components), Subsection NC (Class 2 Components), 1995 Edition.
III-NF-2: ANSI/ASME Boiler and Pressure Vessel Code, Section III Division 1 (Rules for Construction of Nuclear Power Plant Components), Subsection NF (Class 2 Supports for NC Class 2 Components and Piping), 1995 Edition.

14.3.2 Performance Test Code

Field performance tests with no heat load shall be in accordance with ASME performance test code PTC-9-1970 or the ITER site equivalent.