Design Requirements and Guidelines Level 1

(DRG1)

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Introduction

Following on from the Plant Design Specification (PDS), which describes the externally imposed, essentially design-independent requirements, the Design Requirements and Guidelines Level 1 (DRG1) is a control document which contains:

1. Plant level (multiple systems) requirements, guidelines, reference values as well as interfaces and specifications affecting more than one system (part 1);
2. Function of systems within the entire plant (part 2).

Design requirements and guidelines affecting only each specific system by itself are described in the Design Requirements and Guidelines Level 2 (DRG2).

In several instances this document refers to its annexes which deal upon a particular subject more in depth.

Whenever possible this document will contain numeric values of parameters in tabular format.

In some occasions a parameter may be specified for more than one condition:

H value, indicates the specification for operation with Hydrogen plasmas in the initial operation/commissioning phase;

DT value, indicates the nominal design value foreseen for operation during the DT Phase;

TBA value, it is not a design requirement. It is a value whose consequences on the design need to be assessed by the designers in view of possible machine operation with or without upgrades. Upgrades that are already foreseen are specified elsewhere as design requirements.

This document can be modified, with the required management approvals, in response to design decisions.

1 Parameters and Interfaces

1.1   Machine Parameters and Configuration

The plasma size and basic parameters of the ITER device derive from both physics and engineering/technology considerations and represent a global optimisation of the device and plasma performance with a pre-determined cost target. To ensure reliable choice of the basic plasma parameters, the following physics guidelines are introduced so as to determine a nominal pulse mode operation point:

- a plasma current sufficient to provide adequate plasma energy confinement and MHD stability;
- adequate in-vessel volume for reliable power exhaust and impurity control;
- plasma energy confinement sufficient to achieve extended burn in inductively driven plasmas with Q = 10, based on empirical H-mode confinement scaling (IPB98(y,2)) with H_H factor of 1
- safety factor at the nominal plasma current $q_{95} \approx 3$;
- normalised beta $\beta_N = \beta aB/I \leq 2.5$ at the nominal plasma current;
- moderate plasma elongation $\kappa_{95} \leq 1.7$ at the nominal plasma current;
- single null divertor configuration.

The overall machine configuration (layout) and space allocation is set through configuration models which belong to the 10.XXXX series up to the pit, and 62.XXXX series for the rest of the plant.

Table 1.1-1   Basic Machine Design Parameters

Parameter	Unit	H	DT	TBA
Plasma major radius, R	m	=>	6.2	
Plasma minor radius, a	m	=>	2.0	
Plasma current, I_p [5]	M A	=>	15.0	17[1]
Additional H & CD power	MW	=>	73[2]	110[2]
Fusion power	MW	0	500[2]	700[3]
Toroidal field at major radius, B_o	T	=>	5.3	
Elongation at 95% flux, κ_{95}		=>	1.7	
Triangularity at 95% flux, δ_{95}		=>	0.33	
Plasma volume	m^3	=>	840	
Plasma surface	m^2	=>	680	
Nominal Normalised beta, β_N		1.5	2.0	2.5
Plasma nominal thermal energy	GJ	0.27	0.36	0.45
Plasma nominal magnetic energy ($\mu_0 R l_i I_p^2/4$)	GJ	=>	0.37	0.5
MHD nominal safety factor at 95% flux, q_{95}		=>	3.0	2.6
Average neutron wall load at first wall	MWm^{-2}	0	0.56	0.79
Neutron wall load at outboard FW at midplane	MWm^{-2}	0	0.78	1.09
Total average neutron fluence at the first wall	$MWam^{-2}$	0	0.3	0.5
Integrated full power operation time	h	4600		7600
Peak burn duty cycle	%	=>	25	
Nominal number of pulses		30000[4]		
Number of TF coils		18		

Parameter	Unit	H	DT	TBA
Number of CS modules			6	
Number of PF coils			6	
Vacuum vessel segmentation			9	
Divertor segmentation			54	
Number of limiters			2	

Note:

(1) This scenario is the most demanding of those to be assessed to see whether they can be accommodated within machine operation without significant additional costs.

(2) Nominal operation assumes 33MW NB plus 40 MW RF. Various configurations are considered to increase the heating power, see Section 1.11. Upgrading of additional heating power shall be accommodated with the additional investment for auxiliary systems.

(3) This high power operation would be achieved at a reduced pulse length and duty cycle so that costs should not be increased.

(4) Mostly used for fatigue assessment, the machine should be operated 30000 pulses with conditions given in the Design Scenario 1, see Section 1.3.

(5) See Section 1.7 for the reference direction.

1.2   ITER Plant Operation

Table 1.2-1   ITER Plant Operation State

ITER Operation State Plant subsystem		Construction/Long Term Maintenance (LTM)	Short Term Maintenance (STM)	Test & Conditioning Operation (TCS)	Short Term Stand-by (STS)	Plasma Operation (POS)
Duration		>30 days	1-30 days		<8 hrs	
Magnet	State	Maintenance / [Vacuum] / [Cold]	Cold / [Stand-by / [Idle]	Stand-by / [Idle/Ready for pulse]	Idle / [Ready for pulse]	Ready for pulse
	Temp.(K)	RT/[10]	5/[10]	5/[RT]	5	5
	TF current	OFF	OFF/[ON(reduced)]	OFF/[ON]	ON	ON
	PF current	OFF	OFF	OFF/[ON]	OFF	ON
Vacuum vessel						
	Pressure	Atmosphere / [Vacuum]	Vacuum	Vacuum	Vacuum	Vacuum
Fueling	State(Pellet)	Stop	Stop	Gas delivery (Injection)	Gas by-pass	Gas delivery (Injection)
	Pellet inj.	OFF	OFF	OFF/[ON]	Ready (no ice pellet)	ON (normal)
	State(Gas)	Stop	Stop	Gas delivery (Injection)	Gas by-pass	Gas delivery (Injection)
	Gas puff.	OFF	OFF	OFF/[ON]	Ready (valve closed)	ON (normal)
Wall conditioning						
	GDC	OFF	OFF	ON/OFF	OFF	OFF
	RF cleaning	OFF	OFF	ON/OFF	OFF/[ON]	OFF/[ON]
	Baking	OFF	OFF/[ON]	ON/OFF	OFF/[ON]	OFF
Cryostat						
	Pressure	Atmosphere / [Vacuum]	Vacuum	Vacuum	Vacuum	Vacuum
Thermal shield						
	Temp.(K)	RT	80	80 / RT	80	80
VVPSS	State	Vent/Normal	Normal	Normal	Normal	Normal
	Pressure	0 MPa	0 MPa	0 MPa	0 MPa	0 MPa
Tokamak pit		Open / [Closed]*	Open / Closed	Closed / [Open]	Closed	Closed
Tokamak cooling water						
	State(VV)	[OFF]/Partial maintenance	Part.maintenance /decay heat	Decay heat/Baking	Decay heat	POS(Normal)
	VV PHTS	[stop,drain]/Full,RT	Full,RT	Full,RT~100°C /Full,200°C	Full,~100°C	Full,100°C
	State(others)	[OFF] /Partial maintenance	Partial maintenance /Decay heat	Decay heat/baking	Decay heat	POS(Normal)
	Blanket PHTS	[stop,drain]/CVCS,RT	CVCS,RT/ Low,RT~100°C	Low,RT~100°C /240°C	Low/Full,~100°C	Low/Full,100°C
	Divertor PHTS	[stop,drain]/CVCS,RT	CVCS,RT/ Low,RT~100°C	Low,RT~100°C /240°C	Low/Full,~100°C	Low/Full,100°C
	Additional heating	[stop,drain]/CVCS,RT	CVCS,RT/ Low,RT~100°C	Low,RT~100°C /240°C	Low/Full,~100°C	Low/Full,100°C
	Diagnostics and others	[stop,drain]/CVCS,RT	CVCS,RT/ Low,RT~100°C	Low,RT~100°C /240°C	Low/Full,~100°C	Low/Full,100°C
	Comp. cooling	[OFF]/Ope.(Full),40°C	Ope.(Full),40°C	Ope.(Full),40°C	Ope.(Full),40°C	Ope.(Full),40°C
	Chilled water	[OFF]/Ope.(Full),5°C	Ope.(Full),5°C	Ope.(Full),5°C	Ope.(Full),5°C	Ope.(Full),5°C
	HRS	[OFF]/Ope.(Low),35°C	Ope.(Low),35°C	Ope.(Low)/[Ope.(Full)], 35°C	Ope.(Low),35°C	Ope.(Full),35°C
Vacuum pumping						
	VV	OFF/[ON]	ON	ON	ON	ON
	Cryostat	OFF/[ON]	ON	ON	ON	ON
	Roughing	OFF/[ON]	ON	ON	ON	ON
	Leak detect.	OFF/[ON]	OFF/[ON]	OFF/[ON]	OFF/[ON]	OFF/[ON]
Tritium plant						
	Tritium flow	Storage	Storage	Storage / [ON]	ON	ON
	State(ISS)	Maintenance/Shutdown	Stand-by	Stand-by	Stand-by	POS
	ISS Temp(K)	amb/20~amb	20	20	20	20
	MDS	OFF/[ON]	OFF	OFF	OFF	OFF
	WD, ADS	M/S.D/Stand-by/Ope	Ope/[Stand-by]	Ope	Ope	Ope
Cryoplant	State	OFF/Maintenance	Zero flow stand-by	Zero flow stand-by	Low LHe stand-by	Normal
Coil power supply						
	A.C Dist.	Shutdown	ON / [OFF]	ON	ON	ON
	TF P/S	Shutdown	OFF / [Ready/ON]	OFF / [Ready/ON]	ON	ON
	CS P/S	Shutdown	OFF	OFF / [Ready/ON]	Ready	ON
	PF P/S	Shutdown	OFF	OFF / [Ready/ON]	Ready	ON
	CC P/S	Shutdown	OFF	OFF / [Ready/ON]	Ready	ON
AH power supply						
	IC,EC,NB P/S	OFF	OFF	OFF/[ON]	ON	ON
SS power supply		ON/[OFF]	ON	ON	ON	ON
AH system						
	NBI	OFF/Maintenance	OFF/Maintenance	OFF/[Ready for conditioning]	Ready for Pulse	Pulse(Ready for injection, Dwell)
	NB Cryo	OFF/Maintenance	OFF/Maintenance	Normal/Slow PRS	Normal	Normal/Fast PRS
	IC H&CD	OFF	OFF/S1	OFF/[Pulse (S2-S5)]	S1	Pulse(S2-S5)

ITER Operation State Plant subsystem	Construction/Long Term Maintenance (LTM)	Short Term Maintenance (STM)	Test & Conditioning Operation (TCS)	Short Term Stand-by (STS)	Plasma Operation (POS)
Duration	>30 days	1-30 days		<8 hrs	
EC H&CD	Stop	Stop	Stop/[Pulse(HV,BM,RF)]	Ready RF	Pulse
Radiation monitoring	ON	ON	ON	ON	ON
Water distribution	ON/[OFF]	ON	ON	ON	ON
Gas distribution(Air)	ON/[OFF]	ON	ON	ON	ON
SCS, Interlock	ON	ON	ON	ON	ON
Diagnostic	OFF	OFF	OFF/[ON]	ON(Ready)	ON
FPSS	OFF	OFF	OFF/[ON(Ready)]	ON(Ready)	ON(Ready)

[ ] is optional status for their maintenance or other system's activity requirement.
"/" is OR (selection) status which depends on the specific actions.
"," is AND which needs all designated conditions.
( ) is additional description of the status.
* : Except during cask transporting.
Note:
(1) For operation states TCS, STS and POS, all applicable loading conditions and combinations as specified in the Load Specification and Combination (LS) annexed to the DRG1 should be considered.
(2) Normal transitional sequences are described in the Control System Design and Assessment (CSD) annexed to the PDD.

The following table gives bounding number of operational transition which may affect subsystem's capacity and fatigue damage.

Table 1.2-2   Number of Operational Transitions

Baking operation	200[1]
TF magnetisation	1000
VV vacuum pump-down	30[2]
Cryostat vacuum pump-down	15[3]
Magnet cooldown/warm-up	100

Note:
(1) Assuming 10 cycles of operation per year, ~10 days of wall conditioning operation and ~2 weeks of plasma operation in one cycle.
(2) Twice a year during first 5 years, once a year next 10 years and twice in the remaining years. Including 8 unscheduled maintenance of in-vessel components.
(3) Once a year during first 10 years, then once every 2 years.

1.3   Plasma Operation Scenarios

Variants of the nominal scenario are designed for plasma operation with extended-duration, and/or steady-state modes with a lower plasma current operation, with H, D, DT and He plasmas, potential operating regimes for different confinement modes, and different fuelling and particle control modes.   Flexible plasma control should allow "advanced" tokamak scenario based on active control of plasma profiles by current drive or other non-inductive means.

Four reference scenarios are identified for design purposes. Three alternative scenarios are specified for assessment purposes where it shall be investigated if and how plasma operations will be possible within the envelope of the machine operational capability with the possibility of a reduction of other concurrent requirements (e.g. pulse length).

Design scenarios:
1.   Inductive operation I: 500 MW, Q = 10, 15 MA operation with heating during current ramp-up
2.   Inductive operation II: 400 MW, Q = 10, 15 MA operation without heating during current ramp-up
3.   Hybrid operation
4.   Non-inductive operation I: weak negative shear operation

Assessed scenarios:
5.   Inductive operation III: 700 MW, 17 MA operation, with heating during current ramp-up.
6.   Non-inductive operation II: strong negative shear operation
7.   Non-inductive operation III: weak positive shear operation

All these scenarios are summarised in the following tables.

Table 1.3-1 Design Scenarios and Main Parameters (During Burn)

Parameter	1.Inductive operation I	2.Inductive operation II	3.Hybrid operation	4.Non-inductive operation I
R/a (m/m)	6.2 / 2.0	6.2 / 2.0	6.2 / 2.0	6.35 / 1.85
Volume (m^3)	831	831	831	730
Surface (m^2)	683	683	683	650
Sep. length (m)	18.2	18.2	18.2	16.9
Cross-section (m^2)	21.9	21.9	21.9	18.7
Toroidal field, B_T (T)	5.3	5.3	5.3	5.18
Plasma current, I_P (MA)	15.0	15.0	13.8	9.0
Elongation, κ_x/κ_{95}	1.85 / 1.7	1.85 / 1.7	1.85 / 1.7	2.0 / 1.85
Triangularity, δ_x/δ_{95}	0.48 / 0.33	0.48 / 0.33	0.48 / 0.33	0.5 / 0.4
Confinement time, τ_E (s)	3.4	3.7	2.7	3.1
$H_{H\text{-IPB98 (v.2)}}$	1.0	1.0	1.0	1.57
Normalised beta, β_N	2.0	1.8	1.9	3.0
Electron density, $<n_e>$ ($10^{19} m^{-3}$)	11.3	10.1	9.3	6.7
f_{He} [%]	4.4	4.3	3.5	4.1
Fusion power, P_{fus} (MW)	500	400	400	356
P_{add} (MW)	50	40	73	59
Energy multiplication, Q	10	10	5.4	6
Burn time (s)	500	400	1000[1]	3000[1]
Minimum repetition time (s)	2000	1800	4000	12000
Total heating power, P_{TOT} (MW)	151	121	154	130
Radiated power, P_{rad} (MW)	61	47	55	38
Alpha-particle power, P_α (MW)	100	80	80	71
Plasma thermal energy, W_{th} (MJ)	353	320	310	287

Note:

(1)The burn duration of reference design is 400 second. The extended burn under the hybrid and non-inductive operations shall be accommodated with the additional investment for auxiliary systems.

Table 1.3-2   Design Scenario 1: Inductive Operation I

Phase	XPF[1]	SOH[1]	SOF/B[1]	EOB[1]	EOC[1]
t (s)	30	70	100	600	660
I_P (MA)	7.5	13	15	15	12
P_{add} (MW)	0	50	50	50	0
nom. $\langle n_{e,20} \rangle$	0.25	0.4	1.15	1.15	0.4
q_{95}	5.3	3.2	3.0	3.0	6.4
q_0	1.0	1.0	1.0	1.0	1.0
nom. li	0.84	0.84	0.84	0.84	1.0
min. li	0.7	0.7	0.7	0.7	0.8
max. li	1.2	1.0	1.0	1.0	1.2
nom. β_P	0.1	0.1	0.7	0.7	0.1
max. β_P	0.1	0.1	0.8	0.8	0.1
nom. V_{loop} (V)	-	-	0.075	0.075	-

Note:

(1)XPF: X-point formation, SOH: start of heating, SOF/B: start of flat top/burn, EOB: end of burn, EOC: end of cooling

Table 1.3-3   Design Scenario 2: Inductive Operation II

Phase	XPF	SOF[1]	SOB[1]	EOB	EOC
t (s)	30	100	130	530	590
I_P (MA)	7.5	15	15	15	12
P_{add} (MW)	0	0	40	40	0
nom. $\langle n_{e,20} \rangle$	0.2	0.4	1.0	1.0	0.7
q_{95}	5.3	3.0	3.0	3.0	3.1
q_0	1.0	1.0	1.0	1.0	1.0
nom. li	0.84	0.84	0.84	0.84	1.0
min. li	0.7	0.7	0.7	0.7	0.8
max. li	1.2	1.0	1.0	1.0	1.2
nom. β_P	0.1	0.1	0.65	0.65	0.1
max. β_P	0.1	0.1	0.8	0.8	0.1
nom. V_{loop} (V)	-	-	0.075	0.075	-

Note:

(1)SOF: start of flat top, SOB: start of burn

Table 1.3-4   Design Scenario 3: Hybrid Operation

Phase	XPF	SOH	SOF/B	EOB	EOC
t (s)	30	45	100	1100	1160
I_P (MA)	7.5	9.5	13.8	13.8	11
P_{add} (MW)	0	0	73	73	0
nom. $<n_{e,20}>$	0.23	0.4	0.93	0.93	0.4
q_{95}	5.3	4.3	3.3	3.3	3.6
q_0	1.0	1.0	1.0	1.0	1.0
nom. li	0.85	0.85	0.9	0.9	1.0
min. li	0.7	0.7	0.7	0.7	0.8
max. li	1.2	1.0	1.0	1.0	1.2
nom. β_P	0.1	0.1	0.8	0.8	0.1
max. β_P	0.1	0.1	0.9	0.9	0.1
nom. V_{loop} (V)	-	-	0.056	0.056	-

Table 1.3-5   Design Scenario 4: Non-inductive Operation I

Phase	SO-ECH[1]	XPF	SOF/B	EOB	EOC
t (s)	0.2	16	40	3100[2]	3200
I_P (MA)	0.5	5	9	9	5
R/a (m/m)	7.4 / 0.8	6.2 / 2.0	6.35 / 1.85	6.35 / 1.85	6.2 / 2.0
P_{add} (MW)	6	8	59	59	0
nom. $<n_{e,20}>$	0.1	0.2	0.67	0.67	0.4
q_{95}	4	9	5.3	5.3	9
q_0	5	3	2.8	3.5	3
q_{min}	4	2.5	2.7	2.2	-
nom. li	0.8	0.8	0.6	0.7	0.9
min. li	0.6	0.6	0.6	0.6	0.6
max. li	0.9	0.9	0.9	0.9	1.2
nom. β_P	-	0.3	1.3	1.5	0.2
max. β_P	-	0.3	1.9	1.9	0.2
nom. V_{loop} (V)	-	-	0	0	-

Note:

(1)Start of EC heating

(2)The Burn duration for the reference design is 400 second. This is a design guideline for PF coils system.

Table 1.3-6   Assessed Scenarios and Main Parameters (During Burn)

Parameter	5.Inductive operation III	6.Non-inductive operation II	7.Non-inductive operation III
R/a (m/m)	6.2 / 2.0	6.35 / 1.85	6.35 / 1.85
Volume (m^3)	831	730	730
Surface (m^2)	683	650	650
Sep. length (m)	18.2	16.9	16.9
Cross-section (m^2)	21.9	18.7	18.7
Toroidal field, B_T (T)	5.3	5.18	5.18
Plasma current, I_P (MA)	17.0	9.0	9.0
Elongation, κ_x/κ_{95}	1.85 / 1.7	2.0 / 1.86	2.0 /1.86
Triangularity, δ_x/δ_{95}	0.48 / 0.33	0.5 / 0.41	0.5 / 0.41
Confinement time, τ_E (s)	3.6	3.1	3.1
$H_{H-IPB98 (v.2)}$	1.0	1.61	1.56
Normalised beta, β_N	2.2	2.9	2.9
Electron density, $<n_e>$ ($10^{19}m^{-3}$)	12.3	6.5	6.7
f_{He} [%]	5.2	4.0	4.0
Fusion power, P_{fus} (MW)	700	340	352
Heating power, P_{add} (MW)	35	60	57
Energy multiplication, Q	20	5.7	6.2
Burn time (s)	100	3000[1]	3000[1]
Minimum repetition time (s)	-	12000	12000
Total heating power, P_{TOT} (MW)	175	128	127
Radiated power, P_{rad} (MW)	70	36	35
Alpha-particle power, P_α (MW)	140	68	70
Plasma thermal energy, W_{th} (MJ)	434	287	284

Note:

(1)The burn duration of reference design is 400 second. The extended burn under the non-inductive operations shall be accommodated with the additional investment for auxiliary systems.

Table 1.3-7   Assessed Scenario 5: Inductive Operation III

Phase	XPF	SOH	SOF/B	EOB	EOC
t (s)	30	90	130	230	300
I_P (MA)	7.5	15	17	17	14
P_{add} (MW)	0	0	35	35	0
nom. $<n_{e,20}>$	0.23	0.4	1.23	1.23	0.4
q_{95}	5.3	3.0	2.7	2.7	3.1
q_0	1	1	1	1	1
nom. li	0.85	0.85	0.77	0.77	1.0
min. li	0.7	0.7	0.7	0.7	0.8
max. li	1.2	1.0	1.0	1.0	1.2
nom. β_P	0.1	0.1	0.7	0.7	0.1
max. β_P	0.1	0.1	0.8	0.8	0.1
nom. V_{loop} (V)	-	-	0.085	0.085	-

Table 1.3-8   Assessed Scenario 6: Non-inductive Operation II

Phase	SO-ECH	XPF	SOF/B	EOB	EOC
t (s)	0.1	15	40	3100	3200
I_P (MA)	0.5	5	9	9	5
R/a (m/m)	7.4 / 0.8	6.2 / 2.0	6.35 / 1.85	6.35 / 1.85	6.5 / 1.7
P_{add} (MW)	4	9	60	60	0
nom. $<n_{e,20}>$	0.1	0.2	0.65	0.65	0.4
q_{95}	6	9	5.3	5.4	4
q_0	4	2.5	2.4	5.9	3
q_{min}	4	2.5	2.2	2.3	-
nom. li	0.8	0.7	0.7	0.6	0.9
min. li	0.6	0.6	0.6	0.6	0.6
max. li	0.9	0.9	0.9	0.9	1.2
nom. β_P	-	0.3	1.4	1.5	0.2
max. β_P	-	0.3	1.9	1.9	0.2
nom. V_{loop} (V)	-	-	0	0	-

Table 1.3-9   Assessed Scenario 7: Non-inductive Operation III

Phase	SO-ECH	XPF	SOF/B	EOB	EOC
t (s)	4	16	40	3100	3200
I_P (MA)	2	5	9	9	5
R/a (m/m)	7.4 / 0.8	6.2 / 2.0	6.35 / 1.85	6.35 / 1.85	6.2 / 2.0
P_{add} (MW)	5	15	57	57	0
nom. $<n_{e,20}>$	0.1	0.2	0.67	0.66	0.4
q_{95}	4	8	5.3	5.3	8
q_0	2.5	2.2	2.6	2.7	3
q_{min}	2.5	2.2	2.7	2.2	-
nom. li	0.9	0.8	0.7	0.7	0.9
min. li	0.6	0.6	0.6	0.6	0.6
max. li	0.9	0.9	0.9	0.9	1.2
nom. β_P	-	0.3	1.4	1.5	0.2
max. β_P	-	0.3	1.9	1.9	0.2
nom. V_{loop} (V)	-	-	0	0	-

1.4 Plasma Initiation, Ramp-up, Ramp-down, and Poloidal Flux

The PF system should provide plasma initiation near the outboard first wall with a toroidal electric field of 0.3 V/m and EC assist of about 2 MW. The value of magnetic stray field at breakdown should be less that 2 mT in a region with centre located at R = 7.48 m, Z = 0.62 m and minor radius 0.8 m.

Inductive plasma current ramp-up shall be assumed to take place in an expanding-aperture limiter configuration located on the outboard first wall.

Normal plasma current ramp-down (following from EOC) in a similar contracting-aperture limiter configuration shall be assumed to be located on the outboard first wall.

The flux swing capability of the poloidal field system shall satisfy the plasma operation scenario requirements outlined in section 1.3.

Table 1.4-1 lists the assumptions on the poloidal field flux loss which should be used for design of the PF system.

Table 1.4-1   Assumptions on Resistive Consumption of Poloidal Magnetic Flux

Parameters	Unit	Value
Resistive flux loss at breakdown	Wb	10
Resistive flux loss during the plasma current ramp-up until the Start Of Heating (SOH)	Wb	$0.45\mu_0\Delta(R_pI_p)$
Resistive flux loss from SOH to Start Of Burn (SOB) for inductive scenarios	Wb	10
Resistive flux loss from SOH to Start Of Burn (SOB) for hybrid and non-inductive scenarios	Wb	17
Resistive flux loss during the plasma cooling	Wb	10
Resistive loop voltage during the plasma current ramp-down (after plasma cooling).	V	0.4

1.5 Plasma Position, Current and Shape Control

At the plasma current flattop, in the absence of fast disturbances, the plasma current shall be controlled to be less than ±2% or ±0.05 MA whichever is less restrictive.

During operation in a limiter configuration, the plasma position and shape control system shall be capable to control plasma position and shape. The plasma position shall be controlled with plasma current as low as 0.5 MA.

Diagnostics used for control of plasma current, position and shape, including vertical stabilisation, shall meet the requirements as specified in Table 1.13-2

Dynamic control of the separatrix during the power-producing phase shall minimise the recovery time for restoration of the separatrix deviations from its desired quasi-static position. Dynamic control should limit transient contact of the 10 mm SOL with the first wall surface to ≤ 1 s. The 10 mm SOL is defined as the flux surface that passes through a point 10 mm outside the separatrix at the outboard equator.

The plasma shape control system shall be able to maintain the following minimum quasi-static (time scales >10 s) clearance gaps:

Table 1.5-1 Quasi-static Shape Control Gaps

Parameters	Unit	Value
Minimum clearance between separatrix and port limiter	cm	8
Minimum clearance between 40mmSOL and first wall (unless otherwise specified) [1]	cm	8
Nominal clearance between separatrix and first wall at inboard equator	cm	16
Maximum static deviation of separatrix in divertor and baffle region	cm	6
Maximum static deviation of separatrix in antenna region	cm	4

Note:
(1) The 40 mm Scrape off layer flux line (40 mm SOL) is defined as the line that passes through a point 40 mm outside the separatrix at the outboard equator.

The control system shall be able to control the plasma current, position and shape in the presence of perturbations produced by ELMs, sawteeth, minor disruptions etc., specified for scenarios with positive magnetic shear as follows:

Table 1.5-2   Plasma Disturbances for Position and Shape Control

Minor Disruption	An instantaneous l_i drop of $0.2(l_{i0} - 0.5)$ without recovery simultaneous with β_p drop of $0.2\beta_{p0}$ followed by 3 s exponential recovery, or only β_p drop of $0.2\beta_{p0}$ followed by 3 s exponential recovery (without variation of l_i). One minor disruption should be considered during the driven burn and two minor disruptions should be considered during the plasma current ramp-up and ramp-down phases.
Compound ELMs	During the sustained burn, an instantaneous l_i drop of $0.06(l_{i0} - 0.5)$ followed by a 1 s linear recovery simultaneous with β_p drop of $0.03\beta_{p0}$ followed by 0.2 s linear recovery. The repetition time is about 10 s.
Type 1 ELMs	During the burn, an instantaneous β_p drop of $0.03\beta_{p0}$ followed by 0.1 s linear recovery with frequency 3 Hz.

The response time constant of the AC/DC converters shall be:

Table 1.5-3   Response Time Constant of AC/DC Converters

Transfer function for slow control	$e^{-0.015s} \cdot \dfrac{1}{1 + 0.015s}$
Transfer function for fast control	$e^{-0.0025s} \cdot \dfrac{1}{1 + 0.0075s}$

1.6 Single Turn Electrical Resistance

The combined toroidal electrical resistance of the VV and all in-vessel components shall be high enough to achieve initial plasma break down and current ramp-up with acceptable loss of magnetic flux, and also allow the penetration of control magnetic field with acceptable damping effect. The total combined toroidal resistance of the VV and blanket components shall be larger than 7 $\mu\Omega$. All other systems shall make a negligible contribution to the toroidal conductance.

1.7 Toroidal Field and Plasma Current Direction

The reference directionality of the toroidal current and field shall be as follows: plasma current in the clockwise direction looking from above with the same direction for the toroidal field, giving a downward (towards divertor X-point) ion grad-B drift direction.

The direction of the toroidal field and plasma current shall be reversible, in such a way that the field line maintains the same pitch angle.

1.8   Toroidal Field Ripple

The toroidal field ripple magnitude is defined as $\delta(R,Z) = (B_{max}-B_{min})/(B_{max}+B_{min})$, where B_{max} and B_{min} are maximum and minimum values of the toroidal magnetic field on the circle with coordinates (R,Z).

The ripple magnitude and distribution should cause the peak heat flux on the plasma facing components of the high-energy particles (ripple associated losses) to be less than 0.3 MW/m^2. Anyway the peak TF ripple shall be limited to 1.0%.

Ferromagnetic inserts may be used for reduction of the toroidal field ripple. Optimisation of the inserts distribution should be done for the nominal value of the toroidal magnetic field minimising the volume between the surface with $\delta = 0.1\%$ and the outer part of the reference separatrix.

1.9 Magnet Fast Discharge and Quench

Table 1.9-1   Magnet Fast Discharge and Quench Parameters

Discharge sequencing of PF, CS, CC	Simultaneous

Discharge times   CS
                                              PF
                                              CC
	7.5 s
	14 s
	20 s

Maximum time delay before resuming normal operation after fast discharge (under the assumption of no faults and at full TF)	2 days
Expected number of fast discharges during plant life	See Table 3-1 in Load Specification and Combination, annexed to DRG1.
Expected number of quench during plant life	10

1.10 Error Field Correction

To avoid locked-modes and associated disruptions, the amplitudes of n = 1, m = 1, 2 and 3 helical components of the error magnetic field shall be limited and satisfy the following criterion:

$$B_{3-\mathrm{mod}\,e} = \sqrt{0.2B_{1,1}^2 + B_{2,1}^2 + 0.8B_{3,1}^2} \leq 5 \times 10^{-5} B_{tor},$$

where $B_{1,1}$, $B_{1,2}$, $B_{1,3}$ are the amplitudes of the normal component of the helical magnetic field on the q = 2 magnetic surface, B_{tor} is the value of toroidal magnetic field in the plasma geometrical centre.

1.11 Heating and Current Drive

Plasma facing components of the RF H&CD system port plugs and test blanket modules shall not be in the line of sight of a neutral beam.

Table 1.11-1 Heating and Current Drive Parameters

	Unit	H	DT
EC power for initial breakdown assist[4]	MW	=>	2
EC frequency for initial breakdown assist	GHz	=>	~120
IC H&CD power[3,7]	MW	=>	20-40
Resonance frequency for second tritium harmonic and ^{3}He minority heating	MHz	=>	53
IC resonance frequency for D-minority heating	MHz	=>	40
	MHz	=>	56
IC number of allocated equatorial ports[3]		=>	1-2
EC H&CD power[3] [4] [5]	MW	=>	20-40
EC H&CD frequency	GHz	=>	170
EC number of allocated top ports[6]		=>	3
EC number of allocated equatorial ports		=>	1
LH H&CD power[3]	MW	0	0-40
LH H&CD frequency	GHz	=>	5
LH H&CD # of allocated equatorial ports[3]		=>	0-2
NB H&CD injection power[3]	MW	27	33-50
NB H&CD beam energy	MeV	0.8	1
NB H&CD # of allocated equatorial ports[3]		=>	2-3
NB tangency radius[1]	m	=>	5.276
NB lowest beam axis level at the tangency point[1]	mm	=>	-420
NB highest beam axis level at the tangency point[1]	mm	=>	+154
NB e-folding length of beam profile at the tangency point in vertical direction, B [2]	m	=>	0.32
NB e-folding length of beam profile at the tangency point in horizontal direction, A [2]	m	=>	0.22

Note:

(1) The parameters refer to beam aiming at the first wall between ports (no beam strike area in the ports).

(2) Beam profile at tangency point described as $P(x,y) = Ce^{-\left[\left(\frac{x}{A}\right)^2 + \left(\frac{y}{B}\right)^2\right]}$

(3) The lower value of the range represents the foreseen design requirement. The upper value of the range represents a design requirement in the event of an upgrade, in other words the design shall be upgradable (with additional investments) to the upper value of the range.

The upgrade of the LH, IC, and NB cannot be all carried out at the same time, as only 2 upgrades are required and compatible with the port allocation. In all cases no more than ~130 MW of installed power will be present and no more than 110 MW will be available at the same time to the scenario.

(4) The same Equatorial port launcher will be used by the gyrotrons employed for EC H&CD and EC breakdown assist.

(5) EC H&CD gyrotrons will be able to use, by means of switches, both equatorial and top ports launchers.

(6) To provide, through steered RF beams, selective heating and current drive of island structures caused by NTMs (neo-classical tearing modes), thereby mitigating their effect on plasma stability and energy confinement.

(7) The conditions pertinent to the IC heating shall be obtained with 70-100% of the full toroidal field, a volume averaged density between $2x10^{19}$ and $20x10^{19}$, and a volume averaged electron temperature below 12 keV.

Table 1.11-2 AH Possible Maximum Upgrade Scenarios

	Startup		Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Power [MW]	No. of Equat ports	Power [MW]	No. of Equat ports	Power [MW]	No. of Equat ports	Power [MW]	No. of Equat ports	Power [MW]	No. of Equat ports
NB	33	2	33	2	50	3	50	3	50	3
IC	20	1	40	2	20	1	40	2	20	1
EC	20	1	40	1[1]	40	1[1]	40	1[1]	20	0[1]
LH	0	0	20	1	20	1	0	0	40	2
Total Installed	73	4	133	6	130	6	130	6	130	6

Note:

(1) EC H&CD will be able to use 3 allocated top ports for the power upgrade. No additional equatorial ports are therefore foreseen for this system.

1.12 Port Allocation

Table 1.12-1   AH Upgrade Scenarios and Equatorial Port Allocation

Port	Startup	Scenario 1	Scenario 2	Scenario 3	Scenario 4
#1		(Test Blanket)	(Test Blanket)	(Test Blanket)	(Test Blanket)
#2		(Test Blanket)	(Test Blanket)	(Test Blanket)	(Test Blanket)
#3 (RH port)	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics
#4 (small rad.)	D-NB[4]	D-NB	D-NB	D-NB	D-NB
#4 (tangential)	H-NB[4]	H-NB	H-NB	H-NB	H-NB
#5 (tangential)	H-NB	H-NB	H-NB	H-NB	H-NB
#6 (tangential)		Diagnostics	H-NB	H-NB	H-NB
#7	Closed[1]	Closed[1]	Closed[1]	Closed[1]	Closed[1]
#8 (RH port)	Limiter, Diagnostics[2]	Limiter, Diagnostics[2]	Limiter, Diagnostics[2]	Limiter, Diagnostics[2]	Limiter, Diagnostics[2]
#9	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics
#10	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics
#11	Diagnostics[3]	IC	Diagnostics[3]	Diagnostics[3]	Diagnostics[3]
#12 (RH port)	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics
#13	IC	IC	IC	IC	IC
#14	EC	EC	EC	EC	LH
#15		LH	LH	IC	LH
#16	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics
#17 (RH port)	Limiter, Diagnostics[2]	Limiter, Diagnostics[2]	Limiter, Diagnostics[2]	Limiter, Diagnostics[2]	Limiter, Diagnostics[2]
#18		(Test Blanket)	(Test Blanket)	(Test Blanket)	(Test Blanket)

Note:

(1) With small VV penetrations available for diagnostics in the case that Scenario 1 is chosen.

(2) Minimal diagnostic systems with no penetration through the first wall.

(3) No diagnostics necessary for machine protection and basic plasma operation should be located in this port since they may have to be relocated for upgrade Scenario 1.

(4) D-NB: Diagnostics NB, H-NB: Heating NB

Table 1.12-2 Port Allocation at Lower and Upper Level

#	Lower level	Upper level
1	Pellet injection Gas injection MDS[2]	Diagnostics
2	Cryopump Glow discharge IVV[2]	Diagnostics
3	RH[2] Diagnostic cassette/rack	Gas injection Diagnostics[1]
4	Cryopump Diagnostic cassette	Diagnostics
5	Cryopump Glow discharge IVV	Diagnostics[1]
6	Cryopump	Diagnostics[1] Gas injection
7	Pellet injection Gas injection MDS	Diagnostics[1]
8	Cryopump Glow discharge IVV	Diagnostics
9	RH Diagnostic cassette/rack	Gas injection Diagnostics
10	Cryopump	Diagnostics
11	Cryopump Glow discharge IVV	Diagnostics
12	Diagnostic cassette/rack	EC Gas injection
13	Pellet injection Gas injection MDS	EC
14	Cryopump Glow discharge IVV	Diagnostics
15	RH Diagnostic cassette/rack	EC Gas injection
16	Cryopump Diagnostic cassette	Diagnostics
17	Cryopump Glow discharge IVV	Diagnostics
18	Diagnostic cassette/rack	Diagnostics Gas injection

Note:
(1)Neutron camera with no plug.
(2)MDS: maintenance detritiation system, IVV: in-vessel viewing system,
  RH: remote handling

1.13 Plasma Measurements

Table 1.13-1 List of Required Plasma Measurements classified by their Operational Role

Group 1a Machine Protection and Basic Control	Group 1b Advanced Control	Group 2 Evaluation and Physics
• Shape/Position • Vertical Speed • Locked Modes • I_p, q(a), q(95%), β • m = 2 Mode, I_{halo}, V_{loop} • Impurity and D, T Influx (main plasma & divertor) • Runaway Electrons • Line-Averaged Density • Divertor Detachment (J_{sat} (divertor)) • Surface Temperature (divertor plates & FW) • Radiation Power from Core, X-point and Divertor • Fusion Power • n_T/n_D in Plasma Core • Z_{eff} Line-Average • H/L Mode Indicator • ELMs (typ) • Gas Pressure (divertor & duct) • Gas Composition (divertor & duct) • Toroidal Magnetic Field	• Low m/n MHD Activity • Shape/Position (very long pulse) • Neutron Profile • α-Source Profile • n_{He} Profile • Plasma Rotation (toroidal & poloidal direction) • Impurity Profile • T_e Profile (core) • n_e Profile (core) • T_i Profile (core) • n_e Profile (edge) • q Profile • P_{rad} Profile • Z_{eff} Profile • n_{He} (divertor) • Heat Deposition Profile in Divertor • Divertor Ionisation • Front Position • Neutral Density (near wall) • Particle Source • n_e, T_e (divertor) • Impurity & D, T Influxes in Divertor with Spatial Resolution • Alpha Loss • Neutron Fluence • ELMs • Sawteeth • NTMs • RWMs • Erosion (plate)	• Fishbones • TAE Modes • Confined α-Particles • $n_T/n_D/n_H$ (edge) • $n_T/n_D/n_H$ (divertor) • T_e Profile (edge) • n_e, T_e Profile (X-point) • n_e, T_e (plate) • T_i in Divertor • Plasma Flow (divertor) • Pellet Ablation • T_e Fluctuations • n_e Fluctuations • Radial E Field and E Fluctuations • Edge Turbulence. • MHD Activity in Plasma Core

Table 1.13-2 Requirements for Plasma and First Wall Measurements: Parameter Ranges, Target Measurement Resolutions and Accuracy

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	RESOLUTION Time or Freq.	RESOLUTION Spatial or Wave No.	ACCURACY
1. Plasma Current	I_p	Default	$0 - 1$ MA	1 ms	Integral	10 kA
			$1 - 17.5$ MA	1 ms	Integral	1 %
		I_p Quench	$20 - 0$ MA	0.1 ms	Integral	30 % + 10 kA
2. Plasma Position and Shape	Main plasma gaps, Δ_{sep}	$I_p > 2$ MA, full bore	-	10 ms	-	1 cm
		I_p Quench	-	10 ms	-	2 cm
	Divertor channel location (r dir.)	Default	-	10 ms	-	1 cm
		I_p Quench	-	10 ms	-	2 cm
	dZ/dt of current centroid	Default	$0 - 5$ m/s	1 ms	-	0.05 m/s (noise) + TBD % (absolute)
3. Loop Voltage	V_{loop}	Default	$0 - 30$ V	1 ms	4 locations	5 mV
		I_p Quench	$0 - 500$ V	1 ms	4 locations	10 % + 5 mV
4. Plasma Energy	β_p	Default	$0.01 - 3$	1 ms	Integral	5 % at $\beta_p=1$
		I_p Quench	$0.01 - 3$	1 ms	Integral	$\sim 30\%$
5. Radiated Power	Main Plasma P_{rad}	Default	TBD $- 0.3$ GW	10 ms	Integral	10 %
	X-point / MARFE region P_{rad}	Default	TBD $- 0.3$ GW	10 ms	Integral	10 %
	Divertor P_{rad}	Default	TBD $- 0.3$ GW	10 ms	Integral	10 %
	Total P_{rad}	Disruption	TBD $- 50$ GW	3 ms	Integral	20 %
6. Line-Averaged Electron Density	$\int n_e\,dl / \int dl$	Default	$1\cdot10^{18} - 4\cdot10^{20}$ /m^3	1 ms	Integral	1 %
		After killer pellet	$8\cdot10^{20} - 2\cdot10^{22}$ /m^3	1 ms	Integral	100 %
7. Neutron Flux and Emissivity	Total neutron flux		$1\cdot10^{14} - 5\cdot10^{20}$ n/s	1 ms	Integral	10 %
	Neutron / α source		$1\cdot10^{14} - 4\cdot10^{18}$ n/m^3/s	1 ms	a/10	10 %
	Fusion power		TBD $- 1$ GW	1 ms	Integral	10 %
	Fusion power density		TBD $- 10$ MW/m^3	1 ms	a/10	10 %
8. Locked Modes	Br(mode)/Bp		$10^{-4} - 10^{-2}$	1 ms	(m,n) = (2,1)	30 %
9. Low (m,n) MHD Modes, Sawteeth, Disruption Precursors	Mode complex amplitude at wall		TBD	DC – 3 kHz	$(0,0) < (m,n) < (10,2)$	10 %
	Mode – induced temperature fluctuation		TBD	DC – 3 kHz	$(0,0) < (m,n) < (10,2)$ $\Delta r = a /30$	10 %
	Other mode parameters TBD					
10. Plasma Rotation	VTOR		$1 - 200$ km/s	10 ms	a/30	30 %
	VPOL		$1 - 50$ km/s	10 ms	a/30	30 %
11. Fuel Ratio in Plasma Core	nT/nD	r/a < 0.9	$0.1 - 10$	100 ms	a /10	20 %
12. Impurity Species Monitoring	Be, C rel. conc.		$1\cdot10^{-4} - 5\cdot10^{-2}$	10 ms	Integral	10 % (rel.)
	Be, C influx		$4\cdot10^{16} - 2\cdot10^{19}$ /s	10 ms	Integral	10 % (rel.)
	Cu rel. conc.		$1\cdot10^{-5} - 5\cdot10^{-3}$	10 ms	Integral	10 % (rel.)
	Cu influx		$4\cdot10^{15} - 2\cdot10^{18}$ /s	10 ms	Integral	10 % (rel.)
	W rel. conc.		$1\cdot10^{-6} - 5\cdot10^{-4}$	10 ms	Integral	10 % (rel.)
	W influx		$4\cdot10^{14} - 2\cdot10^{17}$ /s	10 ms	Integral	10 % (rel.)
	Extrinsic(Ne,Ar, Kr) rel. conc.		$1\cdot10^{-4} - 2\cdot10^{-2}$	10 ms	Integral	10 % (rel.)
	Extrinsic (Ne, Ar, Kr) influx		$4\cdot10^{16} - 8\cdot10^{18}$ /s	10 ms	Integral	10 % (rel.)

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	RESOLUTION		ACCURACY
				Time or Freq.	Spatial or Wave No.	
13. Zeff(Line-averaged)	Zeff		1 – 5	10 ms	Integral	20 %
14. H-mode: ELMs and L-H Transition Indicator	ELM D_α bursts	Main Plasma	–	0.1 ms	One site	–
	ELM density transient	r/a > 0.9	TBD	TBD	TBD	TBD
	ELM temperature transient	r/a > 0.9	TBD	TBD	TBD	TBD
	L-H D_α step	Main Plasma		0.1 ms	One site	–
	L-H Pedestal formation (ne, Te)	r/a > 0.9	–	0.1 ms	–	TBD
15. Runaway Electrons	E_{max}		1 – 100 MeV	10 ms	–	20 %
	$I_{runaway}$	After Thermal quench	$(0.05 – 0.7) \cdot I_p$	10 ms		30 % rel
16. Divertor Operational Parameters	Max. surface temperature		200 – 2500°C	2 ms	–	10 %
	Real-time net erosion		0 – 3 mm	1 s	1 cm	10 %
	Gas pressure		$1 \cdot 10^{-4}$ – 20 Pa	50 ms	Several points	20 % during pulse
	Gas composition	A = 1-100 ΔA = 0.5	TBD	1 s	Several points	20 % during pulse
	Position of the ionisation front		0 – TBD m	1 ms	10 cm	–
17. First Wall (FW) Visible Image & Wall Temperature	FW image		TBD	100 ms	TBD	–
	FW surface temperature		200 – 1500°C	10 ms	TBD	20°C
18. Gas Pressure and Composition in Main Chamber	Gas pressure		$1 \cdot 10^{-4}$ – 20 Pa	1 s	Several points	20 % during pulse
	Gas composition	A = 1-100 ΔA = 0.5	TBD	10 s	Several points	50 % during pulse
19. Gas Pressure and Gas Composition in Ducts	Gas pressure		< 7 kPa	100 ms	Several points	20 % during pulse
	Gas composition	A = 1-100 ΔA = 0.5	TBD	1 s	Several points	20 % during pulse
20. In-Vessel Inspection	Wall image		100 % coverage of FW and divertor	–	1 mm	
21. Halo Currents	Poloidal current	In disruption	$0 – 0.2\ I_p$	1 ms	9 sectors	20 %
22. Toroidal Magnetic Field	B_T		2 – 5.5 T	1 s	2 locations x 2 methods	0.1 %
23. Electron Temperature Profile	Core T_e	r/a < 0.9	0.5 – 30 keV	10 ms	a/30	10 %
	Edge T_e	r/a > 0.9	0.05 – 10 keV	10 ms	0.5 cm	10 %
24. Electron Density Profile	Core N_e	r/a < 0.9	$3 \cdot 10^{19} – 3 \cdot 10^{20}$ /m^3	10 ms	a/30	5 %
	Edge N_e	r/a > 0.9	$5 \cdot 10^{18} – 3 \cdot 10^{20}$ /m^3	10 ms	0.5 cm	5 %
25. Current Profile	q(r)	Physics study	0.5 - 5	10 ms	a/20	10 %
			5 – TBD	10 ms	a/20	0.5
	r(q=1.5,2)/a	NTM feedback	0.3 – 0.9	10 ms	–	5 cm / a
	r(q$_{min}$)/a	Reverse shear control	0.3 – 0.7	1 s	–	5 cm / a
26. Z_{eff} Profile	Z_{eff}	Default	1-5	100 ms	a/10	10 %
		Transients	1-5	10 ms	a/10	20 %
27. High Frequency Macro Instabilities (Fishbones, TAEs)	Fishbone–induced perturbations in B,T,n		TBD	0.1 –10 kHz	(m,n) =(1,1)	–
	TAE mode – induced perturbations in B,T,n		TBD	30 –300 kHz	n = 10 - 50	–

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	RESOLUTION		ACCURACY
				Time or Freq.	Spatial or Wave No.	
28. Ion Temperature Profile	Core T_i	$r/a < 0.9$	$0.5 - 50$ keV	100 ms	$a/10$	10 %
	Edge T_i	$r/a > 0.9$	$0.05 - 10$ keV	100 ms	TBD	10 %
29. Core He Density	n_{He}/n_e	$r/a < 0.9$	$1 - 20$ %	100 ms	$a/10$	10 %
30. Confined Alphas	Energy spectrum	Energy resolution TBD	$(0.1 - 3.5)$ MeV	100 ms	$a/10$	20 %
	Density Profile		$(0.1 - 2)\ 10^{18}/m^3$	100 ms	$a/10$	20 %
31. Escaping Alphas	First wall flux	Default	TBD $- 2$ MW/m^3	100 ms	$a/10$ (along poloidal direction)	10 %
		Transients	TBD $- 20$ MW/m^3	10 ms	TBD	30 %
32. Impurity Density Profile	Fractional content, $Z<=10$	$r/a < 0.9$	$0.5 - 20$ %	100 ms	$a/10$	20 %
		$r/a > 0.9$	$0.5 - 20$ %	100 ms	5 cm	20 %
	Fractional content, $Z>10$	$r/a < 0.9$	$0.01 - 0.3$ %	100 ms	$a/10$	20 %
		$r/a > 0.9$	$0.01 - 0.3$ %	100 ms	5 cm	20 %
33. Fuel Ratio in the Edge	n_T/n_D	$r/a > 0.9$	$0.1 - 10$	100 ms	Radial integral	20 %
	n_H/n_D	$r/a > 0.9$	$0.01 - 0.1$	100 ms	Radial integral	20 %
34. Neutron Fluence	First wall fluence		$0.1 - 1$ MWy / m^2	10 s	TBD	10 %
35. Impurity and D,T Influx in Divertor	$\Gamma_{Be}, \Gamma_C, \Gamma_W$		$10^{17} - 10^{22}$ at/s	1 ms	5 cm	30 %
	Γ_D, Γ_T		$10^{19} - 10^{25}$ at/s	1 ms	5 cm	30 %
36. Plasma Parameters at the Divertor Targets	Ion flux		$10^{19} - 10^{25}$ ions/s	1 ms	0.3 cm	30 %
	n_e		$10^{18} - 10^{22}$ /m^3	1 ms	0.3 cm	30 %
	T_e		1 eV $-$ 1 keV	1 ms	0.3 cm	30 %
37. Radiation Profile	Main plasma P_{rad}		$0.01 - 1$ MW/m^3	10 ms	$a/15$	20 %
	X-point/MARFE region P_{rad}		TBD $- 300$ MW/m^3	10 ms	$a/15$	20 %
	Divertor P_{rad}		TBD $- 100$ MW/m^3	10 ms	5 cm	30 %
38. Heat Loading Profile in Divertor	Surface temperature		$200 - 2500°C$	2 ms	3 mm	10 %
	Power load	Default	TBD $- 25$ MW/m^2	2 ms	3 mm	10 %
		Disruption	TBD $- 5$ GW/m^2	0.1 ms	TBD	20 %
39. Divertor Helium Density	n_{He}		$10^{17} - 10^{21}$ /m^3	1 ms	$-$	20 %
40. Fuel Ratio in the Divertor	n_T/n_D		$0.1 - 10$	100 ms	integral	20 %
	n_H/n_D		$0.01 - 0.1$	100 ms	integral	20 %
41. Divertor Electron Parameters	n_e		$10^{19} - 10^{22}$ /m^3	1 ms	10 cm along leg, 3 mm across leg	20 %
	T_e		$0.3 - 200$ eV	1 ms	10 cm along leg, 3 mm across leg	20 %
42. Ion Temperature in Divertor	T_i		$0.3 - 200$ eV	1 ms	10 cm along leg, 3 mm across leg	20 %
43. Divertor Plasma Flow	V_p		TBD $- 10^5$ m/s	1 ms	10 cm along leg, 3 mm across leg	20 %
44. n_H/n_D Ratio in Plasma Core	n_H/n_D		$0.01 - 0.1$	100 ms	$a/10$	20 %
45. Neutral Density between Plasma and First Wall	D/T influx in main chamber		$10^{18} - 10^{20}$ at/m^2/s	100 ms	Several poloidal and toroidal locations	30 %

1.14 Safety

Safety requirements at this DRG level are specified in the Plant Safety Requirements (PSR) annex of this document.

1.15 Static Heat Loads and Heat Transfer Specifications

Table 1.15-1 Static Heat Loads Specification (Nuclear)

Parameters	Unit	H	DT	TBA
Total heat from plasma to in-vessel components [1]	MW	73	812	1090
Maximum power excursion	%		20	
Power excursion duration	s		10	
Maximum power to SOL [2]	MW	50	136	<= [4]
Maximum radiated power to FW [3]	MW	50	136	<= [4]

Note :

(1) Includes a neutron energy multiplication factor of 1.5 and 5% error for fusion power measurement.

(2) For an upper bound, 75 % of the total thermal power is assumed to flow to the SOL.

(3) For an upper bound, 75 % of the total thermal power is radiated to the FW.

(4) 700 MW operation can be performed to limit other operation conditions such as short burn time etc. Another important condition is to restrict the thermal heat loads to the divertor and first wall.

Table 1.15-2 Static Heat Loads Specification for Components

Parameters	Unit	H	DT	TBA
Maximum power to limiters during start up	MW		15[1]	
Maximum thermal power to divertor (total)	MW		See "Max power to SOL" in Table 1.15-1	
Maximum fraction of thermal power to outboard divertor			2/3	
Maximum fraction of thermal power to inboard divertor			1/2	
Localised MARFEs radiated heat flux to baffle region FW, peak value	MW/m^2		1.3	
Duration of MARFE	s		~ 10	
Alpha-particle losses peak heat loads in outboard equator	MW/m^2	0	0.1	0.3

Note:

(1) 15 MW is total power to the limiters. Protruding limiter may receive maximum power of 9 MW.

Table 1.15-3 Static Heat Loads Specification for In-vessel Cooling Systems

Parameters	Unit	H	DT	TBA
Maximum power to vacuum vessel cooling system[1]	MW	0	10	14
Maximum power to blanket cooling system [2]	MW	55	690	875
Maximum power to divertor cooling system including limiter [3]	MW	50	202	223

Note:

(1) In the ITER geometry, 1.6% of neutron energy is absorbed at the VV.

(2) In the ITER geometry, 88% of neutron energy is absorbed at the blankets.

(3) In the ITER geometry, 9% and 1.4% of neutron energy are absorbed at the divertors and limiters, respectively.

Table 1.15-4 Static Heat Loads Specification (Auxiliary)

Parameters	Unit	H	DT
Max power to EC cooling [1]	MW	30	60
Max power to IC cooling [1]	MW	10.8	21.6
Max power to LH cooling [1]	MW	0	(2)
Max power to NB cooling [1]	MW	~77[3] [65.6(LV)] [11.2(HV)]	~102[4] [86.9(LV)] [15.3(HV)]
NB, Power to be removed from high voltage components per one NB injector	MW	HNB	4.1
		DNB	3.0
NB, Power to be removed from low voltage components per one NB injector	MW	HNB	21.3(injection) + 19.6(conditioning)
		DNB	1.8(injection) + 1.75(conditioning)
Integrated nuclear heating to one duct and liner	kW	0	110
Peak nuclear heating to the duct/duct liner	kW/m	0	100
NB, integrated beam power to 1 duct liner	kW	700	
NB, peak beam power density to duct liner	MW/m^2	0.1	
NB, max power density at far wall under normal conditions	MW/m^2	1	
Total power to component cooling water system	MW	~76	~120
Total power to chilled water system	MW	~44	~49

Note:

(1) Cooling water system relating to the H&CD system should be designed to be capable of removing the heat from each system at upgraded performance.

(2) Included in EC and IC cooling capacity.

(3) Two HNB and DNB injectors are foreseen in the Hydrogen phase at the maximum, according to Note (1) above.

(4) Installation of the third HNB injector foreseen sometime in the DT phase, and hence, 3 HNB and DNB are counted as the maximum.

Table 1.15-5 Heat Loads Specification (Magnet System)

Parameters	Unit	H	DT	TBA
Operating condition total nuclear heating to TF coils, total during burn	kW	0	13.7	
Operating condition total nuclear heating to TF coils, inboard legs	kW	0	9.93	
Heat load radiated to magnet system from thermal shields, normal conditions	kW	=>	5.6	
Heat load radiated to magnet system from thermal shields, baking conditions	kW	=>	12.1	

Averaged pulsed heat load on magnet system (excluding heat loads of joints in the CS, PF coils and CCs)	kW		10.3
Averaged heat load of joints (all coils)	kW		1.13
Static heat load on magnet system, nominal conditions (excluding heat load of TF coil joints)	kW		11.2
Heat load conducted to TF cases through supports of VV, VVTS and magnet system, normal conditions	kW		3.8
Heat load conducted to TF cases through supports of VV, VVTS and magnet system, baking conditions	kW		4.1

Note:

Specifications of heat loads to structures cooled at cryogenic temperature shall be considered as the nominal value for the heat removal systems (e.g. the cryoplant) and as a maximum allowable value for the shielding (e.g. thermal and nuclear shields) systems.

Table 1.15-6 Cooling Conditions

Parameters	Unit	H	DT	TBA
Vacuum Vessel				
Operation, nominal inlet pressure	MPa		~1.1	
Operation, max. cooldown time to maintenance temperature (50°)	h		24	
Operation, nominal inlet temperature	°C		100	
Baking, maximum inlet temperature	°C		200	
Baking, maximum pressure	MPa		~2.6	
Baking, maximum vessel heat-up time from RT	h		< 100	
Baking, maximum vessel heat-up rate	°C/h		5	
Baking, maximum cooldown time to operation temp.	h		24	
Blanket				
Operation, nominal inlet pressure	MPa		3.0	
Operation, nominal inlet temperature	°C		100	
Baking, maximum inlet pressure	MPa		5.0	
Baking, maximum inlet temperature	°C		240	
Divertor				
Operation, nominal inlet pressure	MPa		4.2	
Operation, nominal inlet temperature	°C		100	
Baking, maximum inlet pressure	MPa		5.0	
Baking, maximum inlet temperature	°C		240	
Circulating Water System				
Nominal feed temperature	°C		< 35	
Maximum return temperature	°C		75	

Table 1.15-7 Cooling Conditions (Auxiliary)

Parameters	Unit	H	DT	TBA
RF Systems				
IC MTL, nominal inlet temperature	°C		30-40	
IC MTL, max. inlet-outlet temperature difference	°C		< 35	
IC MTL, coolant pressure	MPa		< 0.1	
IC tubes, nominal inlet temperature	°C		40	
IC tubes, nominal outlet temperature	°C		70	
IC tubes, nominal inlet pressure	MPa		0.3	
EC gyrotrons, nominal inlet temperature	°C		40	
EC gyrotrons, maximum outlet temperature	°C		70	
EC gyrotrons, nominal inlet pressure	MPa		0.6	
NBI				
Low V parts, NB, nominal inlet temperature	°C		80	
Low V parts, NB, nominal inlet pressure	MPa		2	
Low V parts, NB, nominal pressure drop	MPa		1	
Low V parts coolant flow for one NB injector	kg/s		225 (injection) + 153 (conditioning)	
High V parts, NB, nominal inlet temperature	°C		30	
High V parts, NB, nominal inlet pressure	MPa		2	
High V parts, NB, nominal pressure drop	MPa		1	
High V parts coolant flow (for one NB injector)	kg/s		24	

Table 1.15-8 Cooling Conditions (Cryogenically Cooled Systems)

Parameters	Unit	H	DT	TBA
Thermal Shield (TS)				
TS nominal inlet temperature	K		80	
TS nominal inlet pressure	MPa		1.8	
VV TS, nominal outlet temperature	K		100	
VV TS, average heat load	kW		135	
VV TS, nominal outlet temperature during VV baking	K		121	
VV TS, average heat load on 80K cryoplant during VV baking	kW		277	
Cryostat TS, nominal outlet temperature	K		95	
Cryostat TS, average heat load on 80K cryoplant	kW		47	
Transition TS, nominal outlet temperature	K		95	
Transition TS, average heat load on 80K cryoplant	kW		170	
Transition TS, nominal outlet temperature during VV baking	K		119	
Transition TS, average heat load on 80K cryoplant during VV baking	kW		375	
VV support TS, nominal outlet temperature	K		100	
VV support TS, average heat load on 80K cryoplant	kW		19	
VV support TS, nominal outlet temperature during VV baking	K		110	

Parameters	Unit	H	DT	TBA
VV support TS, average heat load on 80K cryoplant during VV baking	kW		27	
Gravity support TS, nominal outlet temperature	K		100	
Gravity support TS, average heat load on 80K cryoplant	kW		13	
Magnet System				
Windings				
Windings - inlet temperature	K		4.35 - 4.5	
Windings - inlet pressure	MPa		0.6	
TF coils - flow rate	kg/s		2 - 3	
TF coils - pressure drop	MPa		0.08 - 0.15	
CS - flow rate	kg/s		2.0	
CS - pressure drop	MPa		0.1	
PF coils - flow rate	kg/s		1.8	
PF coils - pressure drop	MPa		0.10	
Correction coils - flow rate	kg/s		0.2	
Correction coils - pressure drop	MPa		0.10	
Structures				
Structures - inlet temperature	K		4.35 - 5.0	
Structures - Inlet Pressure	MPa		0.6	
Structures - flow rate	kg/s		4.5	
Structures - pressure drop	MPa		0.04	
Current Leads				
Current leads - inlet temperature	K		4.5	
Current leads - inlet pressure	MPa		0.6	
TF coils - flow rate	kg/s		0.061	
Correction coils - flow rate	kg/s		0.004	
PF coils - flow rate	kg/s		0.016	
CS - flow rate	kg/s		0.016	
Backup after PF Module Fault Condition				
PF1-PF6, backup condition after double pancake bypass, nominal inlet temperature	K		4.0	
PF1-PF6, backup condition after double pancake bypass, nominal inlet pressure	MPa		0.6	
Vacuum Pumping				
Torus cryopumps				
Nominal inlet temperature	K		4.5	
Nominal inlet pressure	MPa		0.5	
Nominal pressure drop	MPa		0.035	
Nominal He mass flow rate	kg/s		1.2	
Average refrigeration load on 4.5K cryoplant	kW		1.0	
Average liquefaction load on 4.5K cryoplant for fast cool-down during regeneration	kg/s		0.06	
Average refrigeration load on 80K cryoplant	kW		70	
Cryostat cryopumps				
Nominal inlet temperature	K		4.5	

Parameters	Unit	H	DT	TBA
Nominal inlet pressure	MPa		0.4	
Nominal pressure drop	MPa		0.035	
Nominal He mass flow rate	kg/s		0.018	
Average refrigeration load on 4.5K cryoplant	kW		50	
Average liquefaction load on 4.5K cryoplant for cool-down during regeneration	kg/s		0.03	
Average refrigeration load on 80K cryoplant	kW		115	
NB cryopumps				
Nominal inlet temperature	K		4.5	
Nominal inlet pressure	MPa		0.5	
Nominal pressure drop	MPa		0.035	
Nominal He mass flow rate	kg/s		0.09	
Average refrigeration load on 4.5K cryoplant	kW		1.35	
4.5K He storage tank capacity for the replaced cold helium during regeneration	kg		42	
Liquefaction load on 4.5K cryoplant for fast cool-down during regeneration (extra storage capacity)	kg		25	
Average refrigeration load on 80K cryoplant	kW		108	
Average refrigeration load on 80K cryoplant during regeneration	kW		200	
Fuelling				
Pellet units, average liquefaction load on 4.5K cryoplant	kg/s		0.002	
Additional Heating				
ECH & CD gyrotrons, average liquefaction load on 4.5K cryoplant	kg/s		TBD	

1.16 Transient Heat Loads

The plasma facing components must allow transient heat loads during disruptions and VDEs. Their specification from the mechanical loads standpoint can be found in the Load Specification and Combination (LS), which is annexed to DRG1.

Table 1.16-1 Heat Load Conditions during VDEs

Parameters	Unit	H	DT	TBA
Plasma thermal energy	GJ		0.36	
Magnetic energy	GJ		0.37	
Energy partition to first wall as conduction	%		50-80	
Energy partition to first wall as radiation	%		50-80	
Direction of movement	-		Up or down	
Peak energy deposition to first wall	MJ/m^2		60	
Duration of the contact with first wall	s		0.2	
Number of events	-		See LS document	

Table 1.16-2 Heat Load Conditions during Disruptions

Parameters	Unit	H	DT	TBA
Thermal energy during thermal quench phase	GJ		0.35	
Energy quench time	ms		1	
Peak energy deposition to first wall	MJ/m^2		0.36	
Peak energy deposition to divertor	MJ/m^2		12	
Energy fraction on first wall as radiation	%		≤ 30	
Energy fraction on divertor target as conduction	%		≤ 100	
Energy fraction on inner target of divertor	%		≤ 80	
Energy fraction on outer target of divertor	%		≤ 80	
Expansion factor for width of scrape-off layer	-		3	
Peaking factor for radiation to divertor targets	-		3	
Peaking factor for radiation to first wall	-		3	
Number of events	-		See LS document	
Predicted runaway current	M A		10	
Energy spectrum of electrons (E_0 for $\exp(-E/E_0)$)	MeV		12.5	
Inclined angle	degree		1 – 1.5	
Total energy deposition due to runaway current	M J		20	
Average energy density deposition	MJ/m^2		1.5	
Duration of the average energy density deposition	ms		100	
Maximum energy density deposition (end of the plasma termination)	MJ/m^2		25	
Duration of the maximum energy deposition	ms		10	
Number of event			Every major disruption	

Table 1.16-3   Heat Load Conditions during Alpha Particle Burst

Parameters	Unit	H	DT	TBA
Energy loss per burst	M J		20	
Peak load due to burst (axi-symmetric wall)	MJ/m^2		0.2	

The fast alpha particles are released with the burst and the burst itself will disappear after a number of bursts because of cool-down of the plasma. The design specification to the plasma facing components is 10 bursts with a frequency of 1 Hz.

Table 1.16-4   Accidental Heat Load Conditions at First Wall due to Neutral Beam

Parameters	Unit	H	DT	TBA
Maximum power density	MW/m^2		50	
Duration	ms		100	

1.17 Radiation Shielding

The main vessel and the in-vessel components together shall provide sufficient nuclear shielding to protect the superconducting coils, and to reduce activation inside the cryostat and at port areas.

Table 1.17-1   Maximum Nuclear Load Limits to the Magnet

Parameters	Unit	H	DT	TBA
Local nuclear heat in the conductor	kW/m^3	0	1	
Local nuclear heat in the case and structures	kW/m^3	0	2	
Peak radiation dose to coil insulator	Gray	0	10×10^6	
Total neutron flux to coil insulator	N/m^2	0	10^{22}	
Total nuclear heat in the magnets	kW	See Table 1.15-5		

ITER shall incorporate shielding design provisions to reduce dose rates in the port regions as low as reasonably achievable to facilitate hands-on maintenance in the port areas. The dose rate shall not be significantly different from those achieved by the shielding capabilities of the bulk shielding (blanket + VV). ITER shall incorporate radiation shielding to permit personnel access in the annular space outside the bioshield. Shielding shall be designed to minimise the number of components located outside the bioshield that require remote maintenance. Shielding cells will be built around dedicated ports to allow parallel hands on maintenance in adjacent volumes when an activated component is in the cell. The level of ionising radiation outside the biological shield (with the exception of the NB cell) immediately surrounding the tokamak shall be limited to 10 µSv/hour 24 hours after shutdown, to allow radiation workers uninhabited access to those areas. The same level of shielding shall be provided to the hot cell facility.

Areas with limited access requirements dedicated for specific maintenance, such as the NB cell and the areas inside the bioshield of the port maintenance areas, shall meet the requirements for Access Zone C, 10^6 seconds after shutdown, and should be limited to 100 µSv/h, the ALARA guideline for allowing radiation workers hands-on access. Areas where the guideline of 100 µSv/h is not met shall be reviewed for acceptability on an individual basis.

ITER shall also incorporate shielding design provisions to reduce dose rates for emergency hands-on repair operation inside the cryostat, such as by reducing fast neutron streaming through gaps. Here the target dose rate is less than 100 µSv/hour 10^6 s (~12 days) after shutdown. Wherever the guideline of 100 µSv/h is not met shall be reviewed for acceptability on an individual basis.

All field welds to vessel and in-vessel RH class 3 components (see Section 1.26) shall be reweldable up to a fluence of 0.5 MWa/m^2 at the first wall. Field welds will be possible only if protected by sufficient shielding to allow rewelding. The limit is provided by the allowable levels for the production of He (< 1 appm for thick plate welding and <3 appm for thin plate or tube welding).

1.18 Electrical Interfaces

Table 1.18-1 Coil Electrical Interfaces

Parameters	Unit	Value
Nominal TF magnet conductor current	kA	68
Maximum TF voltage to ground for normal operation (the voltage indicated here is for the rapid (30 minutes) charge and discharge)	kV	± 0.5
Maximum TF voltage during fast discharge (across current leads of two coils connected in series, but not including transient spike)	kV	8.0
Nominal CS current	kA	45
Maximum CS voltage (between current leads) for normal operation	kV	10
Maximum CS voltage during fast discharge (not including transient spike)	kV	8.0
Nominal PF conductor current	kA	45
Maximum PF voltage for normal operation (PF1, PF6)	kV	10
Maximum PF voltage for normal operation (PF2 to PF5)	kV	14
Maximum PF voltage during fast discharge	kV	7.0
Nominal CC conductor current	kA	10
Voltage (per coil) available for breakdown CS modules, PF1, PF6	kV	10
Voltage (per coil) available for PF scenario & slow control CS modules, PF1, PF6	kV	1.5
Voltage (per coil) available for breakdown PF2 to PF5	kV	5.8
Voltage (per coil) available for PF scenario & slow control PF2, PF5	kV	1.5
Voltage (per coil) available for fast control (for vertical stabilisation), PF2 to PF5	kV	6.0

Note:

Voltages indicated are not the normal operation voltages but maximum values to be used for interface purposes between the power supplies and the magnets.

Table 1.18-2 HVDC Requirements for IC H&CD System

Parameters	Unit	Value
Total power to the plasma (for PS interface definition)	MW	20
Number of power supply units	-	8
Number of generators/sources supplied by each power supply unit	-	1
Anode voltage range	kV	5 - 26
Anode modulation bandwidth	Hz	200
Accuracy of the anode voltage control (% of maximum voltage)	%	± 1
Ripple of anode voltage (% of maximum voltage)	%	± 1
Anode maximum current	A	150
Driver stage voltage range	kV	3 - 18
Accuracy of the Driver stage voltage control (% of maximum voltage)	%	± 1
Ripple of driver stage voltage (% of maximum voltage)	%	± 1
Driver stage maximum current	A	25

IC load protection system		
Fault energy (short circuit energy in case of load fault)	J	≤ 10
Response time of the load protection system	µs	≤ 10
Time to be ready for restart	ms	≈ 200
Rise time of the output voltage	ms	≈ 50

Table 1.18-3 HVDC Requirements for EC H&CD System

Parameters	Unit	Value
Total power to the plasma (for PS interface definition)	M W	20
Number of power supply units	-	2
Number of generators/sources supplied by each power supply unit	-	12
Nominal cathode voltage	kV	-50
Nominal cathode current (at -50 kV)	A	45
Cathode voltage range	kV	-45 to -55
Accuracy of Cathode voltage regulation	%	± 1
Cathode voltage ripple, overshoot and undershoot (% of maximum voltage)	%	2
Acceleration (body) voltage range	kV	0 to +45
Maximum body-to-cathode voltage	kV	90
Accuracy of acceleration voltage control (% of max. voltage)	%	± 0.5
Acceleration voltage ripple (% of max. voltage)	%	± 0.5
Maximum acceleration current (per tube)	A	0.1
Acceleration voltage Modulation range	%	20 to 100
Maximum Acceleration Voltage modulation frequency	kHz	1
Anode voltage range	kV	0 to -50
Anode voltage control: by resistive voltage division from cathode voltage		
Fault energy (short circuit energy in case of load fault)	J	≤ 10
Response time of the load protection system	µs	≤ 10
Time to be ready for restart	ms	~ 200
Rise time of the cathode voltage	ms	1

Table 1.18-4 HVDC Requirements for LH H&CD System

Parameters	Unit	Value
Total power to the plasma (for PS interface definition)	M W	20
Number of power supply units	-	2
Number of generators/sources supplied by each power supply unit	–	12
Collector voltage of the main supply	kV	80
Collector maximum current	A	25
Accuracy of the voltage control (% of maximum voltage)	%	± 1

Ripple of voltage, overshoot and undershoot (% of maximum voltage)	%	±2
Fault energy (short circuit energy in case of load fault)	J	≤ 10
Response time of the load protection system	µs	≤ 10
Time to be ready for restart	ms	∼ 200
Rise time of the output voltage	ms	1

Table 1.18-5 HVDC Requirements for NB H&CD System

Parameters	Unit	Value
Total power to the plasma (for PS interface definition)	MW	33
Total power from the AC supply	MW	115
Number of power supply units	-	2
Number of generators/sources supplied by each power supply unit		1
Output voltage of the main supply	kV	400-1000
Output current of one power supply unit	A	59
Accuracy of the voltage control (% of maximum voltage)	%	± 2
Ripple of voltage (% of maximum voltage)	%	± 5
Total voltage/current	kV/A	1000/59
Grid 1 voltage/current	kV/A	800/7
Grid 2 voltage/current	kV/A	600/6
Grid 3 voltage/current	kV/A	400/3
Grid 4 voltage/current	kV/A	200/3
Maximum continuous power per unit	MW	48
Auxiliary power referenced to 1MV per unit	MW	3
Auxiliary power referenced to ground per unit	MW	3
DNB acceleration voltage	kV	100
DNB acceleration current	A	71
Fault energy (short circuit energy in case of load fault)	J	≤ 50
Response time of the load protection system	µs	≤ 200

1.19 Grounding

All surfaces, including bus and cooling lines, which are exposed to the cryostat vacuum, shall be at ground potential.

All in-vessel components shall be electrically connected to the VV.

The VV shall be electrically insulated from the magnet system to avoid shunting of designated grounding paths for TF coils and to break local eddy current loops.

The VV is connected to the cryostat via cryostat connecting duct.

1.20 Mechanical Loads and Damage limits

The design of the ITER systems shall be able to withstand loading conditions (including seismic) and combinations as specified and classified in four different likelihood categories in the Load Specifications and Combination [LS document], which is annexed to this document.

Table 1.20-1 below indicates the definition of different types of damage limits for components and plant.

Table 1.20-2 below indicates the relationship between Load Combination Category (loads and likelihood categories defined in LS document) and acceptable damage limit as a function of the component safety class (SIC or non-SIC) as specified, for all components, in the PSR (Plant Safety Requirements) annex to this document.

Table 1.20-1 Damage Limits in Plant and Component Level

Damage Limits	Damage Limits to Component Level	Damage Limits in Plant Level and Recovery of the Plant (Plant Operational Condition)
Normal	The component should maintain specified service function.	Within specified operational limit. No special inspection will be required other than routine maintenance and minor adjustment.
Upset	The component must withstand these loadings without significant damage requiring special inspection or repair.	After minor adjustment, or replacement of the faulty component, the plant can be brought back to normal operation. No effect on other components that may call for special inspection or repair.
Emergency	Large deformations in areas of structural discontinuity, such as at nozzles, which may necessitate removal of the component from service for inspection or repair. Insignificant general permanent deformation that may affect safety function of the component concerned. General strains should be within elastic limits. Active components should be functional at least after transient.	The plant may require decontamination, major replacement of damaged component or major repair work. In addition to the damaged component, inspection may reveal localised large deformation in other components, which may call for the repair of the affected components. Nevertheless, the plant maintains the specified minimum safety function during and after the events.
Faulted	Gross general deformations with some consequent loss of dimensional stability and damage requiring repair, which may require removal of component from service. Nevertheless deformation should not lead to structural collapse which could damage other components. The fluid boundary maintains degraded but reasonable leak tightness and flow passage. Active components may not be functional after transient.	Gross damage to the affected system or component. No loss of safety function which could lead to releases in excess of the guidelines established for Accidents. No design consideration will be given for recovery. The recovery of the plant may be judged from the severity of damage. This level of accident state is not expected to occur, but is postulated because its consequences would include the potential for the release of significant amounts of radioactive material.

Table 1.20-2 Damage Limits for Loading Conditions

Loading Event Category		Category I: Operational Loading	Category II: Likely Loading	Category III: Unlikely Loading	Category IV: Extremely Unlikely Loading	Test Loading
Plant Level		Normal	Normal	Emergency	Faulted	Normal
Component	SIC	Normal	Normal	Emergency	Faulted (note 1)	Normal
	Not-SIC	Normal	Upset	(note 2)	(note 2)	Normal

Notes:
1) Faulted for passive components with no deformation limits. Emergency for active components and some passive components in which general deformations should be limited.
2) Events need not be considered from the safety point of view, only for investment protection.

1.21 Mechanical Clearances and Alignment of FW

The mechanical design of the ITER device shall allow sufficient clearances between components so to avoid undesired mutual interactions under all projected operating conditions and postulated accident conditions of category I, II, and III. For example, an open gap between the vacuum vessel thermal shield and each of its surrounding components (VV and TF Coil) shall be large enough to exclude any damage during machine assembly, component cooling and heating, normal/off-normal operation conditions and accident/fault events.

Table 1.21-1 IC Faraday Shield/LH Antenna FW Position

Parameter	Unit	Value
Location closest to plasma	mm	120 (TBD)
Location relative to FW	mm	10 behind FW (TBD)
Radial tolerance	mm	± 5
Vertical/Toroidal tolerance	mm	± 10

Table 1.21-2 Divertor FW Position

Parameter	Unit	Value
Ovality	mm	3
Concentricity relative to the magnetic center of machine	mm	7
Vertical long wave tolerance	mm	± 10
Alignment of dome & dump target Maximum step between adjacent cassette PFCs	mm	4 [1]
Cassette toroidal positioning At toroidal rail level / Top of the cassette	mm	± 2 / ± 4
Radial alignment of cassettes relative to radial line from magnetic axis of machine	degrees	± 0.05
Maximum radial, toroidal & vertical step in-between any adjacent toroidal & radial rail hard cover plates, chamfers and/or rounded edges	mm	1
Positioning accuracy of toroidal & radial racks Maximum step between adjacent rack segments	mm	1.6

Note:
(1)The alignment of other divertor sub-components is less critical and normal manufacturing tolerances can be applied.

Table 1.21-3   VV Rail and Divertor Support Pads Position

Parameter	Unit	Value
Overall maximum deviation from nominal of the inner VV walls along the radial, toroidal and vertical directions:	mm	± 18 (See Table 1.21-4)
Overall maximum deviation from nominal of the VV divertor port walls along the radial, toroidal and vertical directions:	mm	± 23 (See Table 1.21-4)
Maximum step in-between two adjacent sectors (VV and port), the assembly weld being located in the vertical plane going through the port	mm	TBD (See Table 1.21-4)

Table 1.21-4   VV Wall Position

Parameter	Unit	Value
Surface deviations of a 40-degree sector from the reference geometry after fabrication at factory	mm	± 10 (Same as (1))
Surface deviations of the torus from the reference geometry after assembly at the pit	mm	± 15 (Sum of (1) and (2))
Surface deviations of the torus from the reference tokamak geometry after positioning at the pit (Final deviations)	mm	± 18 (Sum of (1) to (3))
Surface deviations of the equatorial and divertor port structures from the reference tokamak geometry after positioning at the pit (Final deviations)	mm	± 23 (Sum of (1) to (4))
Surface deviations of the upper and NBI port structures from the reference tokamak geometry after positioning at the pit (Final deviations)	mm	± 28 (Sum of (1) to (3) and (5))
- Details		
(1)Surface tolerances of a 40-degree sector from the reference geometry after fabrication at factory	mm	± 10
(2)Vessel weld distortion due to field/shop welds at the site	mm	± 5
(3)Torus positioning versus ideal location with all support fixtures removed	mm	± 3
(4)Weld distortion of the equatorial and divertor port structures due to field/shop welds at the site	mm	± 5
(5)Weld distortion of the upper and NBI port structures due to field/shop welds at the site	mm	± 10
(6)Sector wall thickness (distance inner-outer wall)	mm	± 5
(7)Mismatch of the sector surfaces at field joints	mm	± 5

Table 1.21-5 Blanket FW Position

Parameter	Unit	Value
Primary modules minimum clearance gap to the flux surface which passes through a point 40 mm outside the separatrix at the outside plasma equator	mm	80 ± 10 (where 80 is for the nominal position, and ± 10 is for the tolerance.)
Minimum clearance between separatrix and port limiter.	mm	See Table 1.5-1
Maximum limiter pair misalignment	mm	± 1
Adjacent module FW alignment	mm	± 2
Relative location of test blanket module to FW	mm	-50

1.22 First Wall Conditioning and Bake-out

Water shall be removed from the surface of in-vessel components to avoid unacceptable levels of oxygen in the plasma.

The VV, all in-vessel components and all surfaces exposed to primary vacuum shall be bakable to the following specifications:

Table 1.22-1 Baking Conditions

Parameters	Unit	Value
Vacuum vessel baking temperature	°C	200
In-vessel components baking temperature	°C	240
Baking temperature of surfaces exposed to primary vacuum not included above	°C	240
Heat-up time from room temperature for VV	h	100
Heat-up time from room temperature for in-vessel components	h	100

Outgassing of hydrogen isotopes from in-vessel components shall not be an uncontrolled source of significant particle influx to the plasma. The in-vessel components must be bakable to a maximum temperature compatible with retaining sub-cooled conditions.

Means shall be provided to allow glow discharge cleaning with H and other gases, if necessary, with no toroidal field, and discharge cleaning using auxiliary heating systems in the presence of a toroidal magnetic field.

The specifications do not differ in different operation phases and are summarised as follows:

Table 1.22-2 Glow Discharge Cleaning Requirements

Parameters	Unit	Value
First wall current density	A/m^2	> 0.1
Conditioning gas	-	H_2, D_2 and He
Operating pressure	Pa	0.1 – 0.5
Pumping speed	m^3/s	100 - 150
H_2,D_2 throughput (max.)	Pam^3/s	50

Table 1.22-3 ECR/ICR Discharge Cleaning Requirements

Parameters	Unit	H / DT
Power	MW	~ 1
Distance of resonance layer to inner wall at equator	mm	TBD
Conditioning gas	-	H_2, D_2 and He
Operating pressure	Pa	$0.01 - 0.10$
Pumping speed	m^3/s	100 - 150
H_2, D_2 throughput (max.)	Pam^3/s	15

Table 1.22-4 Reactive Cleaning Requirements

Parameters	Unit	H / DT
Conditioning gas	-	TBD
Operating temperature	°C	TBD
Operating pressure	Pa	TBD
Throughput	$Pa\text{-}m^3/s$	TBD

1.23 Vacuum

After bake-out and conditioning, the value of vacuum pressures and integrated primary vacuum leak rates shall be:

Table 1.23-1   Torus Vacuum Condition

Parameters	Unit	Value
Base vacuum pressure for hydrogen isotopes	Pa	$<10^{-5}$
Base vacuum pressure for impurity gases	Pa	$<10^{-7}$
Integrated global leak rate into the primary vacuum boundary	Pa m^3/s	10^{-7}

The torus roughing system is designed for the evacuation of the torus from atmospheric pressure to 50 Pa < 60 hours. This evacuation time shall be achieved when the torus is vented to dry air or nitrogen as the back-fill gas.

For the cryostat, the vacuum pressures and integrated primary vacuum leak rates are followings:

Table 1.23-2   Cryostat Vacuum Condition

Parameters	Unit	Value
Nominal pressure inside cryostat	Pa	$<10^{-4}$
Global in-leakage (including outgassing) into the cryostat including all internally-mounted components before initiating operation	Pa m^3/s	$<10^{-4}$
Global in-leakage (including outgassing) into the cryostat including all internally-mounted components during tokamak operations	Pa m^3/s	$<10^{-1}$

Provision shall be made to warm up the cryostat wall and all the cold components inside the cryostat to room temperature in TBD hours after venting of the cryostat.

The cryostat pumping system shall be designed to evacuate the cryostat from atmospheric pressure to $< 10^{-2}$ Pa in less than 100 hours and to a base pressure of $< 10^{-4}$ Pa in (TBD) hours prior to cooling of the magnets. This evacuation time shall be achieved when the cryostat is vented with dry air or nitrogen as the back-fill gas and the global in-leakage (including outgassing) into the cryostat, including all internally mounted components is $< 10^{-5}$ Pam^3/s.

During tokamak operations, following cool down of the magnets, the cryostat pumping system, shall be capable of maintaining a pressure of 10^{-3} Pa when the maximum global helium in-leakage (including outgassing) into the cryostat from all internally mounted components does not exceed 10^{-3} Pam^3/ s.

The cryostat pumping system shall evacuate the cryostat, following a helium in-break from 3,000 Pa to 1 Pa in 100 hours when the maximum in-leakage into the cryostat does not exceed TBD Pam^3/ s.

The IC VTL (vacuum transmission line) pressure should be maintained within maximum operating value of 10^{-2} Pa.

The pumping requirements for the NB H&CD injectors are the following:

Table 1.23-3 NB Pumping Requirements

Parameters	Unit	Value
NB, pumping speed in D_2 for 1 NB Injector	m^3/s	2.6×10^3
NB, pumping speed in H_2 for 1 NB Injector	m^3/s	3.8×10^3
NB, overall regeneration time	s	<1200

A roughing system shall evacuate the EC waveguides to the cross-over pressure of the high-vacuum pumps in < 1 day. The high-vacuum pumps shall evacuate the waveguide runs to < 10^{-3} Pa in less than 2 days. Components shall be cleaned and prepared such that their outgassing rate is < 10^{-8} Pam^3/s

A pumping system is to be provided to pump all port plugs in which the LH H&CD antennas are installed. This pumping system shall maintain the pressure in the transmission lines within the following limits in order to prevent RF breakdown.
        Base vacuum pressure: 10^{-4} Pa
        Maximum operating pressure: 10^{-3} Pa
        Outgassing rate: 10^{-4} Pam^3s^{-1}

1.24 Divertor Neutral Recycling

The divertor is designed to achieve a reduction of neutral density between the private flux region below the dome, relative to that above the dome below the X-point, of 10^{-1}, and, relative to that in the main plasma chamber at the equator wall, of $\sim 10^{-4}$.

The flow back of neutrals from the divertor area to the main plasma area shall be limited to 5 Pam^3/s.

1.25 Plasma Pumping and Fuelling

The pumping and fuelling system shall be capable of providing He removal and plasma core fuelling at a rate which corresponds to the nominal fusion power, as well as the required density ramp-up during the start-up phase (see Table 1.25-1).

The torus roughing pumps shall exhaust directly to the tritium plant which shall be capable of processing the plasma exhaust at the average composition and flow rates detailed in Tables 1.25-2 and 1.25-3 during the various phases of plasma operations. The outgassing species listed in these tables are the result of plasma wall interactions, outgassing, and other mechanisms e.g. chemical erosion, sputtering, minor water leaks, and the long term release of vent gases etc. that occur.

Table 1.25-1 Plasma Pumping Requirements

Parameters	Unit	Value
Divertor pressure during plasma operations	Pa	$0.1 - 10$
Maximum throughput during plasma operations	Pam^3/s	253[1]
Minimum He pumping speed during plasma operations	m^3/s	> 50
Base pressure between pulses	Pa	$10^{-3} - 10^{-4}$
Pumping speed regulation, $0 - 100\%$	s	< 10

Note :

(1) The net pumping speed from the divertor volume must be adjustable between 0 and at least 200 m^3/s to provide particle control with the prevailing fuelling rate and when the pressure in the pumping duct varies between 0.1 and 10 Pa.

Table 1.25-2 Average Plasma Exhaust Composition and Flow Rates during Helium, Hydrogen and Deuterium Discharges

Gas Species	He Discharge Pam^3/s		H$_2$ Discharge Pam^3/s		D$_2$ Discharge[4] Pam^3/s		DT Discharge[5] Pam^3/s	
	Min[3]	Max[3]	Min[3]	Max[3]	Min[3]	Max[3]	Min[3]	Max[3]
H$_2$	0	10	200	200	0	10	0	10
D$_2$					200	200	0	0
T$_2$					0	0	0	0
DT					0	0	200	200
He	100	100	0	20	0	20	0	20
C$_x$Q$_y$[1]	0	5	0	5	0	5	0	5
Q$_2$O[1]	0	1	0	1	0	1	0	1
O$_2$	0	1	0	1	0	1	0	1
CO$_x$	0	5	0	5	0	5	0	5
NQ$_3$[1]	0	1	0	1	0	1	0	1
N$_2$	0	10	0	10	0	10	0	10
Ar	0	10	0	10	0	10	0	10
Ne	0	10	0	10	0	10	0	10
Σ(N$_2$+Ar+Ne)[2]	0	10	0	10	0	10	0	10
Total	100	133	200	243	200	253	200	253

Notes:

(1) Q is defined as any one or combination of the hydrogen isotopes H, D or T.

(2) The maximum combined exhaust flow rate for N$_2$, Ar and Ne.

(3) The composition of the plasma exhaust may vary from discharge to discharge between the minimum and maximum values specified for each gas species in any combination.

(4) The table excludes the production of trace amounts of tritium from the DD reaction of < 0.01% of the full throughput.

(5) The proportion of T/D may vary over the range 0/100 to 90/10, with the flow rate decreasing progressively from the nominal value above 50/50 (see Table 1.25-3).

Table 1.25-3 Plasma Fuelling Parameters

Parameters	Unit	^{3}He, ^{4}He	H$_2$, D$_2$, DT, T$_2$
Fuelling gas[(1)(2)(3)]			
Average/Peak fuelling rate for H$_2$, D$_2$, DT for gas puffing [(2)(3)]	Pam^3/s		200/400
Average/Peak fuelling rate for T$_2$ for pellet injection [(2)(3)]	Pam^3/s		50/50
Average/Peak fuelling rate for ^{3}He or ^{4}He	Pam^3/s	100/200	
Gas purity for each fuelling gas H$_2$, D$_2$, and He	mole %		> 99
Isotopic purity for T$_2$	mole %		> 90
Allowable H$_2$ in D$_2$, DT or T$_2$	mole %		< 0.5
Allowable non-hydrogenic gases in H$_2$, D$_2$, DT, T$_2$	mole %		< 0.05
Duration at peak fuelling rate	s		< 10
Response time to 63% at 20 Pa-m^3/s	s		< 1
Set point control precision of fuelling rate	%		5

Notes:

(1)The fuelling isotope mixture should be adjustable, on a pulse by pulse basis, between 100%D and 100%H during H/D operation, and between 100%D and 90%T during DT operation.

(2)The plasma fuelling rate during DT operations for isotopic mixtures up to 90%T shall not exceed the average fuelling rates define by Table 1.25-4.

(3)During DT operations the plasma fuelling system shall be capable of providing the fuelling scenarios detailed in Table 1.25-4.

Table 1.25-4 Maximum Time-averaged Fuelling Flow Rates during DT Discharges as a Function of T/D Ratio

Typical Fuelling Cases	1	2	3	4	5	6	7	8
T/D ratio (-)	25/75	40/60	50/50	50/50	60/40	70/30	75/25	10/90
D$_2$ Product flow rate, Pa.m$_3$/s	140	80	0	40	6.7	0	0	0
DT, Product flow rate, Pa.m$_3$/s	10	70	200	114	114	50	30	0
T$_2$, Product flow rate, Pa.m$_3$/s	50	50	0	50	50	50	30	50
Total, Pa.m$_3$/s	200	200	200	200	166.7	100	80	50

Provision shall be made to inject impurity gases into the private region of the divertor to promote radiative cooling.

Table 1.25-5   Impurity Gas Injection for Radiative Cooling of Divertor

Parameters	Unit	Value
Impurity gases		N_2, Ar, Ne
Maximum number of impurity gases to be injected simultaneously		3
Average/Peak injection rate for each gas	Pam^3/s	10/100
Average/Peak simultaneous injection rate all gases	Pam^3/s	10/100
Allowable impurities	mole %	< 3
Duration at peak fuelling rate	s	< 10
Response time to 63% at 5 Pa-m^3/s	s	< 1
Set point control of fuelling rate	%	5

Provision shall be made to inject impurity pellets into the plasma for physics studies.

Table 1.25-6   Impurity Pellet Injection for Physics Studies

Parameters	Unit	Value
Impurity pellets		N_2, Ar, Ne
Maximum number of impurity gas species injected per pulse		1
Average/Peak injection rate	Pam^3/s	10/50
Allowable impurities	mole %	< 3

A fusion power shutdown system (FPSS) shall be implement to terminate the plasma discharge by the injection of impurity gases.

Table 1.25-7   Fusion Power Shut-down System (FPSS)

Parameters	Unit	Value
Impurity gases		N_2, Ar, Ne
Number of impurity gases to be injected simultaneously		2
Total quantity of gas to be injected		200 Pam^3
Response time to 63% following initiation of FPSS	s	< 3

The NB and Diagnostic NB fuelling system shall supply the injectors with the required hydrogen isotopes as dictated by HH, HD, DD and DT operations.

Table 1.25-8 NB and Diagnostic NB Fuelling Parameters

Parameters	Unit	H phase	D_2/DT phase
NB Injector, D_2 gas flow for 1 NB injector	Pam^3/s		18
NB Injector, H_2 gas flow for 1 NB injector	Pam^3/s	36	
Diagnostic NB Injector, H_2 gas flow to neutraliser, HH operation only.	Pam^3/s	9	
Diagnostic NB Injector, D_2 gas flow to neutraliser, DD and DT operation only.	Pam^3/s		6
Diagnostic NB Injector, D_2 gas flow to beam source, HH, DD and DT operation.	Pam^3/s	8	8
NB Injector and Diagnostic NB Injector maximum allowable gas impurity for hydrogenic species	atom %		H < 0.5 T<0.02
NB Injector and Diagnostic NB Injector maximum allowable gas impurity for other impurities	ppm	< 10	< 10
D_2, H_2, fuelling gas pressure	MPa		0.6

The blanket shall be capable of sustaining without damage a series of impacts on the plasma facing surfaces from pellets delivered by the pellet injector prior to injector shut down following an undemanded termination or disruption of the plasma.

Table 1.25-9 Pellet Impact on Blanket following Plasma Disruption

Pellet diameter	mm	2	3	4	6
Pellet mass	g	1.58E-03	5.33E-03	1.26E-02	4.27E-02
Pellet velocity	m/s	500	500	500	500
Impact force	N	261	588	1050	2350
Impact area	mm^2	3.14	7.07	12.57	28.27
Pellet delivery frequency	Hz	199	59	25	7
Pellet injector shut down time after disruption	s	2	2	2	2
Number of impacts		398	118	50	15

1.26 Maintainability

ITER components' design shall include maintainability features which will allow scheduled maintenance operation to be performed reliably and in a timely manner thus maximising machine availability. The possibility and optimisation of hands-on maintenance shall always be considered first; hands-on assistance shall be considered in remote handling procedures as far as practical.

In-vessel interventions will generally be preceded by in-vessel inspection to obtain information on the extent of damage and maintenance activities required.

Access to the components within the primary vacuum boundary shall be possible from the outside without the need to break the cryostat vacuum.

Maintenance of in-vessel components will generally consist of the replacement of components. The removed, activated and contaminated components will be transported to the hot cell for eventual repair and refurbishment, or, alternatively for preparations for disposal as waste.

RH equipment will be introduced into the vacuum vessel from casks docked to ports of the vacuum vessel.

Casks are sealed, but not shielded, hence requiring restricted access of personnel to the pit and gallery areas when casks are transported to and from the hot cell. The cask transporter is based on air cushion flotation.

Preparatory activities prior to initial cask docking, will involve hands-on (assisted) operations, including gaining access to the bioshield plug, its removal, opening of the cryostat closure plate, etc.

All components inside the cryostat must be designed to last the lifetime of the ITER machine, hence not requiring maintenance. Should however, components inside the cryostat require repair, then hands-on repair is the reference procedure, with remote repair as a backup.

Gross failure of components inside the cryostat may require their replacement. The design and layout of components inside the cryostat, as well as the design of the cryostat itself must not preclude the replacement of large components.

Rescue procedures shall be available for every RH procedure, i.e., all RH equipment shall be designed for remote recovery if a RH operation fails.

Components that obstruct access for remote maintenance shall be given at least the same classification as the component to which the access is blocked, if they require remote handling.

RH Class 1 component maintenance shall not require opening of the cryostat, and shall be completed in the minimum time. RH Class 2 component maintenance shall avoid opening of the cryostat where possible, and also be completed in the minimum time. The projected maintenance time in case of failure for RH Class 3 components may be long.

All RH equipment for Class 1 and 2 operations must be designed in detail during the EDA. The feasibility of Class 1 tasks shall be verified during the EDA and may involve the use of mock-ups. The feasibility of Class 2 tasks shall be verified during the EDA where deemed practical and necessary and may involve the use of mock-ups. The procedure of maintenance of Class 3 components shall be defined during the EDA.

Table 1.26-1 RH Classification of ITER Components

Maintenance classification	Components
RH Class 1	• Divertor cassette including divertor RH port components • Limiter • Test blanket module • NB filament and oven ,caesium cleaning
RH Class 2	• Blanket modules • NB front liner, fast shutter, ion source • Diagnostics • Cryopump valve • RF port plug
RH Class 3	• NB Drift duct liner, bellows, Neutralizer, Residual Ion Dump, Calorimeter • Cryopump body • CS coil, PF coil, TF coil, CC, Vacuum Vessel, etc.,
RH Class 4	• Others

Remote handling requirements, such as limit of weight, size of connecting pipes are described in the Remote Handling Standard, which is annexed to this document.

1.27 Decommissioning

The ITER project requirement is to provide a feasible and flexible plan for the decommissioning of the ITER machine and associated active components/plants.

1.28 Plant Services

The plant services must distribute various services to the many buildings and locations around the site. These services are summarised as:

Table 1.28-1 Parameters of Plant Services

System or Service	Description	Parameter value	Comments
Potable water	based on supplying 1,000 people	~ 300 m^{3}d^{-1} at ~0.8 MPa	
Fire-fighting water	a pressurised, plant-wide system	0.4 m^{3}s^{-1} at ~ 1.3 MPa	
Steam and condensate	supplies and distributes steam to components and systems (including HVAC) which require auxiliary heating	15,000 kgh^{-1} at ~0.5 MPa	
Demineralized water	water for process purposes and makeup to cooling systems	200 m^{3}d^{-1} at ~1 MPa	1.0 µMhocm^{-1} with dissolved oxygen and chlorine concentrations less than 0.1 ppm.
Raw water		TBD	
Sanitary sewage	for a site population in operation of 1,000	Suitable for 1,000 people	15 day (~2,000 m^3) hold-up
Industrial sewage	discharged to an off-site receiver pipeline	200 m^{3}d^{-1}	includes cooling tower blowdown
Instrument and service air	clean, oil-free and dry air for instruments; undried, unfiltered for services	~690 kPa(g)	See Table 1.28-3
Breathing air	oil-free compressors, non-cycling refrigerated dryers operating in parallel, coupled to air receivers	50 std m^{3}h^{-1} air flow at ~520 kPa(g)	
Special gases		various	See Table 1.28-2
Steady-state electrical power	power to all ITER plant electric loads except the magnet and the heating and current drive systems	124MW connected loads; 112MW delivered at 11kV, 3.3kV, and 0.4kV	receives continuous electrical power from at least two connections. See Table 1.28-4
Emergency power	based on diesel generators	6.2MW at 11kV	See Table 1.28-4

Table 1.28-2 Nitrogen, Helium and Special Gas Demands

Gas	Supply Capacity	Purity Specification
Industrial Nitrogen	100,000 std m^3/month (max.) 45,000 std m^3/month(avg.)	< 0.1% impurity
Industrial Helium	20,000 std m^3/month(max.) 10,000 std m^3/month(avg.)	< 0.1% impurity
SF$_6$	6,000 kg initial fill; makeup at 60 kg/month	Industrial grade
Ultra-Pure Nitrogen	5 std m^3/month	Ultra-high purity
Ultra-Pure Helium	5 std m^3/month	Ultra-high purity
Deuterium	5 std m^3/month	Ultra-high purity
Hydrogen	25 std m^3/month	Laboratory Grade
Argon	10 std m^3/month	Laboratory Grade
Neon	10 std m^3/month	Laboratory Grade

Table 1.28-3 Compressed Air Station Capacities

Station	Buildings Served	Instrument Air Capacity std m^{3}h^{-1}	Service Air Capacity std m^{3}h^{-1}
1	Tokamak Building	4,050	450
2	Tritium Building	1,080	120
3	Hot Cell Building	1,080	120
4	Cryoplant Building	1,080	120
5	Emergency Power Supply Building	1,080	120
6	Auxiliary Buildings	4,050	450
7	Site Services Building	1,080	120

Table 1.28-4 Steady-state Power Supply and Emergency Loads

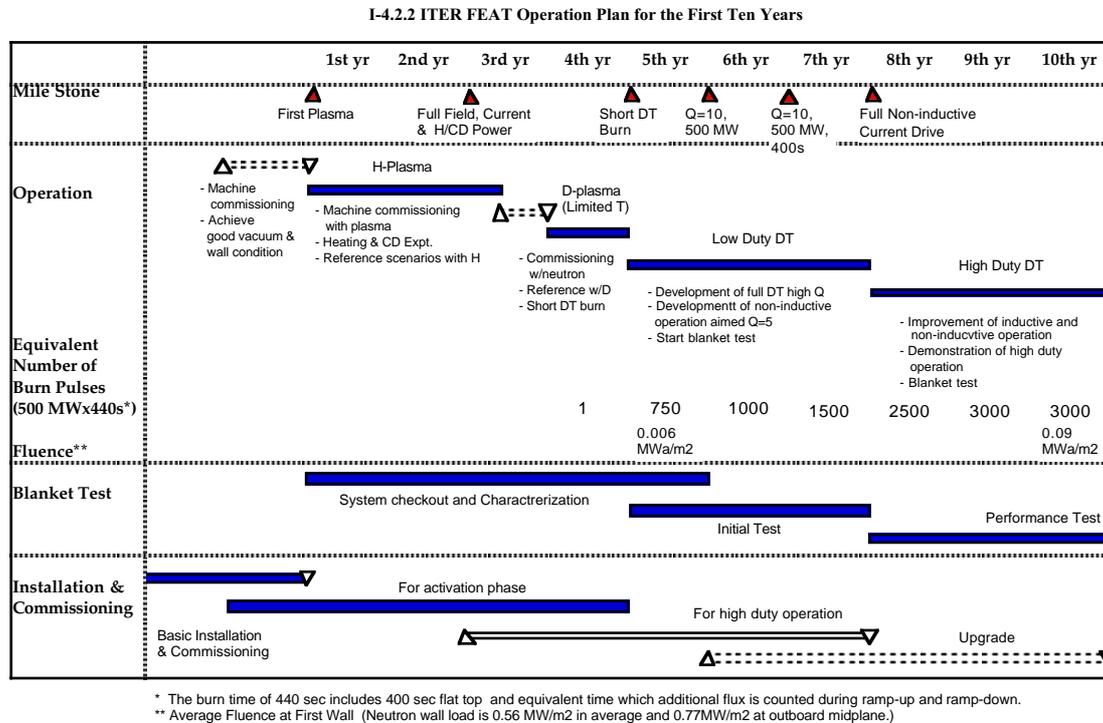| System	Connected loads (MW)	Class IV Power in POS (MW)	Class IV Power in LTM (MW)	Class III Power (MW)
Cooling Water	60.4	46.1	21.1	2.1
Cryoplant & Cryodistribution	33.9	26.7	8.5	(3)
Buildings and Layout	12.3	5.5	6.8	0.9
Heating &Current Drive (total)	2.9	2.6	0.3	(3)
-IC H&CD (for 20MW)	2.3	2.2	0.3	(3)
-EC H&CD(for 20MW)	0.6	0.4	(3)	(3)
-NB H&CD(for 33MW)	(3)	(3)	(3)	(3)
Remote Handling Equipment	3.0	0.0	1.0	0.0
Liquid and Gas Distribution	2.8	1.8	1.8	0.5
Tritium Plant & Detritiation	1.6	0.5	0.5	0.6
Diagnostic	2.0	2.0	0.2	0.1
Power Supplies	1.9	1.4	0.3	0.3
Vacuum Pumping & Fuelling	1.1	0.5	0.7	0.2
Hot Cell and Waste Processing	1.1	0.4	0.5	0.0
Radiological and Environmental Monitoring	0.4	0.2	0.2	0.1
Supervisory Control, Interlock and General Alarm System	0.2	0.2	0.2	0.2
Magnet	0.1	0.1	0.1	0.1
Others	0.3	0.2	0.1	0.1
Total	124.0	88.2	42.3	5.2
Total, including uncertainty factor [1]		101.5		5.7
Total, including future growth factor [2]		112.0		6.2

Note:

(1)15% for class IV, 10% for class III

(2)25% for class IV, 15% for class III, with exception of the Cooling Water system, the requirements of which correspond to the extended capability.

(3)Less than 100 kW. Accounted in Others.

(4)For classification of power, see Section 2.19.

1.29 Fluence Scenario for the First Ten Years

I-4.2.2 ITER FEAT Operation Plan for the First Ten Years

* The burn time of 440 sec includes 400 sec flat top and equivalent time which additional flux is counted during ramp-up and ramp-down.
** Average Fluence at First Wall (Neutron wall load is 0.56 MW/m2 in average and 0.77MW/m2 at outboard midplane.)

The ITER fluence scenario for the first ten years is shown above. The possible equivalent numbers of burn plasma are specified each year in the figure. For the nominal burning plasma of 500MW, assuming an additional 40 second burning plasma during ramp-up and ramp-down phase to flattop burn time of 400 second, the average neutron fluence at the first wall is evaluated as shown in Table 1 for each first ten year.

Table 1.29-1 Neutron Fluence during the First Ten Year Operation (MWa/m^2)

	1~3	4	5	6	7	8	9	10	total
Equivalent number of nominal pulses	0	1	750	1000	1500	2500	3000	3000	11751
Average neutron fluence at FW	0.0	0.0	0.006	0.008	0.012	0.020	0.024	0.024	0.09

The total neutron fluence at the end of tenth year is 0.09 MWa/m^2 on average at the first wall, and at the outboard first wall on the equator is 0.12 MWa/m^2. Hybrid and non-inductive operation are also planned in this phase. The burn time of their operation is longer than 400 second and thus the total fluence is expected be to larger than 0.09 MWa/m^2. It is noted that many different types of operations, such as lower current, shorter pulses, lower fusion power are also planned. Therefore, the real number of pulses will be larger than equivalent number of nominal pulses.

1.30 Manuals, Handbooks, Design Criteria

The various ITER components shall be designed in accordance with the criteria referenced or set in the Structural Design Criteria annex to this document.

The use of properties to determine structural allowables shall be in accordance with the ITER structural design criteria, with which the design shall conform.

The source of material properties and behaviour under ITER working conditions for design shall be the ITER Material Properties Handbook and Material Assessment Report.

The drawings describing the ITER design shall be prepared according to the rules and guidelines contained in the ITER Computer Aided Design Reference Manual.

The design shall include use of standards and design rules contained in the Radiation Hardness Design Manual and the Remote Handling and Standard Components Manual. The use of standard components, materials, and processes is required wherever reasonable. Exceptions to these manuals can be taken for appropriate technical or economic reasons, but these exceptions must be documented in the appropriate Design Description Document (DDD) and require an approval similar to the one employed for this document.

The ITER design shall be prepared according to the rules and guidelines contained in the ITER Vacuum Design Handbook.

1.31 Quality Assurance

Quality Assurance (QA) is defined as all those planned and systematic actions necessary to provide adequate confidence that an item will perform satisfactorily in service.
QA shall be an integral part of any task no matter where or when it is performed.

ITER shall develop, implement and maintain a QA Program to ensure that:
- the level of QA appropriate to achieving the safety and performance objectives of ITER is specified and obtained,
- sufficient objective evidence is maintained to demonstrate that the required quality has been achieved.

The ITER QA Program:

- shall include a QA policy statement that establishes the management's concept and objectives regarding quality;
- shall cover the full life cycle of the ITER machine (e.g. design, R&D, procurement, manufacturing, construction, commissioning, operations and decommissioning);
- shall be based on conventional QA principles as described in the ISO 9000 series of standards or IAEA Code 50-C-QA;
- shall make use of the experience gained in the implementation of QA programs applied to similar projects, when available;
- shall be structured to take into account the specific nature of fusion and the multi-national, multi-participant and multi-disciplinary characteristics of the ITER Project;
- shall be subject to periodic evaluation and updating.

The ITER QA Program shall be further developed into QA documents (e.g. plans, procedures, instructions, and guidelines) as may be necessary to integrate QA to ITER activities.

ITER QA documents:

- shall provide for a disciplined and systematic approach to activities affecting quality and for production of objective evidence to demonstrate that the required quality has been achieved;
- shall detail requirements, assign responsibilities and authorities and provide for the performance and assessment of work.

1.32 Tokamak Cooling Water Chemistry

Table 1.32-1 Tokamak Cooling Water Chemistry (on CVCS) Main Specifications

Parameters	Feed water	Upper limits for action
Conductivity (at 20°C), µS/cm	<0.1	<0.3
Oxygen, µg/kg	<100	<10 [1]
Chloride and/or Fluoride, µg/kg	<0.5	<5
Sulphate, µg/kg	<20	<5
Copper, µg/kg	<0.5	<5
Iron, µg/kg	<1	<5
Hardness (Ca, Mg, etc.), µg/kg	<5	<5
Oil products, organic, µg/kg	<100	<100

(1) The oxygen content for the vacuum vessel cooling system shall be limited <100 µg/kg.

25 cm^3/kg (at STP) of Hydrogen shall be added to suppress the water radiolysis.

Corrective measures shall be initiated at once if any of the above parameters exceeds its upper limit.

A plasma pulse shall not be initiated if any of the above limits is foreseen to be exceeded during the course of pulse itself.

Feed water should be added periodically if necessary or during cooling system maintenance. The pH of the water shall be neutral at room temperature.

1.33 Operational Waste Scenario

Amount of operational waste should be estimated based on the following preliminary best estimate scenario.

Table 1.33-1 Scenario for Divertor Operational Waste Estimation

Armour Material of Divertor Targets	Target Design	Disruption Frequency	Lifetime (Number of Disruptions)
CFC	Current Design	30% of pulses	3000
CFC	Advanced Design	20% of pulses	3000
CFC	Advanced Design	10% of pulses	3000
Tungsten	Advanced Design	6% of pulses	8000
Tungsten	Advanced Design	3% of pulses	16000

1.34 Tokamak Machine Displacement and Loading Combination

The displacements of the tokamak machine are summarised in the following tables.

Table 1.34-1 Thermal Movement of VV and Magnets (from Room Temperature to Operating Temperature)

Position[1]	Displacement (mm)							
	Normal operating temperature		Baking temperature		VV Loss of coolant		VV outgassing	
	Radial	Vertical	Radial	Vertical	Radial	Vertical	Radial	Vertical
1	23.1	-5.7	42.7	3.0	55.4	8.5	42.7	19.4
2	23.1	-11.5	42.7	-7.8	55.4	-5.5	42.7	8.7
3	23.1	-14.6	42.7	-13.5	55.4	-12.8	42.7	3.0
4	23.1	-20.4	42.7	-24.2	55.4	-26.8	42.7	-7.7
5	23.1	-23.2	42.7	-29.5	55.4	-33.6	42.7	-13.0
6	23.1	-29.1	42.7	-40.2	55.4	-47.5	42.7	-23.7
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	15.9	-20.6	29.3	-24.6	38.0	-27.2	29.3	-8.1
9	-26.1	-13.0	-26.1	-13.0	-26.1	-13.0	18.8	-10.7
10	-27.3	-8.5	-27.3	-8.5	-27.3	-8.5	0.0	0.0
11	8.6	-27.8	16.0	-37.9	20.7	-44.5	16.0	-21.4
12	-16.0	-0.2	-16.0	-0.2	-16.0	-0.2	0.0	0.0
13	5.3	-18.4	9.8	-20.6	12.8	-22.1	9.8	-4.1
14	-9.3	-17.9	-9.3	-17.9	-9.3	-17.9	0.0	0.0
15	8.7	-9.1	16.1	-3.3	20.8	0.4	16.1	13.2
16	-16.0	-35.5	-16.0	-35.5	-16.0	-35.5	0.0	0.0
17	-30.8	-21.8	-30.8	-21.8	-30.8	-21.8	0.0	0.0
18	-31.9	-18.0	-31.9	-18.0	-31.9	-18.0	0.0	0.0
19	16.9	-16.3	31.2	-16.6	40.4	-16.9	31.2	-0.1
20	17.7	-18.4	32.7	-20.5	42.5	-21.9	32.7	-4.0
21	11.3	-25.3	20.9	-33.2	27.1	-38.4	20.9	-16.7

(1) Selected positions are listed in Table 1.34-2.

Table 1.34-2 Locations of Selected Positions

Position	Radial coordinate	Vertical coordinate	Toroidal position	Description
1	14000	7730	Port mid-plane	Upper port cryostat extensions (top bellow)
2	14000	4200	Port mid-plane	Upper port cryostat extensions (bottom bellow)
3	14000	2350	Port mid-plane	Equatorial port cryostat extensions (top bellow)
4	14000	-1180	Port mid-plane	Equatorial port cryostat extensions (bottom bellow)
5	14000	-2900	Port mid-plane	Divertor port cryostat extensions (top bellow)
6	14000	-6430	Port mid-plane	Divertor port cryostat extensions (bottom bellow)
7	10750	-7250	TF mid-plane	Gravity support lower flange
8	9599	-1300	TF mid-plane	Vessel support upper flange
9	9442	-2063	TF mid-plane	Vessel support - thermal anchor
10	9109	-3126	TF mid-plane	Vessel support - lower flange
11	5236	-5663	TF mid-plane	Vessel outer shell lowest point
12	5333.5	-5873	TF mid-plane	TF coil (inner lowest point)
13	3228	0	TF mid-plane	Vessel outer shell inboard
14	3084.5	0	TF mid-plane	TF inner leg
15	5265	5674	TF mid-plane	Vessel outer shell top point
16	5333.5	5873	TF mid-plane	TF coil (inner top point)
17	10250	1319	516	TF-3 coil NBI duct
18	10628	36	3323	TF-4 coil NBI duct
19	10215	1312	711	NBI duct left
20	10736	36	3197	NBI duct right
21	6844.5	-4126	Port mid-plane	Divertor outer rail

Table 1.34-3 Radial and Vertical Displacement along TF Coil Perimeter for In-plane Load Cases

Position[1]	Displacement (mm)					
	After preload of precompressing ring		After TF coils cooldown		At TF coils energisation	
	Radial	Vertical	Radial	Vertical	Radial	Vertical
A	2.66	-0.03	-3.96	-16.69	-11.84	-14.30
B	0.75	-0.69	-5.89	-29.98	-9.18	-21.70
C	-1.14	1.69	-19.67	-34.93	-19.06	-25.81
D	-1.18	1.09	-24.08	-33.81	-21.86	-24.16
E	-1.52	0.52	-29.95	-30.10	-27.00	-23.05
F	-1.76	0.21	-34.63	-22.81	-34.64	-19.33
G	-1.95	0.14	-35.79	-16.63	-36.67	-14.50
H	-1.90	0.12	-35.56	-14.11	-36.19	-12.47
I	-1.88	-0.02	-32.43	-6.04	-30.42	-6.66
J	-1.23	-0.88	-24.10	0.53	-21.76	-4.71
K	-1.13	-1.64	-19.67	1.58	-19.04	-2.86
L	0.72	0.63	-5.89	-3.41	-9.18	-6.90
A2	-1.95	-0.05	-30.37	-7.42	-29.33	-9.08

(1)Selected positions are listed in Table 1.34-5.

Table 1.34-4 Radial, Vertical and Toroidal Displacement along TF Coil Perimeter for Out-of-plane Load Cases

Position[1]	Displacement (mm)								
	PF coils energise			Start of flat top			End of burn		
	Radial	Vertical	Toroidal	Radial	Vertical	Toroidal	Radial	Vertical	Toroidal
A	-11.84	-14.30	-0.19	-11.84	-14.32	2.57	-11.84	-14.33	2.91
B	-9.18	-21.70	-0.39	-9.18	-21.72	1.78	-9.18	-21.72	2.85
C	-19.06	-25.81	-0.97	-19.04	-25.82	10.00	-19.04	-25.82	13.20
D	-21.86	-24.15	-0.88	-21.83	-24.15	12.22	-21.83	-24.15	16.20
E	-27.00	-23.05	-0.57	-26.98	-23.05	12.22	-26.98	-23.05	16.80
F	-34.64	-19.33	-0.51	-34.63	-19.33	11.92	-34.63	-19.33	16.40
G	-36.67	-14.50	-0.20	-36.65	-14.50	6.68	-36.65	-14.50	8.89
H	-36.19	-12.47	-0.06	-36.17	-12.46	4.51	-36.17	-12.46	5.85
I	-30.42	-6.66	0.00	-30.34	-6.67	1.39	-30.34	-6.67	1.80
J	-21.75	-4.72	-0.78	-21.64	-4.76	-5.84	-21.64	-4.76	-6.28
K	-19.04	-2.86	-0.53	-18.94	-2.90	-4.75	-18.93	-2.90	-5.13
L	-9.18	-6.91	-0.01	-9.16	-6.95	2.69	-9.16	-6.95	2.67
A2	-29.32	-0.05	-9.08	-29.26	1.24	-9.10	-29.26	1.70	-9.10

(1)Selected positions are listed in Table 1.34-5

Table 1.34-5 Characteristic Positions along TF-Coil

Position	Description
A	Nose of TF casing equatorial plane
B	Nose of TF coil upper straight leg
C	Start of upper OIS[1] segment
D	End of upper OIS segment
E	Start of upper intermediate OIS segment
F	End of upper intermediate OIS segment
G	Equatorial plane outer leg
H	Start of lower intermediate OIS segment
I	End of lower intermediate OIS segment
J	Start of upper OIS segment
K	End of upper OIS segment
A2	TF coil mid-plane -lower flange of the VV support

(1)OIS: Outer Intercoil structure

Table 1.34-6 Displacements Relative to the Basemat for SL-2 Earthquake

Position	Displacement (mm)		
	Radial	Toroidal	Vertical
TFC – peak value	17.1	17.1	2.41
CS winding pack	17.6	17.6	2.58
CS upper support	18.6	18.0	2.55
PF Coils	17.8	17.8	2.44
VV main vessel	24.2	24.1	4.27
VV upper port and duct	25.3	24.8	6.3
VV equatorial port and duct	22.7	21.9	6.74
VV lower port and duct	19.7	19.2	3.75
Divertor	20.7	20.7	4.37
Thermal shield – peak value	30.3	30.0	3.28
Cryostat – peak value	12.5	12.5	2.55

Table 1.34-7 Maximum Absolute Displacements due to an Asymmetric VDE/S-D III (with respect to Normal Operating Condition)

Position	Displacement (mm)		
	Radial	Toroidal	Vertical
Top of VV	3.0	6.1	2.1
Inboard wall	3.6	8.0	2.7
Bottom of VV	3.0	7.2	2.1
Outboard wall	2.4	0.62	1.6
End of port duct of upper port	4.7	5.0	2.2
End of port duct of equatorial port	2.5	2.4	1.4
End of port duct of divertor port	3.5	4.1	1.1
Upper port plug (or antenna)	2.2	1.82	2.0
Equat. port plug (or antenna)	1.8	0.35	1.4

Table 1.34-8 Maximum Absolute Displacements in the VVTS for Selected Load Combinations (with respect to Assembly Condition)

Regime	Direction	Inboard VVTS	Outboard VVTS	Upper port	Equator. port	Lower port	Port support plate
Dead weight (DW)	radial	0.7	0.8	0.3	0.7	0.3	0.5
	vertical	1.5	2.5	1.5	1.5	2.5	-
	toroidal	-	-	-	1.9	1.1	-
Plasma Disruption I,II+ DW	radial	1.0	0.9	0.4	0.9	0.3	2.2
	vertical	1.4	2.4	1.6	1.7	2.4	-
	toroidal	-	-	0.3	2.3	1.8	-
Fast VDE, III + DW	radial	0.7	1.0	0.6	0.9	0.4	2.8
	vertical	1.6	2.7	2.8	1.7	2.7	-
	toroidal	-	-	1.6	2.5	2.1	-
Slow VDE, III + DW	radial	0.7	1.1	0.8	0.9	0.5	3.9
	vertical	1.6	3.6	2.8	2.3	3.6	-
	toroidal	-	-	1.6	3.1	2.8	-
TF fast discharge + DW	radial	0.8	0.5	0.4	0.5	0.4	1.2
	vertical	1.4	1.5	1.5	0.9	1.4	-
	toroidal	-	-	0.5	1.0	0.6	-
TFC out of plane deformation + DW	radial	0.2	0.9	0.4	0.7	0.3	0.5
	vertical	1.0	3.2	3.2	3.5	2.1	-
	toroidal	-	-	17.4	19.2	18.3	-

The loading combinations as the boundary conditions for the tokamak machine structural analysis are summarised in the following tables.

Table 1.34-9 Load Combination for Divertor Cassette Rail

Load Combinations[1,2,3]	Category	Position	Fx[4] (KN)	Fy (KN)	Fz (KN)	Mx[5] (KNm)	My (KNm)	Mz (KNm)
Weight + Th.Loads + Th. quench	I	Inner Support	150	-350	0.0	0.0	0.0	0.0
		Outer Support	-350	-10	0.0	0.0	0.0	0.0
Weight + Th.Loads + Disr. I[6] + F.Disc..	I	Inner Support	750	380	340	90	180	-5
		Outer Support	-370	600	-80	50	470	-5
Weight + Th.Loads + VDE I$_{SLOW(A)}$[7]+ F.Disc.	I	Inner Support	900	1000	0.0	0.0	0.0	0.0
		Outer Support	-450	1250	0.0	0.0	0.0	0.0
Weight + Th.Loads + VDE I$_{SLOW(B)}$ + F.Disc.	I	Inner Support	1400	1050	0.0	0.0	0.0	0.0
		Outer Support	-30	950	0.0	0.0	0.0	0.0
Weight + Th.Loads + ICE II	II	Inner Support	710	-210	0.0	0.0	0.0	0.0
		Outer Support	-710	340	0.0	0.0	0.0	0.0
Weight + Th.Loads + Disr. II	II	Inner Support	380	-120	340	90	180	-5
		Outer Support	-420	200	-80	50	470	-5
Weight + Th.Loads + SL-1 [8] + VDE II$_{SLOW(A)}$	II	Inner Support	600	700	20	0.0	0.0	0.0
		Outer Support	-680	1000	25	0.0	0.0	0.0
Weight + Th.Loads + SL-1 + VDE II$_{SLOW(B)}$	II	Inner Support	1300	750	20	0.0	0.0	0.0
		Outer Support	-40	650	25	0.0	0.0	0.0
Weight + Th.Loads + SL-1 + Disr. I	II	Inner Support	390	-130	350	90	180	-5
		Outer Support	-450	200	-100	50	470	-5
Weight + Th.Loads + VDE III$_{SLOW(A)}$	III	Inner Support	650	900	0.0	0.0	0.0	0.0
		Outer Support	-600	1300	0.0	0.0	0.0	0.0
Weight + Th.Loads + VDE III$_{SLOW(B)}$	III	Inner Support	1550	1000	0.0	0.0	0.0	0.0
		Outer Support	150	800	0.0	0.0	0.0	0.0
Weight + Th.Loads + SL-1 + VDE II$_{SLOW(A)}$ + F. Disc.	III	Inner Support	1000	1200	20	0.0	0.0	0.0
		Outer Support	-500	1500	25	0.0	0.0	0.0
Weight + Th.Loads + SL-1 + VDE II$_{SLOW(B)}$ + F.Disc.	III	Inner Support	1700	1250	20	0.0	0.0	0.0
		Outer Support	100	1100	25	0.0	0.0	0.0
Weight + Th.Loads + SL-1 + Disr. II + F.Disc	III	Inner Support	800	400	350	90	180	-5
		Outer Support	-400	620	-100	50	470	-5
Weight + Th.Loads + SL-2 + VDE I$_{SLOW(A)}$	IV	Inner Support	600	600	50	0.0	0.0	0.0
		Outer Support	-600	900	70	0.0	0.0	0.0
Weight + Th.Loads + SL-2 + VDE I$_{SLOW(B)}$	IV	Inner Support	1100	600	50	0.0	0.0	0.0
		Outer Support	-150	600	70	0.0	0.0	0.0
Weight + Th.Loads + SL-2 + Disr. I	IV	Inner Support	420	-200	400	90	180	-5
		Outer Support	-500	240	-130	50	470	-5

Note:

(1) Design values are increased by ≈ 10 % from the calculated values to take into account the approximation in the load estimate.

(2) No difference is considered for ICE II, III, IV, as only the thermal load at the end of the transient has been considered. Moreover, the time of the ICE is not comparable with the other events so we consider (category II) only the ICE combined with weight and thermal loads due to neutron heating.

(3) Dynamic load factor (1.2) has been included.

(4) Force and moment refer to a coordinate system where "X" is the radial direction, "Y" vertical and "Z" toroidal.

(5) The summation points for the moment on the poloidal midplane of the cassette (Z=0) are for the inner support X=3935.5 mm Y = -3013 mm and for the outer side X = 6838 mm Y = -4128 mm.

(6) The EM loads produced by the eddy current during a VDE$_{FAST}$ has been conservatively used for Disruptions I and II.

(7)The slow VDE has been computed for two different distribution of the halo current along the divertor. In case "A", 25% of the total halo current enters the inner vertical target and 50% the dome while 75% of the total halo current exits from the vertical outer target. In case "B" 75% of the total halo current enters the inner vertical target while 50% of the total halo current exits from the dome and 75% from the vertical outer target.

(8)The reaction forces due to seismic accelerations has bees conservatively applied simultaneously, using the worse direction for each case.

Table 1.34-10 VV Support Load Combination at 4 Toroidal Positions (0°, 90°, 180° and 270°)

Load combination	Category	V (KN) 0°&180°	H (KN) 0°&180°	V (KN) 90°	H (KN) 90°	V (KN) 270°	H (KN) 270°	Note
W	I	6480	0	6480	0	6480	0	
W+SL1	II	8043	3131	8797	0	7289	0	a
W+SL2	IV	11072	9210	13290	0	8854	0	a
W+VDE I	I	8967	1533	8296	0	9638	0	b
W+VDE II	II	9588	1917	8749	0	10426	0	b
W+VDE III	III	10623	2556	9505	0	11741	0	b
W+SL1+VDE I	II	10527	4665	10610	0	11952	0	c
W+SL1+VDE II	III	11148	5048	11064	0	12741	0	c
W+SL1+VDE III	beyond	12184	5687	11820	0	14056	0	c
W+SL2+VDE I	IV	13557	10743	15103	0	16445	0	c
W+SL2+VDE II	beyond	14178	11127	15557	0	17234	0	c
W+SL2+VDE III	beyond	15213	11766	16313	0	18549	0	c

a) Horizontal seismic load oriented from 270° support towards 90° support, application point z=0 middle of VV
b) Highest halo currents at 270°, lowest at 90°, average at 0° and 180° creating and horizontal force from 270° towards 90°
c) Seismic and VDE load aligned as in a) and b) but the oscillating response of the VV to the earthquake with the first horizontal mode frequency 6.4 Hz provides the maximum compression in the support at 270°.
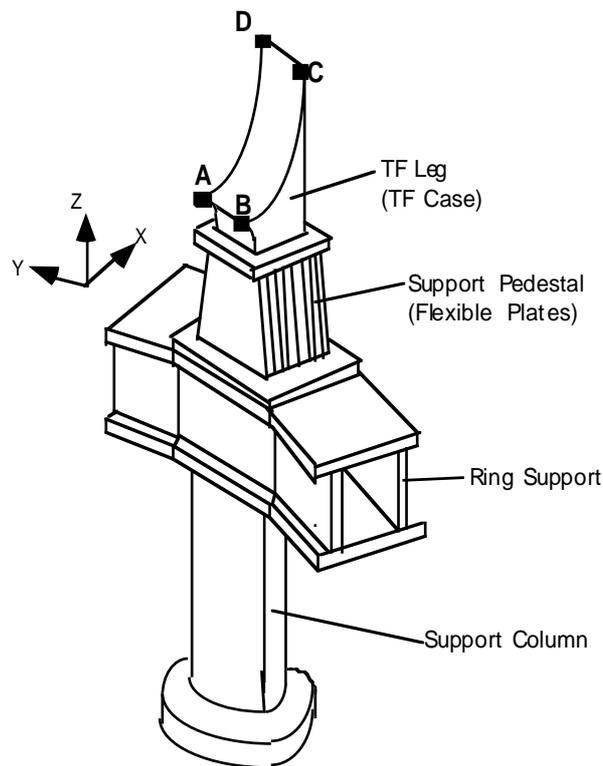
Note:

V : Force applied on the middle of the VV support in the support axial direction

H : Force applied on the middle of the VV support in the toroidal direction

Table 1.34-11 Imposed Displacement on the Interface between TF Leg and TF Case

No.	Load Case[1]	Position[2]	$Ux^{[3]}$ (mm)	$Uy^{[3]}$ (mm)	$Uz^{[3]}$ (mm)
1	Pre-Compression Load (pre-compression rings tensioned)	A	-1.87	0.00	-0.02
		B	-1.87	0.00	-0.02
		C	-1.88	0.02	0.08
		D	-1.88	-0.02	0.08
2	Cool Down of the TF coils	A	-31.75	-1.55	-4.93
		B	-31.75	1.55	-4.93
		C	-35.17	1.57	-12.05
		D	-35.17	-1.57	-12.05
3	TF Coils energized	A	-29.28	-1.60	-5.98
		B	-29.28	1.60	-5.98
		C	-35.64	1.60	-10.81
		D	-35.64	-1.60	-10.81

4	Initial Magnetization (IM-Operation)	A	-29.34	-1.65	-6.00
		B	-29.20	1.56	-5.96
		C	-35.60	1.61	-10.85
		D	-35.68	-1.59	-10.78
5	Start of Flat Top (SOF Operation)	A	-29.82	-0.92	-6.52
		B	-28.57	2.28	-5.46
		C	-35.40	5.08	-10.22
		D	-35.81	1.88	-11.39
6	End of Burn (EOB-Operation)	A	-29.88	-0.64	-6.64
		B	-28.50	2.57	-5.34
		C	-35.41	6.03	-10.00
		D	-35.80	2.83	-11.61

Notes:

(1) In this table, load cases are additive from 1 to 6. For example, the "TF coils energized" case includes the pre-compression and cool-down loads.

(2) Positions A, B, C and D are NOT those defined in Table 1.34-5 but are defined on the sketch above.

(3) Displacement refers to a coordinate system where "X" is the radial, "Y" toroidal and "Z" vertical direction, as shown in the sketch above.

2   System Functional Specification

The function of the various systems into which the ITER design is subdivided is described in the following sections. Each system is described in a corresponding DDD. The plasma control system function is not described below, because its functional requirements and design are described in the CSA plant-level assessment. With that exception, the systems described below cover the complete plant.

2.1 Magnet

The magnet system provides the following.
- TF (toroidal field) coils for the magnetic field that gives the specified plasma safety factor during the various phases of operation.
- A CS (central solenoid) for the majority of the magnetic flux change needed to initiate the plasma, generate the plasma current and maintain this current during the burn time. It contributes towards the fields needed to shape the plasma, but is not used for plasma control.
- PF (poloidal field) coils for the magnetic fields that shape the plasma and control its position during the various phases of operation, including plasma initiation, growth, burn and shut-down. The PF coils also contribute a portion of the magnetic flux change needed to ramp up and maintain the plasma current.
- CC (correction coils) to compensate for field errors due to design asymmetries and geometric tolerances in the as-built machine, and to stabilize MHD instabilities such as resistive wall modes and to provide the field required for the compensation of some helical harmonics of the magnetic field generated by irregularities in the coil current distribution.
- TF coil structures integrated with the PF coil supports and the CS structures to restrain the electromagnetic loads on the coils under normal operating and fault conditions. The TF coil structures also resist the gravity and seismic loads of the magnet system, and operational net loads on the vacuum vessel and its thermal shield, and transfer these loads to the room-temperature floor of the cryostat.

2.2 Vacuum Vessel

The vacuum vessel:
- provides the first confinement barrier and withstands postulated accidents without losing confinement;
- removes the nuclear heating and the surface heat flux within the allowable temperature and stress limits
- removes (via the VV TWCS) the decay heat of all in-vessel components, even in conditions when the other cooling systems are not functioning;
- provides a boundary consistent with the generation and maintenance of a high quality vacuum;
- supports in-vessel components and their loads normal and off-normal operations;
- together with the in-vessel components, maintains a specified toroidal electrical resistance and contributes to plasma stability;
- together with the blanket, divertor, and ancillary equipment in ports, provides adequate radiation shielding for the superconducting coils and reduces activation inside the cryostat and at cryostat connecting ducts to facilitate remote handling and decommissioning;
- provides access ports for in-vessel components, maintenance equipment, fuelling and pumping systems, diagnostics and plasma heating equipment and test blanket modules.;
- provides a conductive shell tight fitting to the plasma to aid plasma vertical stability;
- reduces the toroidal field ripple using ferromagnetic materials inserted in the vessel.

For overpressure protection to the design limits of the vessel, the vacuum vessel is connected to a vacuum vessel pressure suppression system (VVPSS) which limits the maximum pressure in the VV during an in-vessel coolant leak events.

2.3 Blanket

The blanket system:
- removes the surface heat flux and the nuclear heating within the allowable temperature and stress limits, while minimising the impurities influx to the plasma.
- reduces the nuclear responses in the vacuum vessel structural material for the ITER fluence goal.
- protects the superconducting coils, in combination with the vacuum vessel, from excessive nuclear heating and radiation damage.
- contributes to the passive stabilisation of the plasma
- via the limiter, defines the plasma boundary during start up and shut down
- breeds tritium in the case that the outboard shield blanket modules is replaced with tritium breeding blanket modules during the last 10 years of ITER operation
- provides access for the passage of the neutral beams.

For the plasma facing elements attached to the port plugs, all applicable requirements mentioned above should be considered.

2.4 Divertor

The divertor system:
*   exhausts the major part of the alpha particle power as well as He and impurity particles from the plasma, while minimising the impurities influx to the plasma. As the main interface component under normal operation between the plasma and material surfaces, it must tolerate high heat loads while at the same time providing shielding for the vacuum vessel and magnet coils in the vicinity of the divertor.

2.5   Remote Handling Equipment

The function of remote handling equipment is to provide specialised systems for divertor cassette, blanket module and NB injector maintenance, a multipurpose system for port plug removal, and for maintenance inside the cryostat.

The remote handling equipment also includes:
*   the in-vessel viewing/metrology system;
*   dust removal equipment;
*   leak check probe deployment system;
*   any equipment needed for reactor disassembly/re-assembly in addition to that used for initial assembly, in particular that equipment needed for RH Class 3 maintenance;
*   repair/maintenance equipment in the hot cell.

2.6 Vacuum Pumping and Fuelling

The vacuum pumping and fuelling system shall provide the following functions:

Torus Pumping System
- roughing of the torus from atmosphere to cross-over pressure of the torus high vacuum pumps,
- pumping and purging of the vessel prior to the implementation of remote maintenance activities,
- provision of high vacuum pumping of the torus during all phases of operation; following cross over from the torus roughing system, including:-
  - during the pulse to remove excess fuelling gas, impurities and helium,
  - between pulses,
  - during bake-out and conditioning,
  - leak detection
  - recovery of tritium from PFC codeposited layers.

Cryostat Pumping System
- roughing of the cryostat from atmosphere to cross-over pressure of the cryostat high vacuum pumps,
- evacuation of the cryostat to high vacuum prior to the cool-down of the magnets,
- pumping of minor helium leaks from the magnets cooling circuits,
- evacuation of the cryostat following a helium in-break.

Other Systems
- evacuation of the NB injector prior to cool down and regeneration of the NB cryogenic pump to a schedule compatible with NB operation,
- pumping of other heating systems,
- pumping of diagnostics systems, and
- pumping of guard vacuum systems, and
- provision of controlled venting of the torus, cryostat and all other vacuum systems.

Leak Detection Systems
- provision of the leak testing of the vacuum integrity of all major systems which may be exposed to primary or cryostat vacuum,
- measurement of the total in-leakage into the vacuum vessel and cryostat,
- measurement of the in-situ leak rates of individual elements,
- provision of the capability to locate, at the component and element level, i.e. blanket module, divertor module, vacuum vessel port etc., any unacceptable leak rate to allow the intervention of remote maintenance activities to substantiate the source of the leak and implement corrective action, and
- provision of the capability for leak testing, in the operational configuration, the various systems of the torus and cryostat during the final construction and commissioning of the machine.

Fuelling Systems
- provision of the capability for both gas and pellet fuelling,
- provision of fuelling into the main plasma at a rate determined by fusion power, density control and SOL flow requirements, with specified response time,
- injection of impurity gases into the divertor plasma for radiative cooling, and discharge termination,
- provision of wall conditioning gases using the same system used for hydrogenic gas fuelling of the plasma;
- provision of an emergency fusion power shutdown.

Wall Conditioning Systems
- provision of wall conditioning systems that reduce and control impurity and hydrogenic fuel outgassing from plasma facing components for achievement of clean and stable plasma operation.

2.7 Tritium Plant and Detritiation

The tritium plant has the following major functions.

- Handling of incoming and outgoing tritium shipments and transfers to/from the fuel cycle.
- Storage of tritium and deuterium.
- Measurement and determination of tritium inventories.
- Preparation and delivery of deuterium and tritium/deuterium mixtures for fuelling.
- Supply of divertor impurity seeding gases.
- Processing of tokamak exhaust and neutral beam exhaust for recycling of tritium and deuterium, including:
  - separation of hydrogen from all other exhaust gases;
  - separation of hydrogen into specific isotopic species for refuelling;
  - detritiation of impurities for controlled release into environment.
- Detritiation of atmospheres for normal, maintenance and emergency operations.
- Detritiation of water to allow release of excess protium into environment.
- Extraction of tritium from breeding blanket modules (if required) and processing of tritium from test blanket modules.
- Extraction of decay He-3.
- Processing of tritiated gas stream generated during tritium recovery from plasma-facing components.

2.8 Cryostat

The cryostat:
- provides a vacuum environment to avoid the thermal loads applied to the superconducting magnet system by gas conduction and convection**;**
- is a part of the secondary confinement barrier;
- allows passive removal of decay heat, when the cryostat vessel is filled by gaseous helium**;**
- has penetrations for :
    - equipment connecting elements of systems outside the cryostat to the corresponding elements inside the cryostat (magnet feeders, water cooling pipes, instrumentation feedthroughs, CV pumping systems);
    - access corresponding to VV ports;
    - access ways for remote maintenance equipment into the cryostat and the vacuum vessel;
    - access to the CS coil for possible direct removal (access for removal of any TF or PF coil shall be possible as a RH Class 3 operation, even at the expense of cutting and rewelding parts of the cryostat vessel)
- transfers all the loads, which derive from the tokamak basic machine and the cryostat itself during the normal and off-normal operational regimes and at specified accidental conditions, to the floor of the tokamak pit through its support structures.
- includes overpressure protection for itself.

2.9 Thermal Shields

The function of the thermal shield is to limit the heating of the superconducting coils from warm outside sources to levels that can be tolerated by the coils and reasonably removed by the coil refrigeration system. The shields intercept thermal radiation from the warm surfaces of the vacuum vessel outer wall, ports, port extensions and gravity supports, cooling pipes and other warm ducting, and the cryostat inner wall as well as restrict heat loads transferred by conductance through vacuum vessel and machine gravity supports by means of thermal anchors.

2.10 Cryoplant and Cryodistribution

The cryoplant provides cooling for the following components:
- the superconducting magnet system (4.3K forced-flow He),
- the thermal shields (80K forced flow He),
- the torus, NB and cryostat cryopumps (4.3K forced flow He as well as 80K forced flow to the NB pumps),
- small users including pellet fuelling, gyrotrons and diagnostics (combinations of above).

The main load by far is the magnet system.

2.11 Cooling Water

The main functions of the cooling water system which consists of the tokamak cooling water system (TCWS), cooling water systems for auxiliaries, and the site heat rejection system (HRS), are to:
- remove heat deposited in the in-vessel components, the vessel, additional heating systems, and diagnostics during the burn cycle;
- maintain coolant temperatures, pressures, and flow rates to limit component temperatures and retain thermal margins during the operating campaign as required;
- remove decay heat also during shutdown periods;
- provide baking for the in-vessel components;
- maintain water chemistry as required;
- accommodate draining, and provide refilling and drying for maintenance periods;
- provide confinement of radioactive inventories;
- maintain radioactive inventory as required;
- measure heat removed from the in-vessel components and vacuum vessel;
- remove heat from plant auxiliary systems (RF heating power tubes, NB Injectors, etc.);
- reject all the above heat to the environment.

2.12 Pulsed and Steady State Power Supplies

The main functions of this system are to:
- provide pulsed power to the PF and CS and correction coils and energise the TF coils;
- protect the superconducting coils by fast discharge in case of quench;
- protect the coils against over-voltages or/and over-currents due to abnormal or fault operation of power supplies or in case of plasma current disruption;
- ground the magnet system components and provide ground leakage current sensing;
- supply the DC electrical power to the IC H&CD tetrodes, to the EC H&CD gyrotrons, to the LH H&CD klystrons and to the Neutral Beam Injectors;
- provide voltage regulation and control to these loads;
- protect these loads and power supplies in case of breakdown.
- produce a steady state electrical power network (SSEPN) providing
  - class IV and class III AC power for plant loads.
  - the unified grounding grid for the site.

The SSEPN does not supply class I and/or class II AC power to plant loads. Class I&II power supplies are integral parts of those systems, which require such power. However, the SSEPN provides Class III power needed for the Class II loads to limit the capacity of the batteries required by Class II by reducing the power supply interruption time. Class III power is also provided for the continuous recharge of the DC batteries. For classification of power, see Section 2.19.

2.13 Ion Cyclotron H&CD

The IC H&CD system is designed to:
- access H mode and heat plasma at Q>10. (with preference to bulk ion heating),
- provide steady state current drive capability for DT, D, H and He plasmas, in particular to provide central current drive in high bootstrap fraction scenarios,
- accomplish several functions of plasma control, including burn and plasma transport, control by sawtooth frequency control, and current profile control,
- achieve plasma break-down, burn-through and assisted current rise at low start-up electric fields.
- conduct IC resonance discharge cleaning (ICR-DC) at full BT

2.14 Electron Cyclotron H&CD

The EC H&CD system is designed to:
- access H mode and heat plasma to Q>10. (with electron heating),
- provide steady state current drive capability for DT, D, H and He plasmas,
- drive current
- assist plasma control, and in particular provide stabilisation for neo-classical tearing modes (NTMs),
- conduct wall conditioning during the inter-pulse and machine conditioning phase
- assist the poloidal field system in establishing breakdown and current initiation.

2.15 Neutral Beam H&CD

The NB H&CD system is designed to:
- access the H-mode and heat plasma at Q>10,
- provide steady state current drive capability (on-axis, off-axis) for DT, D, H and He plasmas,
- modify current density and q profile,
- provide plasma rotation.
- provide power to sustain the density during shutdown and allow for controlled transition from H to L-mode at the end of burn,

2.16 Lower Hybrid H&CD

The LH H & CD system is designed to:

- provide steady state off-axis current drive capability for DT, D, H and He plasmas,
- modify current density and q profile

2.17 Diagnostics

The function of the ITER diagnostic system is to provide accurate measurements of plasma behaviour and performance. There are three categories of parameters to be measured:

group 1a   those needed for machine protection and basic machine control;
group 1b: those required for advanced plasma control;
group 2:   those required for evaluation and physics studies.

The machine is unable to operate without a working diagnostic providing every group 1a parameter (1b for advanced operation). The machine may operate without a group 2 parameter diagnostic in operation.

Detailed classification and requirements are described in Section 1.13.

2.18 Control, Alarm and Interlock Systems

The functions of data acquisition, command and control shall be performed by a system consisting of both a COmmand control, Data Acquisition and Communication (CODAC) system and individual subsystems dedicated to the same functions for the systems that they serve.
The CODAC shall not be assigned any safety functions.

The functions of General Alarming and preventive/protective action (Interlocks) shall be performed by a separate system, also consisting of a central supervisory system, and individual subsystems dedicated to the systems that they serve.

Safety related instrumentation, control actions and monitoring shall be identified and may be implemented at the subsystem or integrated level, separate from the above mentioned systems. Detail will be determined in the succeeding phase of the project.

2.19 Steady State Power Supply System

Stead State Power Supply is classified into the following four classes to provide necessary power to each component.

Class I   : Uninterruptible DC
Class II   : Uninterruptible AC
Class III   : Temporarily interruptible AC
Class IV   : Indefinitely interruptible AC

2.20 Buildings and Layout

The tokamak building provides the following:
- assembly of the machine from the top, with the surrounding buildings and systems organised to permit approach to the tokamak from both north and south,, and with the tokamak buildings and site arranged to allow future construction for tokamak repair or decommissioning at a minimum cost;
- a convenient and a safe operating environment with the minimum size and cost;
- radiologically controlled areas enclosed in a contiguous boundary, to facilitate maintenance, remote handling, HVAC maintenance, access control, and personnel exposure management.

All buildings must house, support, protect, control access to, provide suitable environmental conditions for, and provide services to the components, systems, personnel and operations which are located or operate within them.

The site layout provides the space necessary to house the tokamak and all of its auxiliary systems and services.

2.21 Radiological and Environmental Monitoring

The personnel radiation monitoring and protection system (PRM & PS) provides radiological monitoring and protection to personnel from ionizing radiation including tritium. The function is accomplished by a combination of sub-systems, which include fixed and movable radiation/contamination monitors working in conjunction with a dosimetry and bioassay system. Personnel radiation protection is provided by protective equipment such as bubble suits and breathing air systems (covered under liquid and gas distribution systems).

The environmental monitoring system (EMS) provides environmental information suitable for monitoring compliance with environmental regulations. The function is accomplished by a combination of fixed and movable environmental monitors working in conjunction with a sampling and inspection program.

2.22 Liquid and Gas Distribution

The functions of the liquid and gas distribution system is to distribute potable and fire-fighting water, remove sanitary and industrial sewage, to supply steam and demineralized water, to supply compressed and breathing air, and to provide nitrogen, helium and special gases.

2.23 Hot Cells and Waste Processing

The function of the hot cell component repair system is to process and repair components, tools, and equipment which have become activated by neutron exposure and/or contaminated with tritium or activated dust. Processing includes examination, preparation of service plan, preparation of samples for material evaluation, evaluation and segregation of parts into those which can be reused and those which must be replaced, disassembly, replacement of parts, re-assembly, and inspection/testing. Components which enter the system for repair may be diverted to the hot cell waste processing system.

The function of the hot cell waste processing and storage system is to process and store solid radioactive materials which have been removed from the tokamak and which will be discarded. Waste processing includes disassembly. The hot cell waste processing and storage system provides up to 6 months storage of radioactive waste for an interim period prior to hand-over to the host.

A low-level waste processing system (LLPS) is provided to process solid and/or liquid waste process streams, which have become contaminated with radioactive materials.

2.24 Test Blanket

The function of the test blanket modules is to test design concepts of tritium breeding blankets relevant to a future fusion power reactor. The test programme includes small test articles and modules that can be inserted in equatorial ports. The potential concepts include:

- water-cooled solid breeder;
- helium-cooled solid breeder;
- self-cooled liquid lithium;
- water-cooled lithium-lead.

The test blanket modules provide their own first wall, shielding and thermal control to appear to the vessel and surrounding blanket modules as a normal port plug. They also provide their own services (cooling and tritium recovery) and connection to site services for heat rejection and tritium environmental control. They conform to tritium inventory limit requirements and can be remotely repaired using the port plug handling system.

The testing of breeding blanket modules should not interfere with the ITER operation, decrease ITER reliability and compromise safety of operation or contradict to ITER operational plans.

Blanket module testing will be done whenever significant neutron fluxes become available. To ensure that test blanket modules will be compatible with tokamak operation they must be installed as early as possible before beginning of the DT operation.

As a rule the TBMs will be changed once per year in accordance with ITER operational schedule. Some modules may need additional replacements, which shall be synchronised among the Parties and with machine operation. Target replacement time must be less than 1 month for all TBM's ports together.

2.25 Assembly Tooling

The function of assembly tooling is to provide equipment to support the tokamak assembly process complementary to that provided with the component to be installed, or for remote maintenance, or as part of the building services.