

**REFERENCE LEVEL 0 – ITER MANAGEMENT
APPROVED SPECIFICATIONS**

**INCLUDED IN THE PLANT INTEGRATION DOCUMENT (PID)
JUNE 2004**

4.22.1 Functional Requirements

The function of the ITER plasma 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. Measurements in each group are shown in Table 1. The requirements for each measurement are shown in Table 2.

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

GROUP 1a Measurements For Machine Protection and Basic Control	GROUP 1b Measurements for Advanced Control	GROUP 2 Additional Measurements for Performance Evaluation and Physics
<ul style="list-style-type: none"> • Plasma shape and position, separatrix- wall gaps, gap between separatrixes • Plasma current, q(a), q(95%) • Loop voltage • Fusion power • $\beta_N = \beta_{tor}(aB/I)$ • Line-averaged electron density • Impurity and D,T influx (divertor, & main plasma) • Surface temp. (div. & upper plates) • Surface temperature (first wall) • Runaway electrons • 'Halo' currents • Radiated power (main pla, X-pt & div). • Divertor detachment indicator (J_{sat}, n_e, T_e at divertor plate) • Disruption precursors (locked modes, $m=2$) • H/L mode indicator • Z_{eff} (line-averaged) • n_T/n_D in plasma core • ELMs • Gas pressure (divertor & duct) • Gas composition (divertor & duct) • Dust 	<ul style="list-style-type: none"> • Neutron and α-source profile • Helium density profile (core) • Plasma rot. (tor and pol) • Current density profile (q-profile) • Electron temperature profile (core) • Electron den profile (core and edge) • Ion temperature profile (core) • Radiation power profile (core, X-point & divertor) • Zeff profile • Helium density (divertor) • Heat deposition profile (divertor) • Ionization front position in divertor • Impurity density profiles • Neutral density between plasma and first wall • n_e of divertor plasma • T_e of divertor plasma • Alpha-particle loss • Low m/n MHD activity • Sawteeth • Net erosion (divertor plate) • Neutron fluence 	<ul style="list-style-type: none"> • Confined α-particles • TAE Modes, fishbones • T_e profile (edge) • n_e, T_e profiles (X-point) • Ti in divertor • Plasma flow (divertor) • $n_T/n_D/n_H$ (edge) • $n_T/n_D/n_H$ (divertor) • T_e fluctuations • n_e fluctuations • Radial electric field and field fluctuations • Edge turbulence • MHD activity in plasma core

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

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	RESOLUTION		ACCURACY
				Time or Freq.	Spatial or Wave No.	
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	–	10 mm
		I_p Quench	–	10 ms	–	20 mm
	Divertor channel location (r dir.)	Default	–	10 ms	–	10 mm
		I_p Quench	–	10 ms	–	20 mm
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	~ 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	$1 \cdot 10^{18} - 4 \cdot 10^{20} / m^3$	1 ms	Integral	1 %
		After killer pellet	$8 \cdot 10^{20} - 2 \cdot 10^{22} / m^3$	1 ms	Integral	100 %
7. Neutron Flux and Emissivity	Total neutron flux		$1 \cdot 10^{14} - 5 \cdot 10^{20} n/s$	1 ms	Integral	10 %
	Neutron / α source		$1 \cdot 10^{14} - 4 \cdot 10^{18} n/m^3/s$	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.		$1 \cdot 10^{-4} - 5 \cdot 10^{-2}$	10 ms	Integral	10 % (rel.)
	Be, C influx		$4 \cdot 10^{16} - 2 \cdot 10^{19} /s$	10 ms	Integral	10 % (rel.)
	Cu rel. conc.		$1 \cdot 10^{-5} - 5 \cdot 10^{-3}$	10 ms	Integral	10 % (rel.)
	Cu influx		$4 \cdot 10^{15} - 2 \cdot 10^{18} /s$	10 ms	Integral	10 % (rel.)
	W rel. conc.		$1 \cdot 10^{-6} - 5 \cdot 10^{-4}$	10 ms	Integral	10 % (rel.)
	W influx		$4 \cdot 10^{14} - 2 \cdot 10^{17} /s$	10 ms	Integral	10 % (rel.)
	Extrinsic(Ne,Ar, Kr) rel. conc.		$1 \cdot 10^{-4} - 2 \cdot 10^{-2}$	10 ms	Integral	10 % (rel.)
	Extrinsic (Ne, Ar, Kr) influx		$4 \cdot 10^{16} - 8 \cdot 10^{18} /s$	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 (n _e , T _e)	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) • I _p	10 ms		30 % rel
16. Divertor Operational Parameters	Max. surface temperature		200 – 2500°C	2 ms	–	10 %
	Erosion rate		1 – 10 x 10 ⁻⁶ m/s	2 s	10 mm	30 %
	Net erosion		0 – 3 mm	Per pulse	10 mm	12 x 10 ⁻⁶ m
	Gas pressure		1 • 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	100 mm	–
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 • 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 – 40 keV	10 ms	a/30	10 %
	Edge T _e	r/a > 0.9	0.05 – 10 keV	10 ms	5 mm	10 %
24. Electron Density Profile	Core N _e	r/a < 0.9	3 • 10 ¹⁹ – 3 • 10 ²⁰ /m ³	10 ms	a/30	5 %
	Edge N _e	r/a > 0.9	5 • 10 ¹⁸ – 3 • 10 ²⁰ /m ³	10 ms	5 mm	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	–	50 mm/a
	r(q _{min})/a	Reverse shear control	0.3 – 0.7	1 s	–	50 mm/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 – 40 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		$(0.1 - 2) \cdot 10^{18}/m^3$	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, $Z \leq 10$	$r/a < 0.9$	0.5 – 20 %	100 ms	a/10	20 %
		$r/a > 0.9$	0.5 – 20 %	100 ms	50 mm	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	50 mm	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	50 mm	30 %
	Γ_D, Γ_T		$10^{19} - 10^{25}$ at/s	1 ms	50 mm	30 %
36. Plasma Parameters at the Divertor Targets	Ion flux		$10^{19} - 10^{25}$ ions/s	1 ms	3 mm	30 %
	n_e		$10^{18} - 10^{22}$ /m ³	1 ms	3 mm	30 %
	T_e		1 eV – 1 keV	1 ms	3 mm	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	50 mm	30 %
38. Heat Loading Profile in Divertor	Surface temperature		200 – 1000°C	2 ms	3 mm	10 %
			1000 – 2500°C	20×10^{-6} s	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	50 mm along leg, 3 mm across leg	20 %
	T_e		0.3 – 200 eV	1 ms	50 mm along leg, 3 mm across leg	20 %
42. Ion Temperature in Divertor	T_i		0.3 – 200 eV	1 ms	50 mm along leg, 3 mm across leg	20 %
43. Divertor Plasma Flow	V_p		TBD – 10^5 m/s	1 ms	100 mm 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 %