FIRE Measurement Specifications (Revised 2/19/02)

(prepared in style used by ITER Group)

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	ΔT or ΔF	ΔX or Δk	ACCURACY
1. Plasma Current	I_p	Default	0 – 1 MA	1 ms	Integral	10 kA
			1 - 8.0 MA	1 ms	Integral	1 %
		I_p Quench	8.0 – 0 MA	0.1 ms	Integral	30 % + 10 kA
2. Plasma Position and Shape	Main plasma gaps, Δ_{sep}	I_p > 1 MA, full bore	-	10 ms	-	0.5 cm
		I_p Quench	-	1 ms	-	1 cm
	Divertor channel location (r dir.)	Default	-	10 ms	-	0.5 cm
		I_p Quench	-	1 ms	-	1 cm
	dZ/dt of current centroid	Default	0 – 100 m s^{-1}	0.1 ms	-	0.05 m/s (noise) + 3% (absolute)
3. Loop Voltage	V_{loop}	Default	0 – 30 V	1 ms	4 locations	5 mV
		I_p Quench	0 – 500 V	0.1 ms	4 locations	10 % + 5 mV
4. Plasma Energy	β_p	Default	.01 – 1	1ms	Integral	5 % @ β_p = 1
		Thermal Quench	.01 – 1	0.1 ms	Integral	~ 30 %
5. Radiated Power	Main Plasma P_{RAD}	Default	TBD –.2 GW	10 ms	Integral	10 %
	X-point / MARFE region P_{RAD}	Default	TBD – 0.2 GW	10 ms	Integral	10 %
	Divertor P_{RAD}	Default	TBD – 0.2 GW	10 ms	Integral	10 %
	Total P_{RAD}	Disruption	TBD – 20 GW	1 ms	Integral	20 %
6. Line-Averaged Electron Density	$\int n_e\, dl / \int dl$	Default	$1 \cdot 10^{18}$ – $1 \cdot 10^{21}$ 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		$1 \cdot 10^{14}$ – $1 \cdot 10^{20}$ n s^{-1}	1 ms	Integral	10 %
	Neutron / α source		$1 \cdot 10^{14}$ – $5 \cdot 10^{18}$ $nm^{-3}s^{-1}$	1 ms	a/10	10 %
	Fusion power		0.01 – 0.25 GW	1 ms	Integral	10 %
	Fusion power density		0.1 - 20 MW m^{-3}	1 ms	a/10	10 %
8. Locked Modes	$B_r(mode)/B_p$		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 – 10 kHz	(0,0) < (m,n) < (10,2)	10 %
	Mode – induced temperature fluctuation		TBD	DC – 10 kHz	0,0) < (m,n) < (10,2) Δr = a /30	10 %
	Other mode parameters		TBD	DC – 30 kHz	Integral	10 %
10. Plasma Rotation	V_{TOR}		1 – 100 km s^{-1}	10 ms	a/30	30 %
	V_{POL}		1 – 50 km s^{-1}	10 ms	a/30	30 %
11. Fuel Ratio in Plasma Core (D-T Operation)	n_T/n_D	r/a < 0.9	0.1 – 10	100 ms	a /10	20 %

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12. Impurity Species Monitoring	O, C rel. conc.		$1 \cdot 10^{-4}$ – $5 \cdot 10^{-2}$	10 ms	Integral	10 % (rel.)
	Be rel. conc.		$1 \cdot 10^{-4}$ – $5 \cdot 10^{-2}$	10 ms	Integral	10 % (rel.)
	Be influx		$4 \cdot 10^{16}$ – $2 \cdot 10^{19}$ s^{-1}	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^{-1}	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^{-1}	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^{-1}	10 ms	Integral	10 % (rel.)
13. Z_{eff} (Line-Averaged)	Z_{eff}		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			
	ELM temperature transient	r/a > 0.9	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 –20 MeV	10 ms	-	20 %
	$I_{runaway}$	After Thermal quench	(0.05 – 0.7) · I_p	10 ms		30 % rel
16. Divertor Operational Parameters	Maximum surface temperature		200 – 2500°C	2 ms	1 cm	10 %
	Real-time net erosion		0 – 3 mm	1 s	1 cm apart	0.2 mm
	Gas pressure		$1 \cdot 10^{-4}$ – 5 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 – 0.3 m	1 ms	2 cm	-
17. First Wall Visible Image & Wall Temperature	1st wall image		TBD	100 ms	1 mm	-
	Wall surface temperature		200 – 1500°C	10 ms	1 cm	20°C
18. Gas Pressure and Composition in Main Chamber	Gas pressure	Between & during pulses	$1 \cdot 10^{-7}$ – 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 Divertor Ducts	Gas pressure	Between & during pulses	TBD	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 first wall and divertor	-	1 mm	-
21. Halo Currents	Poloidal current	In disruption	0 – 0.2 I_p	1 ms	Locations TBD	20 %
22. Toroidal Magnetic Field	B_T		2 – 12 T	1 s	2 locations $\times$ 2 methods	0.1 %

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23. Electron Temperature Profile	Core T_e	r/a < 0.9	0.5 – 15 keV	10 ms	a/30	10 %
	Edge T_e	r/a > 0.9	0.05 – 5 keV	10 ms	0.5 cm	10 %
24. Electron Density Profile	Core N_e	r/a < 0.9	$3 \cdot 10^{19}$ – $1 \cdot 10^{21}$ m^{-3}	10 ms	a/30	5 %
	Edge N_e	r/a > 0.9	$5 \cdot 10^{18}$ – $1 \cdot 10^{21}$ m^{-3}	10 ms	0.5 cm	5 %
25. Current profile	q(r)	Physics study	0.5 - 5	10 ms	a/30	10 %
			5 – TBD	10 ms	1 cm	0.5
	r(q=1.5,2)/a	NTM feedback	0.3 – 0.9	10 ms	2 cm	2 mm
	$r(q_{min})/a$	Reverse shear control	0.3 – 0.7	1 s	2 cm	2 mm
26. Zeff 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, AEs, turbulence)	Fishbone – induced perturbations in B,T,n		(m,n) =(1,1)	0.1 –10 kHz	1 cm	-
	AE Mode – induced perturbations in B,T,n		n = 10 - 50	10 –300 kHz	1 cm	-
	High frequency turbulence	Correlation	-	10 –300 kHz	1 cm	-
28. Ion Temperature Profile	Core T_i	r/a < 0.9	0.5 – 15 keV	100 ms	a/10	10 %
	Edge T_i	r/a > 0.9	0.05 – 5 keV	100 ms	1 cm	10 %
29. Core Helium 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		$(0.1 – 4) \cdot 10^{18}$ m^{-3}	100 ms	a/10	20 %
31. Escaping Alphas	First wall flux	Default	$1 \cdot 10^{-2}$– 2 MW m^{-2}	100 ms	a/10 (along poloidal direction)	10 %
		Transients	$1 \cdot 10^{-1}$– 20 MW m^{-2}	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	2 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	2 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 – 100	100 ms	Radial integral	20 %
34. Neutron Fluence	First wall fluence per pulse		0.1 – 50 MJ m^{-2}	10 s	TBD	10 %
35. Impurity and D,T Influx in Divertor	Γ_{Be},Γ_W		10^{17} – 10^{22} at s^{-1}	1 ms	1 cm	30 %
	Γ_D,Γ_T		10^{19} – 10^{25} at s^{-1}	1 ms	1 cm	30 %

36. Plasma Parameters at the divertor targets	Ion Flux		10^{19}-10^{25} ions s^{-1}	1 ms	0.3 cm	30 %
	n_e		10^{18} – 10^{22} m^{-3}	1 ms	0.3 cm	30 %
	T_e		1eV –1 keV	1 ms	0.3 cm	30 %

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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 – 100	100 ms	integral	20 %
41. Divertor electron parameters	n_e		10^{19} – 10^{22} m^{-3}	1 ms	2 cm along leg, 3 mm across leg	20 %
	T_e		0.3 –200 eV	1 ms	2 cm along leg, 3 mm across leg	20 %
42. Ion Temperature in Divertor	T_i		0.3 –200 eV	1 ms	2 cm along leg, 3 mm across leg	20 %
43. Divertor Plasma Flow	V_p		TBD – 10^5 ms^{-1}	1 ms	2 cm along leg, 3 mm across leg	20 %
44. n_H/n_D Ratio in Plasma Core	n_H/n_D		0.01 – 100	100 ms	a/10	20 %
45. Neutral Density between Plasma and First Wall	D/T influx in main chamber		10^{18} – 10^{20} at $m^{-2}s^{-1}$	100 ms	Several poloidal and toroidal locations	30 %

Note: FIRE is a double null device with two divertors. The determination of what measurements will be duplicated in the divertors has not yet been made.