Neutron diagnostics for JT60-SA Scoping studies – Kick-off Meeting

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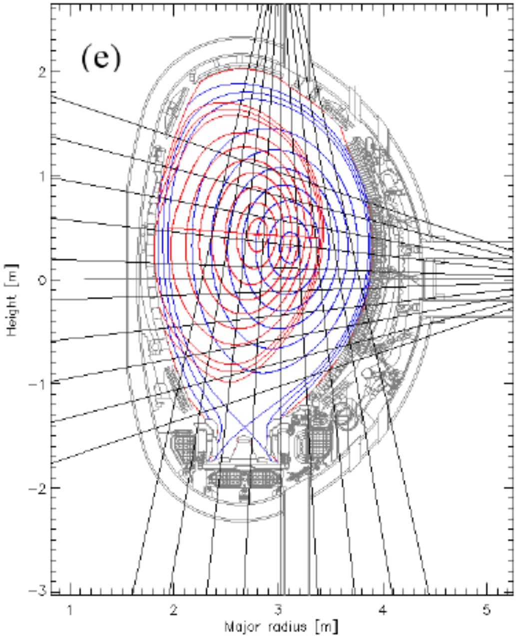
Overview of JT60-SA scenarios

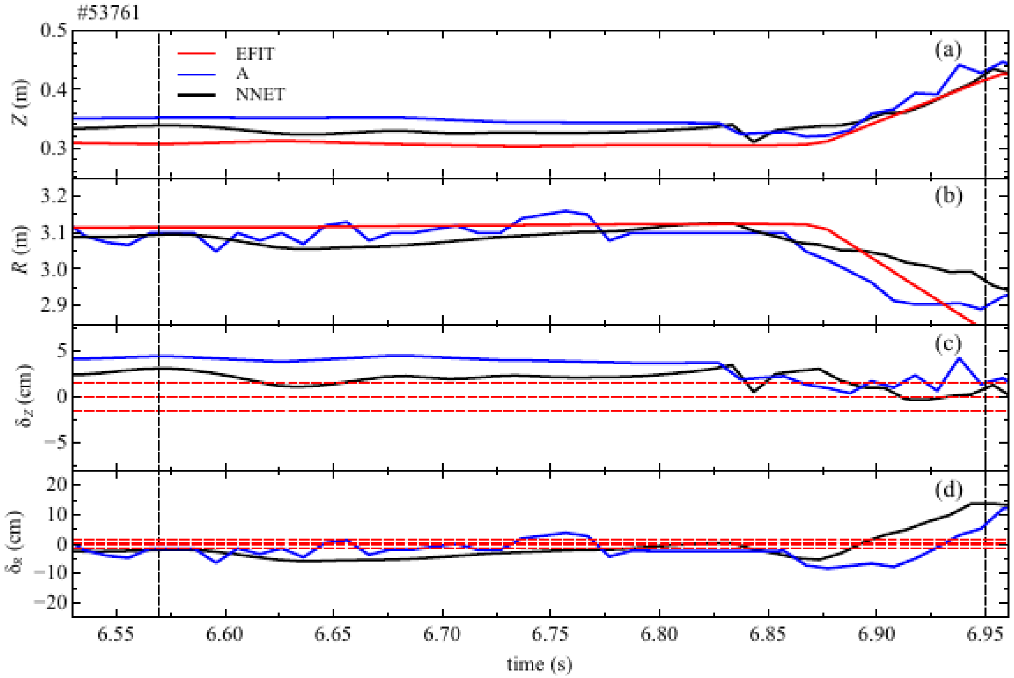
	#1	#2	#3	#4-1	#4-2	#5-1	#5-2	#6[(1)]
	Full Current Inductive DN, 41MW	Full Current Inductive SN, 41MW	Full Current Inductive High density	ITER-like Inductive	Advanced Inductive (hybrid)	High β_N Full-CD	High β_N High f_{GW} Full-CD	High β_N 300s
Plasma Current (MA)	5.5	5.5	5.5	4.6	3.5	2.3	2.1	2.0
Toroidal field BT (T)	2.25	2.25	2.25	2.28	2.28	1.72	1.62	1.41
q_{95}	~3	~3	~3	~3	~4.4	~5.8	6.0	~4
R/a (m/m)	2.96/1.18	2.96/1.18	2.96/1.18	2.93/1.14	2.93/1.14	2.97/1.11	2.96/1.12	2.97/1.11
Aspect ratio A	2.5	2.5	2.5	2.6	2.6	2.7	2.6	2.7
Elongation κ_x	1.95	1.87	1.86	1.81	1.80	1.90	1.91	1.91
Triangularity δ_x	0.53	0.50	0.50	0.41	0.41	0.47	0.45	0.51
Shape factor S	6.7	6.3	6.2	5.7	5.9	7.0	7.0	6.4
Volume (m^3)	132	131	131	122	122	124	124	124
Cross-section (m^2)	7.4	7.3	7.3	6.9	6.9	6.9	6.9	6.9
Normalised beta β_N	3.1	3.1	2.6	2.8	3.0	4.3	4.3	3.0
Electron density ($10^{19} m^{-3}$) Line-average/volume-average	6.3/5.6	6.3/5.6	10./9	9.1/8.1	6.9/6.2	5.0/4.2	5.3/4.3	2.0/
P_{add} (MW) $P_{NNB}/P_{PNB}/P_{EC}$ (MW)	41 10/24/7	41 10/24/7	30 10/20/-	34 10/24/-	37 10/20/7	37 10/20/7	30 6/17/7	13.2 3.2/6/4
Neutron production rate, S_n (n/s)	1.3×10^{17}	1.3×10^{17}	7.0×10^{16}	6.7×10^{16}	5.4×10^{16}	4.5×10^{16}	2.9×10^{16}	1.2×10^{16}

N-NBI (500 keV)
P-NBI (85 keV)

JT-60SA bulk plasma physics

- Long pulse operation at high-β with Real-time plasma position control based on collimated neutron flux monitors
- Off-axis NBCD efficacy and optimization via neutron emission profiles: the behaviour of fast-ions during their slowing-down processes is also a key issue to understand the physics of off-axis NBCD since the current drive is dominated by these fast-ions.
- Scenario development via fuel ion density and temperature profiles
- Triton-burn up contribution (not insignificant)





JT-60SA fast particle physics

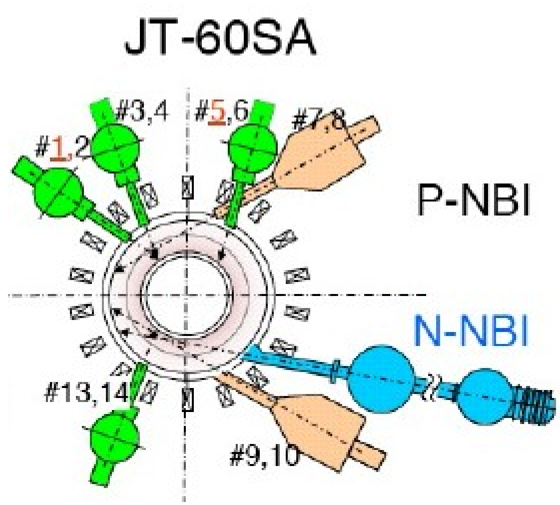
- Positive and negative NBIs @ 85 and 500 keV resulting in two different fast ions populations with different energy and pitch-angle parameters, driving different EPs (FBs) and TAEs, GAEs and CAEs;
- Super-Alfvénic velocity of the N-NBI driven fast ion population driving TAEs, , GAEs and CAEs; impact on current drive efficency.
- Orbits of MeV D ions (from NNB) comparable to α-s orbits at ITER and DEMO;

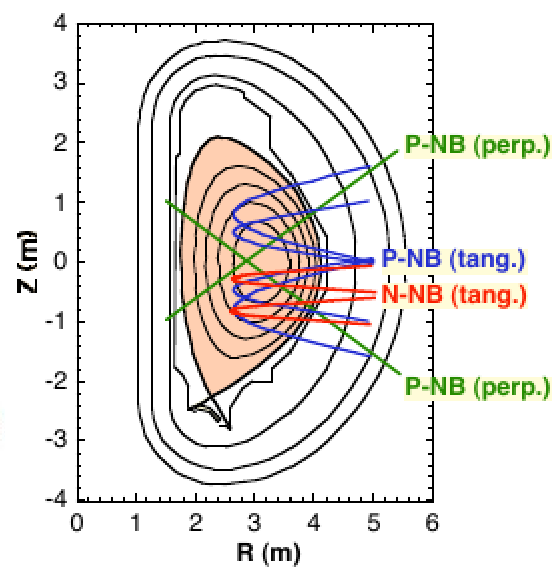
Tokamak	TFTR	JET	JET	JT-60U	ITER	Slim CS	JT-60SA Scen#1-#5-1
Fast ion	Alpha	Alpha	Alpha	Deuterium	Alpha	Alpha	Deuterium
Source	Fusion	Fusion	ICRF tail	Co NBI	Fusion	Fusion	Co NBI
τ_s [s]	0.5	1.0	0.4	0.085	0.8	~2	0.5 - 1.6
n_f _max / $n_e(0)$ [%][a]	0.3	0.44	1.5	2	0.85		0.35 - 2.2
β_f _max [%][a]	0.26	0.7	3	0.6	1.2		0.54 – 2.3
$<\beta>$ [%]	0.03	0.12	0.3	0.15	0.3	~1.2	0.2 – 0.9
β_f _max / $<\beta>$	8.7	5.8	10	4	4		2.5 – 3.2
max $\vert R\nabla\beta_f \vert$ [%]	2.0	3.5	5	6	3.8		5.2 – 65
v_f _max / v_A	1.6	1.6	1.3	1.9	1.9	~2	1.0 – 1.26

- Coupling of anomalous transport of fast ions to micro turbulence controlled by E_{NNBI}/T_e: neutron emissivity profiles to assess diffusion coefficients.
- Verification & validation (V&V) activities of theory-based transport codes for energetic ions through neutron experimental measurements
- Triton burn-up as a proxy for (DT neutrons) to study the transport of 1 MeV tritons which have a Larmor radius similar to that of 3.5 MeV α-s.
- ELMs and RMPs impact on fast ions confinement (neutron emissivity profiles).

NBI system at JT60-SA

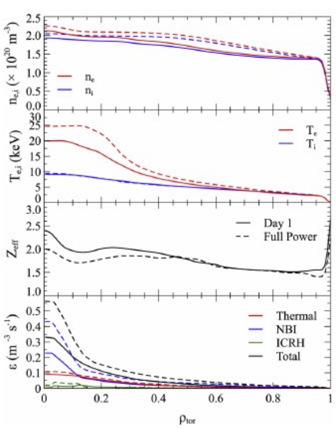
D^0 Beam	No. of unit	Energy (keV)	Power /unit (MW)	Total Power (MW)	duration (s)
Positive Ion Source NB : for heating (ion heating dominant), torque input control, some current drive					
Perpendicular – upper (#2,4,6,14)	4	85	1.7 -> 2 (initial & integrated research phases: 1.7MW/unit, extended research phase: 2MW/unit)	6.8 -> 8	100
Perpendicular – lower (#1,3,5,13)	4			6.8 -> 8	
CO-tangential – upper (#10)	1			1.7 -> 2	
CO-tangential – lower (#9)	1			1.7 -> 2	
CTR-tangential-upper (#8)	1			1.7 -> 2	
CTR-tangential-lower (#7)	1			1.7 -> 2	
Negative Ion Source NB: for heating (electron heating dominant), current drive, small torque & particle input					
CO-tangential – upper (NNB-U)	1	500	5	5	100
CO-tangential – lower (NNB-L)	1			5	
Total	(*) Initial & Integrated Research Phases: 30MW x 60s, 20MW x 100s, Extended Research Phase: 34MW x 100s			30.4 ->34	100 (*)

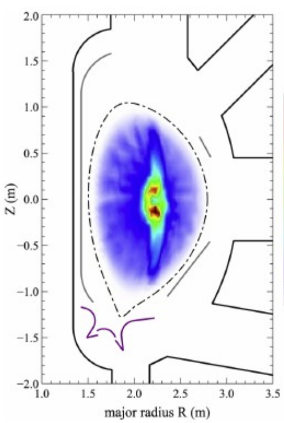


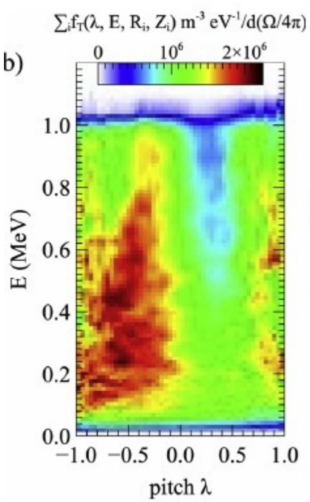


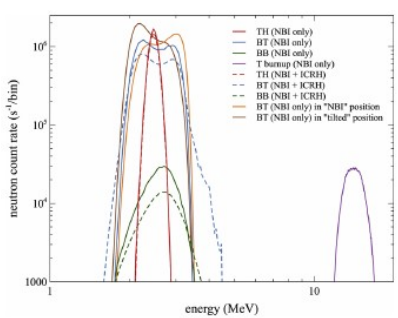
JT-60SA Scenario: neutron emission

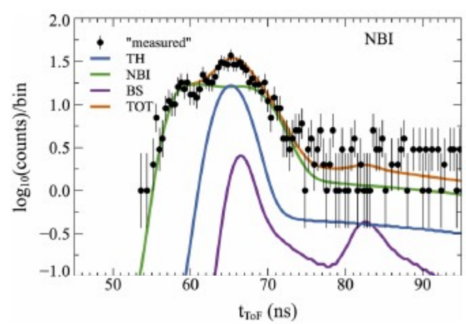
- Scenario developed but spatial neutron emissivity and neutron energy spectra not simulated (including T burnup contributions).
- These are required for a proper assessment of the possible performances of already envisaged neutron diagnostics (such as the collimated neutron flux monitor) and of possible new ones (dedicated spectrometers).
- Optimization of neutron diagnostics require detailed description of the neutron source both in terms of its spatial and energy distribution.
- UU group experienced in generation of fast ion distributions coupled to neutron synthetic diagnostics for such assessments: from JINTRAC via TRANSP/NUBEAM to DRESS.











JT-60SA neutron emission spectrometers

2.45 MeV DD neutrons:

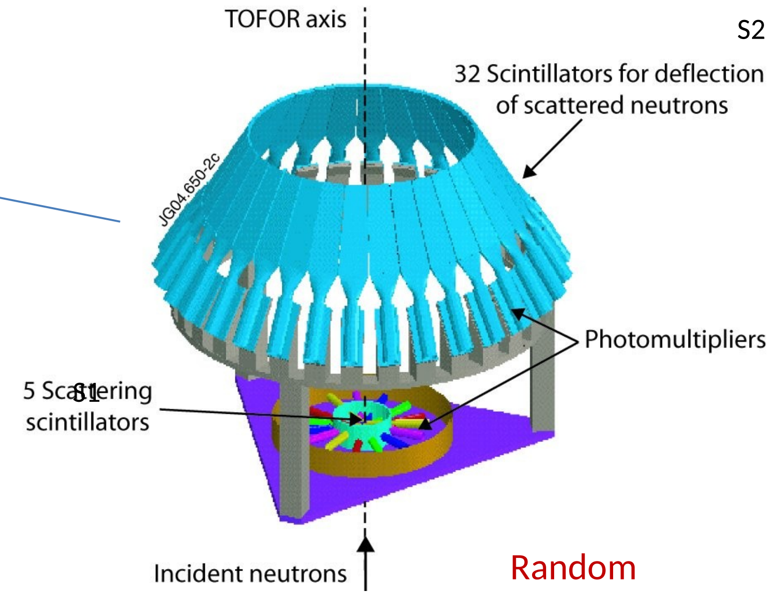
- TOFOR relocation at JT-60SA (and upgrade)
- Time-of-flight spectrometer
- Digital data acquisition
- Recording time and energy of neutron events in scintillators allows for better background discrimination.

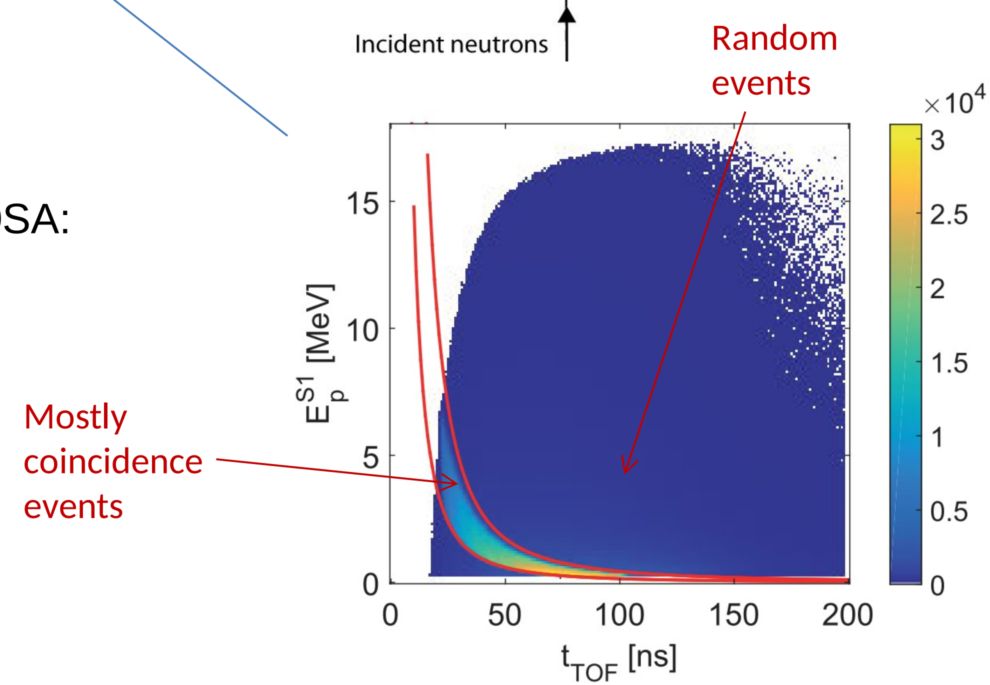
14 MeV DT burn-up neutrons:

- Diamonds
- Liquid scintillators

Modelling tools to be geared towards JT-60SA:

- Neutron spectrum calculator code
- Line-of-sight code
- Detector response function simulations
- Backscatter neutron simulations
- Neutron shielding simulation





Plasma Diagnostics Systems

Table D-2: Core measurements in JT-60SA

Measurement	Diagnostic	Range or Coverage	Time resolution	Spatial resolution or Wave No.	Accuracy	Target
Current profile	Motional Stark effect polarimeter	pich angle~0-15 degree 0<r/a<1	~ 10 ms	~87 mm or dr/a~0.07	~0.2 degree in pich angle	j_r control <1/100 τ_R
Line-averaged electron density	CO2 laser interferometer / polarimeter	tangential & vertica	~ ms	Integral		<1/100 τ_S
Electron density profile	YAG laser Thomson scattering system	ne=0.1-30E+19 m^{-3} 0<r/a<1	~ ms - 20 ms	20-30 mm or dr/a~0.05-0.1	~5%	<1/10 τ_{local} <1/10 L_{ne}
Electron temperature profile	YAG laser Thomson scattering system	Te=0.1-30 keV 0<r/a<1	~ ms - 20 ms	20-30 mm or dr/a~0.05-0.1	~5%	<1/10 τ_{local} <1/10 L_{Te}
Electron temperature profile (fast)	Electron cyclotron emission diagnostics	Te=0.1-20 keV 0<r/a<1	~0.001-0.01 ms	~10-20 mm or dr/a<0.02	~5%	<1/10 L_{Te}
Ion temperature profile	Charge exchange recombination spectroscopy	0.1-50 keV 0<r/a<1	~1 ms	~10-20 mm or dr/a<~0.05	~5%	<1/10 τ_{local} <1/10 L_{Ti} ITB behavior
Toroidal rotation profile	Charge exchange recombination spectroscopy	-500 - +500 km/s 0<r/a<1	~1 ms	~10-20 mm or dr/a<~0.05	~5 km/s	<1/10 τ_{local} <1/10 L_{Vt} ITB behavior
Poloidal rotation profile	Charge exchange recombination spectroscopy	-500 - +500 km/s 0<r/a<1	~1 ms	~10-20 mm or dr/a<~0.05		
Radiation profile (main)	Bolometer (main)		~ 1 ms	~50-100 mm	~10%	<1/100 τ_S <1/10 L_{ne} at ITB
Z_{eff} profile	Z_{eff} monitor (visible bremsstrahlung emission)	0<r/a<1	0.1 ms	50-100 mm or dr/a~0.2	10%	<1/100 τ_S <1/10 L_{ne} at ITB
Impurity density profile Iom temperature profile (core)	Crystal spectrometer (core)	0<r/a<1	~2-3 mm	~10-20 mm		<1/100 τ_S <1/10 L_{ne} <1/10 L_{Ti} at ITB
Impurity species monitoring	VUV spectrometer (core)		~100 ms	Integral	10%	
pellet monitor	Fast Visible TV		0.02 ms	~100 mm		
Energy spectrum of fast neutron	Neutral particle analyzer (Diamond detector)	0- ~ MeV dE~15-20 keV	~ 1ms	1 line for vertical, 1 line for horisontal		
Fast ion Da light	Fast ion Da		< ~ ms	dr/a~0,1		

JT-60SA Port Allocation

Sec.	Port	Use	Port User
P1	Upper	Cooling water	In-vessel
	Upper Oblique	ECRF	ECRF
	Horizontal	CO_2 Laser interferometer/polarimeter (tangential), YAG laser Thomson scattering, Zeff monitor, Neutral gas pressure gauge	Diagnostics
	Lower Oblique	YAG laser Thomson scattering (edge)	Diagnostics
	Lower	Cooling water, Liquid He for cryopanel	In-vessel
P2	Upper	Glow electrode (TBD), Gas fueling	Vacuum Vessel
	Horizontal	YAG laser Thomson scattering (central), Charge exchange recombination spectroscopy (toroidal, BG), In-vessel coil feeder	Diagnostics In-vessel
	Lower	Divertor Thomson scattering (TBD) Gas fueling to divertor Cooling water	Diagnostics Vacuum Vessel In-vessel
P3	Upper	Cooling water	In-vessel
	Horizontal	N-NBI	NBI
	Lower	Cooling water, Liquid He for cryopanel	In-vessel
P4	Upper	Neutron emission profile monitor, Neutral particle analyser	Diagnostics
	Upper Oblique	ECRF	ECRF
	Horizontal	T-NBI(#9,10)	NBI
	Lower Oblique	D_α emission monitor	Diagnostics
	Lower	Boron gas introduction Cooling water	Vacuum Vessel In-vessel
P5	Upper	Cooling water	In-vessel
	Horizontal	Charge exchange recombination spectroscopy (toroidal), YAG laser Thomson scattering (high field side) Glow electrode, In-vessel coil feeder	Diagnostics In-vessel
	Lower	Cooling water, Liquid He for cryopanel	In-vessel
P6	Upper	Visible spectrometer for divertor	Diagnostics
	Horizontal	Remote Handling Neutron monitor, Infrared TV camera (main), Infrared TV camera (divertor) (TBD), Charge exchange recombination spectroscopy (poloidal, BG), Visible TV camera Glow electrode	Remote Handling Diagnostics Vacuum Vessel
	Lower	Visible spectrometer for divertor Gas fueling to divertor Cooling water	Diagnostics Vacuum Vessel In-vessel
P7	Upper	Cooling water	In-vessel
	Upper Oblique	P-NBI(#14)	NBI
	Horizontal	Charge exchange recombination spectroscopy (poloidal) Pellet	Diagnostics Vacuum Vessel
	Lower Oblique	P-NBI(#13)	NBI
	Lower	Cooling water, Liquid He for cryopanel	In-vessel
P8	Upper	CO_2 Laser interferometer/polarimeter (vertical), Neutral gas pressure gauge	Diagnostics
	Upper Oblique	ECRF	ECRF
	Horizontal	CO_2 Laser interferometer/polarimeter (tangential), YAG laser Thomson scattering, Zeff monitor, Neutral particle analyser	Diagnostics
	Lower Oblique	In-vessel coil feeder	In-Vessel
	Lower	CO_2 Laser interferometer/polarimeter (vertical), Neutral gas pressure gauge Cooling water	Diagnostics In-vessel
P9	Upper	Cooling water	In-vessel
	Horizontal	Remote Handling VV inspection Electron cyclotron emission diagnostics, Fast visible TV for pellet	Remote Handling Vacuum Vessel Diagnostics
	Lower	Cooling water, Liquid He for cryopanel	In-vessel
P10	Upper	Gas fueling	Vacuum Vessel
	Horizontal	Neutron monitor, VUV Spectrometer, Neutron emission profile monitor, Crystal spectrometer	Diagnostics
	Lower	Boron gas introduction Reciprocating material probes (TBD) Gas fueling, Cooling water	Vacuum Vessel Diagnostics Vacuum Vessel In-vessel

Discussion points

Status of neutron diagnostics on JT-60SA

- Which neutron diagnostics are actively being developed?
- Which neutron diagnostics are at the conceptual level?
- Collaboration with neutronic experts at JT-60SA
- Interfacing issues
- ...

Activity

- Scoping study for 2.45 and 14 MeV neutrons
- Fast ion population generations for synthetic neutron diagnostics development
- Identification of interfacing issues
- ...