FSD Science Coordination Meeting
on the transition of JT-60SA to W

Upgrade/adaptation of subsystems (heating, diagnostics etc) to support W-wall operation

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WPSA PL

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Switch to W

- Physics objectives of JT-60SA in the initial phase
  1. High Beta plasma scenario developed
  2. Steady state sustainment of the scenario (not mandatorily in C)
  3. Adaptation (preparation) to W wall (not mandatorily in C)
- =>The integration of these initial topics into a sustainable and potentially steady-state scenario in W is likely advantageous for the fusion goal as it is well known that W affects how to operate the machine

- Transition to W wall involves a number of modifications and upgrades to be taken into consideration, besides definition of the technology solution for the PFCs and the physics modeling
- Heating mix
- Diagnostics
- Protection system
- Other supporting technologies and technical aspects

- **DISCLAIMER: this is just a tentative list of items not to forget in developing the planning (to be complemented and analyzed in deep)**

Operation phases and status of key components (present reference)

Table 2: Operation phases and status of key components

Research phase	Focus of exploitation	Operation Campaign	Expected operation schedule		Annual neutron limit	RH	Divertor	Installed NB power	ECRF	Max. usable aux. power
-	Integrated pre-plasma Commissioning	Op-1	2020-2021 (6M) 2023 (6M) First plasma 2023	H	- (N_2 in VV interspace)	R&D	Open upper inertially cooled carbon	0	1.5 MW (2 Gyro.)	1.5MW
Initial research phase I	**Initial stable and reliable operation** • H operation for commissioning towards D operation. • Stable operation at high current heated plasma	Op-1	2020-2021 (6M) 2023 (6M) First plasma 2023	H	- (N_2 in VV interspace)	R&D	Open upper inertially cooled carbon	0	1.5 MW (2 Gyro.)	1.5MW
Initial research phase I	**Initial stable and reliable operation** • H operation for commissioning towards D operation. • Stable operation at high current heated plasma	Op-2	2025-2026 (9M)	H / D	- (N_2 in VV interspace)	R&D	Inertially cooled lower pumped carbon (limits high power heating duration)	PNB 8 units, plus NNB Total 16MW (with H) 23.5 MW (with D)	3 MW (4 gyro)	19MW
Initial research phase II	**ITER and DEMO regime access** (high power and high Ip with short pulses) • Access to the ITER standard scenario • High beta access • ITER risk mitigation (ELM, disruption)	Op-3	2026-2027 (9M)	D	3.2e19 (N_2 in VV interspace)	R&D	Inertially cooled lower pumped carbon (limits high power heating duration)	PNB 8 units, plus NNB Total 16MW (with H) 23.5 MW (with D)	3 MW (4 gyro)	26.5MW
Initial research phase II	**ITER and DEMO regime access** (high power and high Ip with short pulses) • Access to the ITER standard scenario • High beta access • ITER risk mitigation (ELM, disruption)	Op-4	2028 (8M)	D	3.2e19 (N_2 in VV interspace)	R&D	Inertially cooled lower pumped carbon (limits high power heating duration)	PNB 12 units, plus NNB Total 30 MW	3 MW (4 gyro)	33 MW
Integrated research phase I	**High beta long pulse** **Burning plasma relevant** • ITER standard and hybrid stationary (~2-3tR) • High beta steady-state (~2-3tR), DEMO contribution	TBD	TBD	D	4e20 (water in VV interspace)	R&D	Actively cooled lower pumped carbon	PNB 12 units, plus NNB Total 30 MW	7MW (9 gyro.)	37MW
Integrated research phase II	**High beta and metal wall compatibility** • Radiative divertor with impurity seeding • Impurity pumpout from core	TBD	TBD	D	1e21 (water in VV interspace)	Use	Actively cooled lower pumped tungsten	PNB 12 units, plus NNB Total 30 MW	7MW (9 gyro.)	37MW
Extended research phase	**High beta and metal wall compatibility** • Radiative divertor with impurity seeding • Impurity pumpout from core	TBD	TBD	D	1.5e21 (boronated water in VV interspace)	Use	Actively cooled tungsten advanced structure (Upper div. TBC)	34MW	7MW (9 gyro.)	41MW

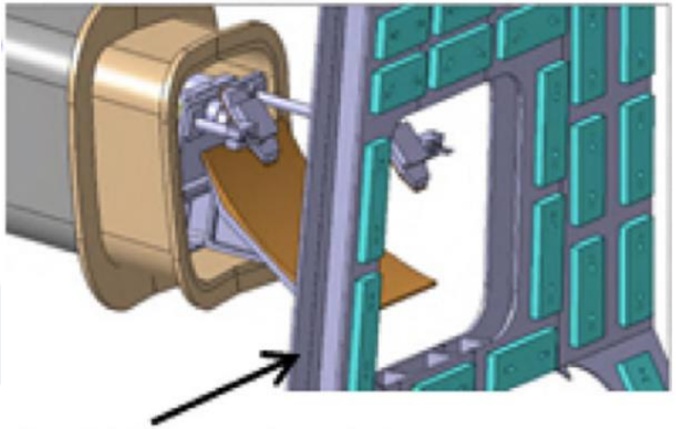
In OP2,3,4
Pumped lower inertially cooled carbon divertor
Allowable heat flux onto the divertor plate <10MW/m2 x ~7.5s, 15MW/m2 x ~5s
(Open upper inertially cooled carbon divertor remains available)

Upgrading of the heating mix toward more central electron heating

- 3 MW of ECRF power foreseen until OP4, 7 MW later (from OP5, y>2029)
- The power of 3MW of ECRF seems ***marginally*** sufficient for stabilization of NTM(2,1) in fully inductive scenario (Ip=5.5 MA) at low density 7.6 10^{19}, ***insufficient at high density*** (1.1 10^{20}).
- Similar (slightly better) for hybrid scenario
- https://idm.euro-fusion.org/?uid=2R8S4H&version=v1.1,
- https://www.epj-conferences.org/articles/epjconf/pdf/2012/14/epjconf_ec2012_02017.pdf

- Impurity control requires central electron heating (ρ<0.2), power amount to be evaluated (1~2 in AUG https://iopscience.iop.org/article/10.1088/0029-5515/51/8/083013/pdf)
- Scaling law not known (hopefully NOT plasma volume, $V_{JT\text{-}60SA} \approx 10\, V_{AUG}$) (JG just suggested 3-7 MW on the basis of JET)

- Foreseen power already low for the development of high beta scenario in C



Stabilizing baffle plate

- Full system 9 sources≈7MW to plasma
- 3 launchers X 2 WGs +
- 1 launcher X 3 WGs with limited steering
- Limited accesses => develop specialized (compact) launchers for core heating, minimal steering? (4x1.5 MW sources might fit in the 4th launcher)

- Under consideration also the upgrading existing equipment e.g. from 1MW/tube to 1.5MW

Emission (spectroscopic) diagnostics

TABLE I. The measurement and application for the different spectroscopic tasks depending on species. Also indicated is the wavelength region most suited to the task—extreme ultraviolet (XUV), vacuum ultraviolet (VUV), visible, or visible charge exchange spectroscopy (CXS).

Species	Measurement	Application	Technique
Be/C	Erosion rate	Redeposition/migration/transport	Visible
	Transients	Machine protection	Visible
	Average density	Dilution and Z_{eff}	XUV/VUV
	Density profile	Core transport	CXS
	Poloidal/SOL profile	Edge transport	Visible/VUV
Ni	Transients	Machine protection	VUV
	Average density	Radiated power and Z_{eff}	VUV/x ray
W	Erosion rate	Redeposition/migration/transport	Visible/near UV
	Transients	Machine protection	Visible/VUV/XUV
	Average density	Radiated power and Z_{eff}	XUV/VUV/x ray
	Density profile	Core transport	VUV/XUV
	Poloidal/SOL profile	Edge transport	Visible/VUV

O'Mullane et al. Rev. Sci. Instrum. 77, 10F520 2006

- C=>W Change of the dominant impurity
- W has 74 ionization stages
- Change in the wall material results in qualitatively different spectroscopic needs with respect the C wall for spectroscopic diagnostics in the visible, extreme ultraviolet, vacuum ultraviolet, and x-ray spectral regions
- Erosion rate
- Melting
- Redeposition
- Transport and core concentration
- Radiated power and Zeff

- Revision needed for physics, operational and machine protection tasks

Divertor and wall monitoring diagnostics

Infrared TV camera （divertor and wide FoV）

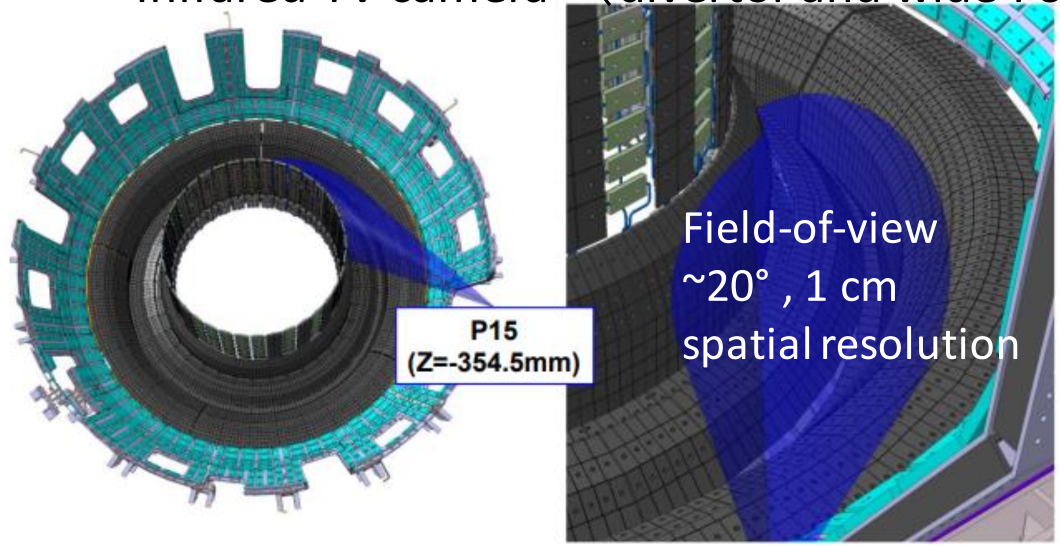
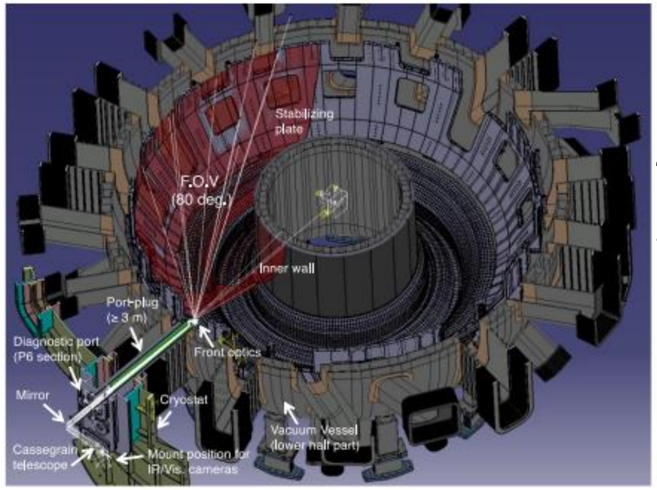


Figure 2.16-18 Bird's eye view of the JT-60SA tokamak, showing the location, direction and FoV of the IRTV diagnostics for divertor.



Field-of-view
~80° , 2 cm
spatial
resolution

Figure 2.16-36 Bird's eye view of the JT-60SA tokamak, showing the location, direction and FoV of the IRTV diagnostics.

Bolometry）

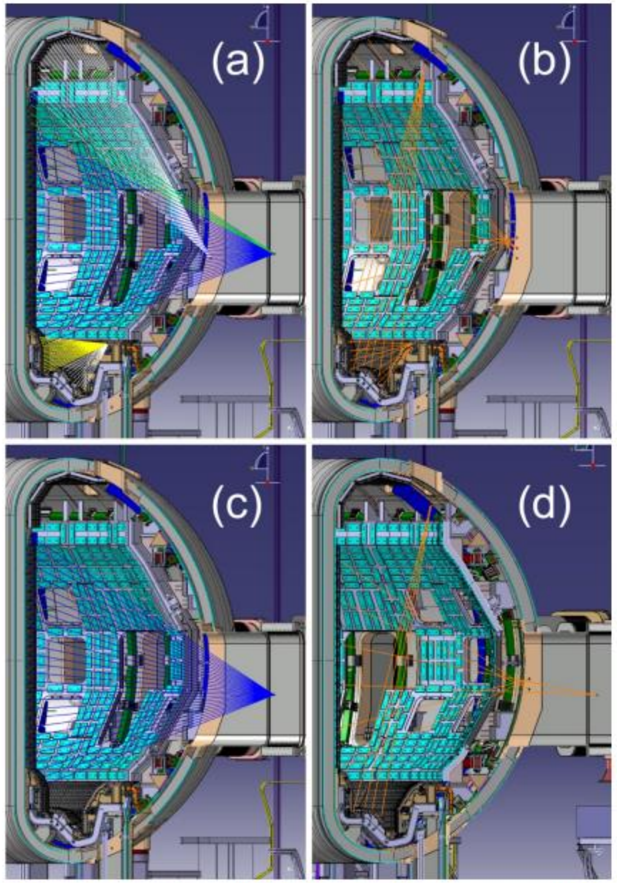


Figure 2.16-33 Viewing chords of (a) and (b) lower radiation energy, and (c) and (d) higher radiation energy

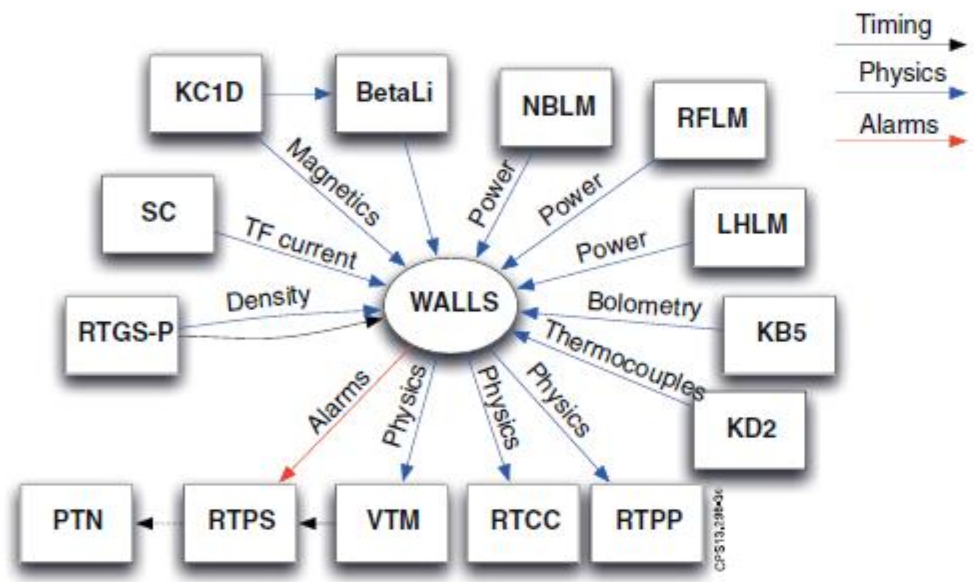
Table 2.16-22 Specifications of Bolometer system

Location of detector		P18 upper port	P18 horizontal port	P16 lower diagnostic slit
Number of detector head	Low energy (T<7.9 keV)	2	4	3
	High energy (T<13.5 keV)	1	2	0
Channels for distribution measurement	Low energy (T<7.9 keV)	8	10	8
	High energy (T<13.5 keV)	4	6	0
Channels for total radiation power	Low energy (T<7.9 keV)	0	6 (3ch × 2sets)	4 (2ch × 2sets)
	High energy (T<13.5 keV)	0	2 (1ch × 2sets)	0
Temporal resolution		5 ms for both total radiation and distribution power measurement		

- Previous review performed by EU experts indicate some weak point (coverage, spatial resolution, number of covered sectors)

revision/upgrading of the protection system

- For reference: The JET real-time plasma-wall load monitoring system (Valcarcel, FED 89 2014 243–258)
- Thermal monitoring of the first wall (IR cameras)
- Surface temperature calculation of the limiter tiles and the bulk energy of the divertor tiles => Vessel Thermal Map uses the surface temperature map, to raise alarms in case of hot-spots.
- Integration in a system providing a model-based thermal map (not relying on IR data)
- Calculation of the power density deposition
- Distance to the plasma boundary
- Divertor strike point position
- Alarm condition when machine's operational limits exceeded



JET REAL TIME DATA NETWORK and interaction among systems (diagnostics, heating, models, protection)

- From C to W: More stringent requirements on plasma position and current control to minimize the possibility of damages De Tommasi, FED 89 (2014) 233–242
  - Vertical stabilization
  - Shape Controller
  - Termination management system
- Disruption management

Other upgrades

- Long pulse operation requires not only the cassettes and associated plasma-facing components of the actively cooled divertor but also
  - the refurbishment of the 2nd motor generator in order to power extended operation of the auxiliary heating systems;
  - Upgrade of the water cooling system to provide sufficient flow for active cooling.
- In the current planning, these upgrades are not planned before completion of OP4

- Remote handling
  - Transition to W will happen after high power (33 MW, not the highest), short pulse operation in D
  - Remote handling is not yet being advanced at this stage (foreseen in P6, P9, P15, P18)
  - Installation with personal entrance possible (? limitation on performance before installation? What if installation is delayed? Assessment needed) but required for further maintenance

Conclusions

- Several actions to be taken for risk mitigation/technical feasibility besides once having identified the solution for W divertor target and first wall (this last at the very beginning actually)
  - Upgrading of the heating mix toward more central electron heating
  - Divertor and wall monitoring diagnostics
  - Extended revision of the spectroscopy diagnostics
  - revision/upgrading of the protection system, including disruption management (prevention, mitigation, runaway)

- Long pulse operation also requires
  - Upgrade of the primary water cooling system
  - Motor generator for high power-long pulse

- Development of remote handling

- In EU now AUG, JET, WEST went through this change: of course valuable experience

- Note: Several of the above upgrades are not listed in the present project plan (and not yet assigned to one of the implementing agencies)