Edge and divertor modelling of JT-60SA ITER-like scenario with carbon wall

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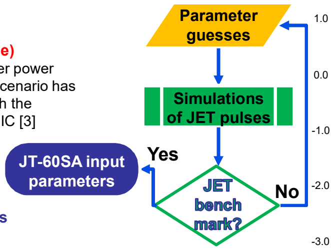
1.1) Introduction

JT-60SA **main objectives**: near fusion scenarios for ITER and DEMO.
Major open issue: divertor heat and particle handling in ITER-like plasma.
Goal of this work: **simulating JT-60SA ITER-like scenario** with carbon wall scrape of layer (SOL) and divertor plasma:

- **41MW** input power [1]
- Full carbon walls
- Inductive single null
- **$n_{e,sep}$=1.0x10^{19}m^{-3}** **(major challenge)**

Similar studies have been made for lower power JT-60SA scenario [2] while the 41 MW scenario has been simulated with higher densities with the integrated divertor simulation code SONIC [3]



Parameter guesses

Simulations of JET pulses

JET bench mark?

No

Yes

JT-60SA input parameters

1.2) Methodology

Divertor plasma conditions depend on:

- perpendicular **transport parameters**
- **recycling coefficients**
- **sputtering yields.**

Precise predictions require **benchmark of those parameters with experimental data** from similar pulses of existing machines, similarly to what was done in [4] for core analysis. Compatible JET pulses were found, a model was benchmarked by using JET data and then applied to JT-60SA ITER-like scenario.

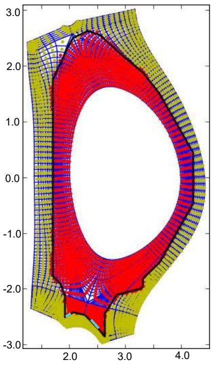
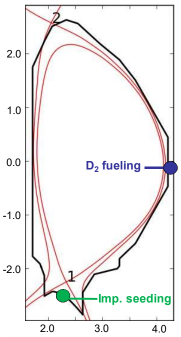


Fig.1: SOLEDGE2D mesh for JT-60SA Scenario 2. Simulated volume in red; carbon wall in black; absorbing pump surfaces in light blue

3) JT60-SA ITER-like scenario early modelling results



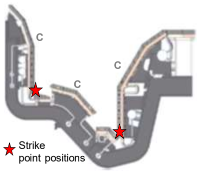


Fig.2: JT-60SA divertor area, pump ducts details and strike point positions calculated for ITER-like scenario

Fig. 8: D fueling is from the outer midplane and impurities seeding from the dome

	Standard Input parameters
Input power P_{sol}	36 MW [5]
Recycling D/Ar/Ne	1.0
Recycling C	0.0
D puffing	1.0x10^{22} s^{-1}
Ar seeding	1.0x10^{20}s^{-1}
Ne seeding	4.0x10^{20}s^{-1}

Tab. 3: JT-60SA standard simulations input parameters

On JT-60SA ITER-like scenario a **scan on transport parameters** was done around the previously validated values on JET with using input parameter shown in [*Tab. 3*]

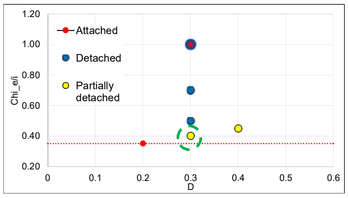


Fig. 9: Transport parameters at the separatrix considered for JT-60SA simulations.

- To reduce power to divertor plates below 15MW/m^2 [1], $n_{e,sep}$ minimum value is ≈ 2.0x10^{19}m^{-3} [*Tab 4*]
- Eich scaling predicts $\lambda_{q,e}$ < 2mm; with $Z_{eff,sep}$ ≈ 3.5, higher $\lambda_{q,e}$ is required to have sustainable power flux to the outer divertor [*fig. 10*]
- Higher impurity level is required if the scaling is respected.

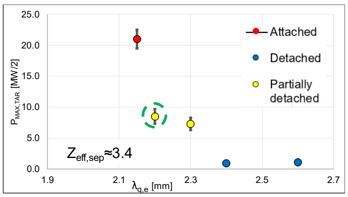
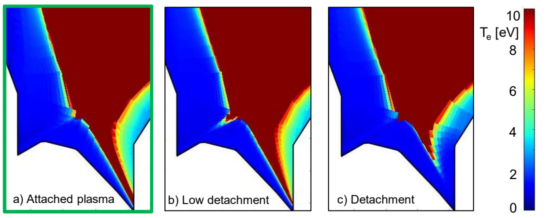


Fig. 10: Maximum power flux to the divertor plates variation over heat flux decay length as calculated from fitting the output of the simulations at the outer midplane.

Elements	$n_{e,sep}$ [x10^{19}m^{-3}]	P_{SOL} [MW]	$Z_{eff,sep}$	$P_{max,tar}$ [MW/m^2]	Outer divertor
D	2.5	8	1	12.2	Attached
D+C	2.4	20	1.6	7.7	Low detach.
D+C+Ar	1.7	36	4.7	5.0	Partial detach.
D+C+Ar	2.0	36	3.4	9.5	Low detach.

Tab. 4: Some results of the simulations with transport parameters profiles validated in JET



a) Attached plasma
b) Low detachment
c) Detachment

Three different divertor plasma obtained:

- Attached, low detachment and fully detached.
- **High asymmetry level between inner and outer divertor**
- **Validated transport model** predicts attached plasma at outer divertor with using standard input parameters

2) Modeling of JET with carbon wall

	JT-60SA Scenario 2	JET #69890	Diff
Toroidal field B_T [T]	**2.25**	**2.18**	**3%**
Plasma Current I_P [MA]	**5.5**	**2.0**	**64%**
Major radius **R** [m]	**2.96**	**3.0**	**1%**
Minor radius **r** [m]	**1.18**	**0.9**	**31%**
Elongation **Kx**	**1.87**	**1.6**	**14%**
Safety factor Q_{95}	3	3.5	16%
β_N	3.1	2.3	26%
Core dens. n_c [10^{19} m^{-3}]	6	7	17%
Sep. dens. n_s [10^{19} m^{-3}]	**1/2**	**3**	**200/50%**
n_c/n_s	6/3	2.3	61 / 22%
G. dens. Frac	0.5	0.6	20%
Heating Power P_{in} [MW]	41	21	49%
P_{in} (normalized [MW] JT-60 sep. surf.)	41	28.6	30%
Magn. Conf.	High elong. SN	High elong. SN	-
Mode	**H**	**H**	-
Strike point pos.	2 vertical	1 vert., 1 horiz.	-
Wall composition	C	C	-
Seeding	Ne/Ar	No	-
Pumping speed [m^3/s]	Up to 100	-	-

Tab. 1: JT-60SA ITER like scecnario and the considered JET pulse

Compatible Jet pulse is found.
Similarity parameters:

- Size
- Wall compositions
- Toroidal magnetic field.
- Plasma shape
- Confinement mode
- Density
- Greenwald density fraction
- safety factor

Major influence on plasma parameters

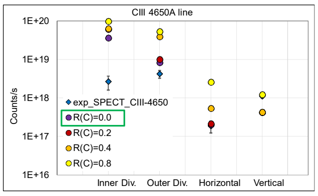


Fig. 3a: Carbon recycling parameters scan

Run #	n_{sep}	Chi (sep)	D (sep)	Div/ SOL	$1/B_T$ Fact.
32	3.0	0.16	0.28	x4	No
33	3.0	0.16	0.28	x6	Yes
36	3.0	0.18	0.35	x4	No
37	4.0	0.18	0.35	x4	No
38	3.0	0.18	0.35	x6	No
39	3.0	0.18	0.35	x6	Yes

Tab.2:Tested transport parameters

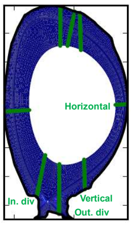


Fig. 4a: JET Spectroscopy chords map

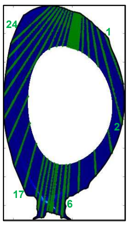


Fig.4b: JET Bolometry chords map

Transport parameters to be determined:

- **Transport parameters at the separatrix**;
- Transport parameters in the far **SOL** and **below the x-point**.

Transport parameters value and shape validation with JET data

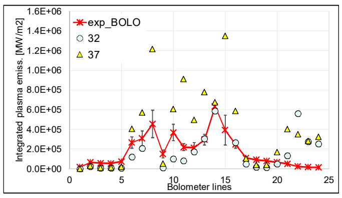


Fig. 5: Transport parameters calibration by comparing simulations output to spectrometer data

The best set of transport parameters is **compatible with Eich scaling**, (Run #33 in *Tab. 2*). Different separatrix density and transport parameters have worst agreement with temperature, density and exp. data from **bolometry** and **spectroscopy** [*fig. 5*, *fig.6*]

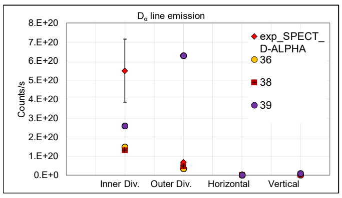


Fig. 6: Transport parameters analysis by comparing simulations output to bolometer data

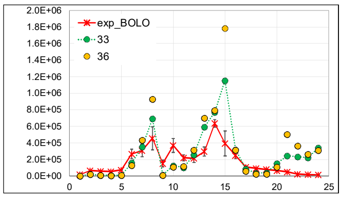


*Fig. 7: Transport parameters analysis, results from **selected transport parameters** are in green*

To decrease radiation at the strike-points and to replicate turbulence effects, the transport is increased below the divertor and rescaled by a factor $1/B_T$. *Fig. 7* shows that best agreement with experimental data is achieved.

The model:
1) R(C) = 0.0
2) Eich scaling compatibility
3) $1/B_T$ factor
4) x6 below Xpoint and far SOL

4.1) Conclusions

- A JET pulse similar to JT-60SA ITER-like scenario has been selected;
- Transport parameters shape was validated with JET data;
- It was found that Eich scaling is respected with respect to the calculated $\lambda_{q,e}$
- The model has been applied to JT-60SA ITER-like scenario
  - ➢ 20 MW is the maximum input power to obtain sustainable heat flux to the divertor in simulations with only carbon impurities;
  - ➢ Full power scenario may be sustainable with $Z_{eff,sep}$≥4 with Ar impurities only if $n_{e,sep}$ ≈ 2.0x10^{19}m^{-3} if the scaling is respected;
  - ➢ Lower density would require higher $Z_{eff,sep}$, thus, producing higher core radiation.

4.2) Future perspectives

- Scan in puffing levels of both deuterium and argon is foreseen;
- Simulations with lower heat flux decay length and higher impurities will be performed;
- A comparison between the minimum amount of impurities required for Argon and Neon case will be done.

References
[1] JT60-SA Research Plan: http://www.jt60sa.org/pdfs/JT-60SA_Res_Plan.pdf
[2] *M. Romanelli et al.*, Investigation of sustainable high-β scenarios in the JT-60SA C-wall, Nucl. Fusion **57** (2017)
[3] *H. Kawashima et al.*, Evaluation of heat and particle controllability on the JT-60SA divertor, J. Nucl. Mater. **415** (2011)
[4] *J. Garcia et al.*, Physics comparison and modelling of the JET and JT-60U core and edge: towards JT-60SA predictions, Nucl. Fusion **54** (2014)
[5] *R. Zagòrski et al.*, Numerical analyses of JT-60SA scenarios with COREDIV code, Nucl. Fusion **56** (2016)

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