

**Summary Report for Joint
Modeling Activity on Steady State
Exploration – IOS-JA7**

C. E. Kessel for P. T. Bonoli (MIT)
7th IOS Topical Group Meeting
Kyoto, Japan
October 18-21, 2011

IOS-JA7: Modeling of Steady State Scenarios

- **Contributors:** P. T. Bonoli (MIT), R. Budny, C. E. Kessel, F. Poli (PPPL), G. Giruzzi, J. Garcia, F. Imbeaux (CEA-Cadarache), A. Fukuyama (Kyoto U.), G. Batemann, A. H. Kritz (Lehigh U.), M. Murakami, J. M. Park (GA), T. Oikawa (IO), V. Parail (JET), A. Polevoi (IO), A. Tuccillo, R. Cesario (Frascati).....
- **Original Objectives:** Analyze the current drive requirements for steady state target discharges using both time dependent and stationary (in time) models:
 - Determine combinations of NBI, ECRF, ICRF, and LHRF powers that can provide SS (100% non-inductive) current profile in combination with BSCD.
 - Determine plasma configurations and their properties.
 - Determine requirements on actuators in terms of powers, combinations, and sensitivity for time dependent access to steady state target discharges.

Feedback from IOS Group in Culham (April, 2011)

- **Proposed Plans for 2011 at Culham Meeting were:**
 - Specify equilibrium and plasma profiles for SS targets.
 - Determine how different simulation models can be applied:
 - Time dependent transport codes would be pre-programmed to evolve to the specified steady state and then execute their actuators.
 - Produce first inter-model comparison for a specified actuator set.
- **But the IOS Group thought that goals needed to be further refined for this joint modeling activity:**
 - **Some specific worthwhile observations were:**
 - (Giruzzi) – use parallel computing capability to establish high physics fidelity simulations that can be used as reference for “reduced” models.
 - (Hubbard) – fixing $n(r, t)$ and $T(r, t)$ focuses the modeling activity on comparing actuators, which you may not want to do.
 - (Joffrin, Ide) – useful to perform sensitivity studies of various models variations in plasma parameters and profiles.
 - (Kessel, Casper) – middle of the road approach, e.g. need to mind both actuators and time dependent modeling.
- **“Steady state exploration” is actually composed of a number of critical components:**
 - Target relaxed flat-top plasma configurations that obtain 100% noninductive current and $Q \sim 5$MHD stability, transport, and other assessments
 - Access to and feedback control of steady state
 - Sensitivity studies of actuators
 - Actuator requirements

Observations and plans for moving forward (Bonoli / Kessel)

- **There has been a lack of progress in moving forward on the 2011 goal of formulating a target case for inter-model comparison:**
 - *Activity leader (Bonoli) has not had time to coordinate this.*
 - **IOS members are working on their own *worthwhile* SSE studies**
 - **Poli / Kessel – SSE studies with TSC-TRANSP.**
 - **Batchelor / Bonoli – IPS and ACCOME ITER simulations.**
 - **Cronos Group – new SS scenario work within F4E Agreement.**
 - **Murakami / Park – ONETWO studies (just published a paper).**
 - **Casper / Kim – Corsica simulations and actuator upgrades**
 - **Budny / Kritz – PTRANSP simulations**
 - **Other Groups – (ASTRA, TASK**)
 - **IOS members are also working on worthwhile actuator studies:**
 - **LHRF – code comparisons, “density limit” studies, etc**
 - **ICRF – code comparisons**
 - **ECRF – launcher optimization studies**
 - **NNBI -- benchmarking, studies of lower energy**

Propose that IOS-JA7 be split into a two parts

- **IOS JA7-A: Steady State Exploration (“SSE”) to be spokespersoned by C. Kessel.**
 - *There are clearly several active groups that have the IM modeling capability with varying sets of actuators to explore access to SS ITER regimes that can contribute.*
- **IOS JA7-B: Actuator Requirements and Comparison (“ARC”) to be led by P. Bonoli.**
 - *There is still a clear need for NB, LHRF, ECRF, and LHRF actuator studies and these could be presented and vetted here, particularly within the context of the time dependent SSE studies.*

Specific Example of a Work Plan and Commitment

- **IOS-JA7-A: (SSE)**
 - Murakami/Park SS configuration existing
 - Garcia/Giruzzi SS configuration existing
 - Kessel/Poli defining SS cases with mixtures of actuators from their TSC-TRANSP studies (see Poli /Kessel talk at this meeting).
 - Others producing SS configurations
- **IOS-JA7-B: (ARC)**
 - Bonoli/Batchelor will commit to simulating one or more of Kessel/ Poli cases with the Integrated Plasma Simulator (IPS), **because they use the same transport code**, in order to test high fidelity models (or resolution) against reduced models
 - *Sensitivity of NBI results to Monte Carlo particle statistics.*
 - *Refinement of internal TSC model for ICRF heating and FWCD using IPS-TORIC & AORSA simulations at low and high spectral resolution.*
 - *Comparison of LHCD from TSC-LSC with predictions from the IPS using GENRAY / CQL3D.*
 - *Refinement of internal TSC model for ECCD using the IPS with GENRAY / CQL3D.*
 - Comparisons by other groups with reduced and high fidelity models (CRONOS, TASK, GA,.....)

Status of activities reported by members

- **Contribution from Poli/Kessel on SSE**
- **Summary from R. Cesario on LH actuators**

Five H/CD combinations, $I_p=7-10$ MA (100% non-inductive)

(F. Poli, C. Kessel - PPPL)

73 MW | 20 MW EC + 20 MW IC |
 20 MW EC + 20 MW LH |
 40 MW EC + 20 MW IC | +33 MW NB
 93 MW | 40 MW LH + 20 MW IC |
 68 MW = 40 MW LH + 20 MW IC | + 8 MW NB

Target plasma:

$R=6.2$, $a=2.0$, $k=1.8$, $d\sim 0.45$

$I_p = 7-10$ MA

$n/n_{Gr} \sim 0.75-1.0$

100% non-inductive current

$n(0)/\langle n \rangle = 1.0-1.5$

EPED1 estimate: (P. Snyder)

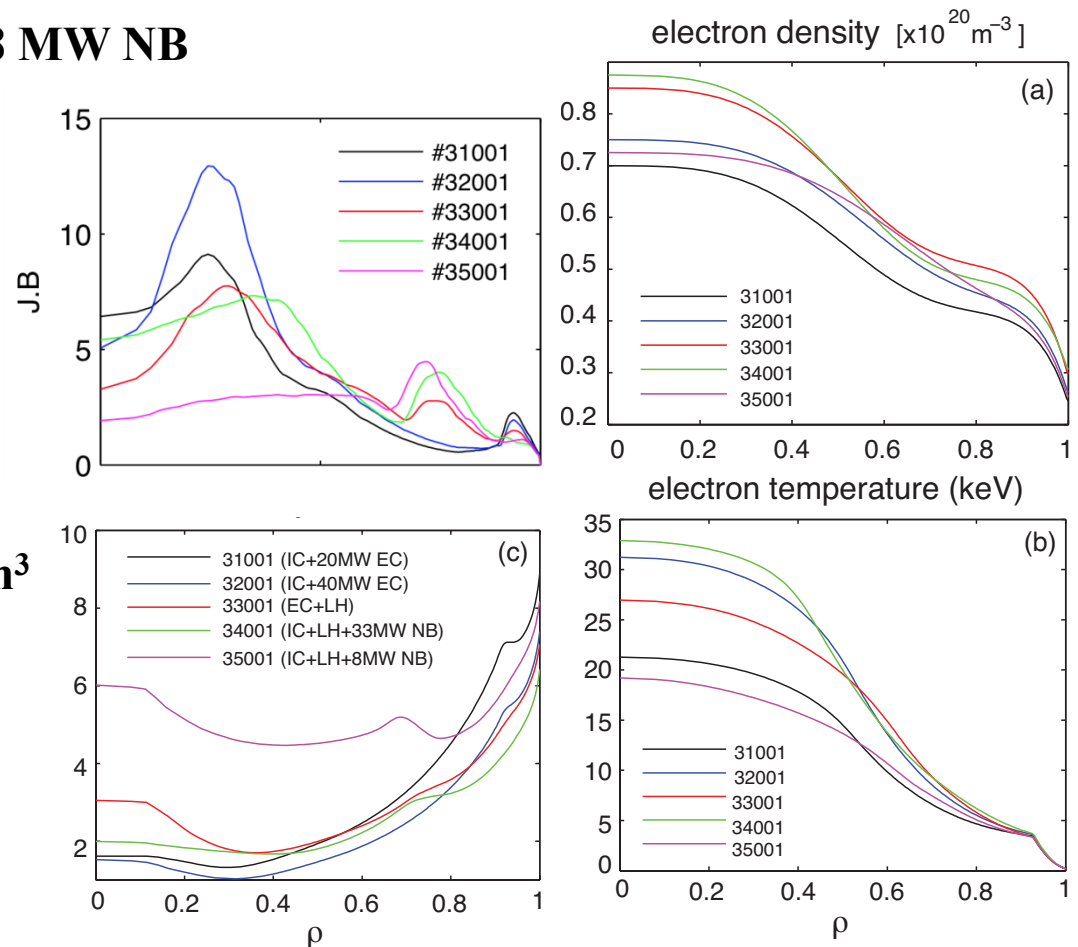
$T_{ped} \sim 3.3-3.7$ keV @ $n_{ped} = 5-6.7 \times 10^{19} / m^3$

$r_{ped} \sim 0.94$

Impurities and radiated power

2% Be , 0.4% Ar

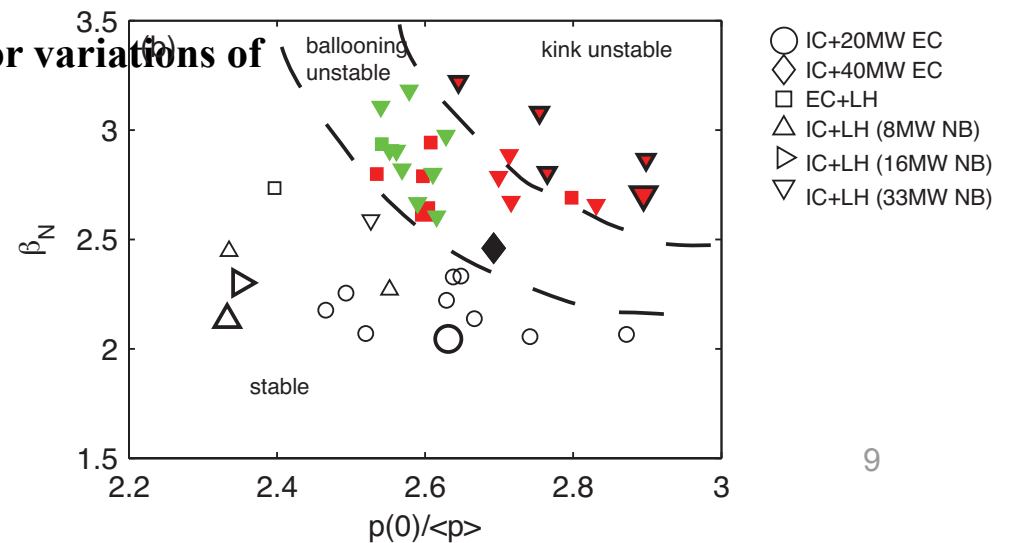
$P_{core, rad} = 25-35$ MW (brem+cyc+line)



Find operational space stable to ideal MHD

- Use TSC/TRANSP
- H/CD settings to maximize performance
 - NB: off-axis steering, peaked at $r=0.35$ $\Rightarrow \sim 3$ MA of CD
 - IC : 48 MHz, on-axis deposition \Rightarrow
200-400 kA FWCD
 - EC : midplane launchers, $r=0.35$ \Rightarrow
 $I_{ECCD} \sim 0.7$ MA (1.4 MA)
 - LH : $n_{\parallel}=2.15$, $\Delta n_{\parallel}=0.2$, ($r_{LH} \sim 0.65$) $P_+ = 85\%$, $P_- = 15\%$ $\Rightarrow I_{LH} \sim 0.8$ MA
- Use $H_{98} \sim 1.6$ as target
- Prescribe the χ to produce an ITB and scale to provide H_{98}

- Analyzed ideal MHD stability in the flat-top for variations of
 - Greenwald fraction (within 1.15 of n_G)
 - Pressure peaking factor
 - Find stable operational space
 $b_N, q, I_i, p(0)/\langle p \rangle$



Current Status of Modeling Activities – LH Actuator – (R. Cesario)

- **Studying use of lower hybrid on steady state discharges in ITER (R. Cesario et al., EPS 2006, EPS 2008, RF conf Gent 2009; Nature Comm. 1(5) 55, 2010, PPCF 53 (2011) 085011):**
 - LHstar code used, for ray-tracing+FP modeling including the effect of non-linear physics of the edge (spectral broadening produced by parametric instability (PI)).
 - Considering the SOL available data expected for ITER ($T_e < 100\text{eV}$ at $r/a = 1.007 - 1.10$), a very external deposition of LH power is expected: see results at this meeting from A. Tuccillo.
 - The lack of LH power penetration in the core of JET AT exps. with ITER-relevant n_e profile has been interpreted as due to strong PI spectral broadening at the edge. Strong single pass LH absorption at high T ($T_{e0} \approx 6\text{keV}$) prevents collisional damping playing a dominant role.
- **Study of LH penetration across steep density gradient (A. Cardinali and F. Santini, Plasma Phys. Contr. Fusion 53 2011):**
 - In the JET AT exps. with ITER-relevant n_e profile with steep gradient and no LH effects, ray deviation effects are negligible.
- **Study of parasitic absorption of LH waves on fusion alpha-particles (E. Barbato and A. Saveliev 2004 Plasma Phys. Contr. Fusion 46 1283):**
 - $f \sim 5\text{Ghz}$ absorption on alphas is below 2% in the Q=5 scenario
 - At worst, 8% in the Q=10 scenario.
- **Additional research on mechanisms for possible LH dissipation at periphery are also being studied:**
 - Paper submitted to NF by Pericoli on Wave Scattering by Density Fluctuations.
 - Paper accepted for publication in NF by Barbato on Collisional absorption.