

Proposal for Submissions of New ITER Plasmas to the Profile Database

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- Need to understand burning plasmas better to improve the chances of achieving practical Tokamak fusion power
 1. Check the ITER design (ex, is P_{aux} sufficient? is ash removal sufficient? is rotation necessary?)
 2. Validity of data for theoretical studies (ex, TAE)
 3. Certify each plasma before it is tried

Difficulties with traditional predictions of ITER plasmas

- 0D efforts study scaling of confinement with dimensionless quantities
 1. Use globally-averaged values of parameters such as ρ_* , ν_* , β
 2. Insensitive to profile effects (ex, density peaking)
 3. Generally exclude many other candidate dimensionless quantities
 4. Large extrapolations necessary
- 1D efforts to predict temperature profiles, etc
 1. Semi-empirical
 2. Root problem: Insufficient data for DT plasmas
- Strategy to achieve the needed capability:
 1. Create database of self-consistent, time-dependent plasmas
 2. Use Microturbulence, MHD, TAE, .. codes to select plasmas that are stable or marginally stable

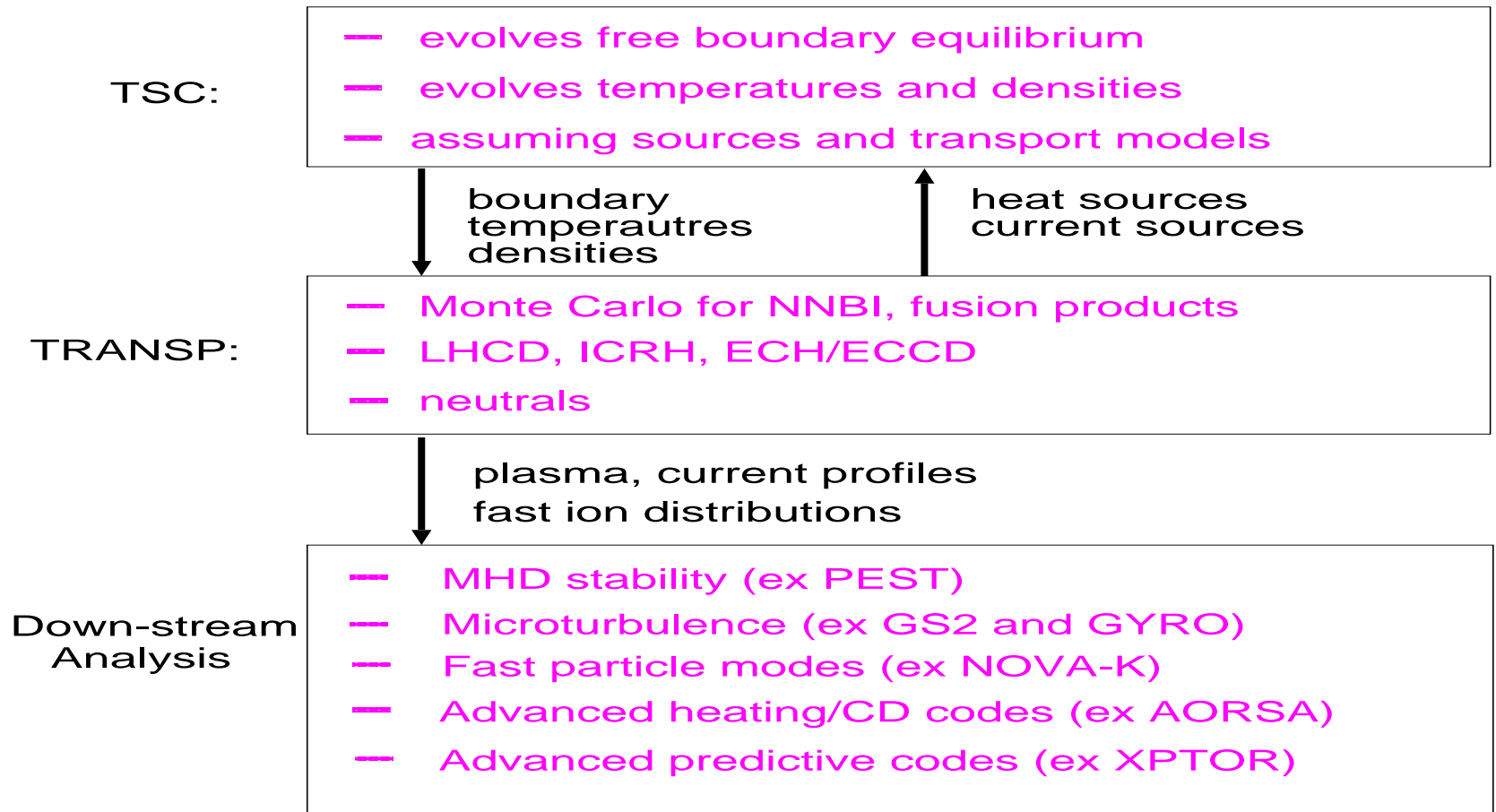
Why Time-Dependent Self-Consistent Integrated Modeling is needed

- Time-Dependent modeling is needed to address the challenges of creating and maintaining steady state plasmas
- Self-Consistent Integrated modeling is needed for the non-linearities and strong coupling of plasma conditions and current drive

Goals of this Talk

- Describe prototype Time-Dependent Integrated Modeling
- Application to ITER plasmas
- Plans for improved Time-dependent Integrated Modeling
- Proposal for submission of wide range of modeled ITER plasmas

Prototype Integrated Modeling using the TSC and TRANSP codes



ITER Plasmas studied

- Steady-State plasma: low current, fully non-inductive
- Hybrid plasma: $q(0) \simeq 1.0-2.0$
- Sawtoothing ELMy H-mode

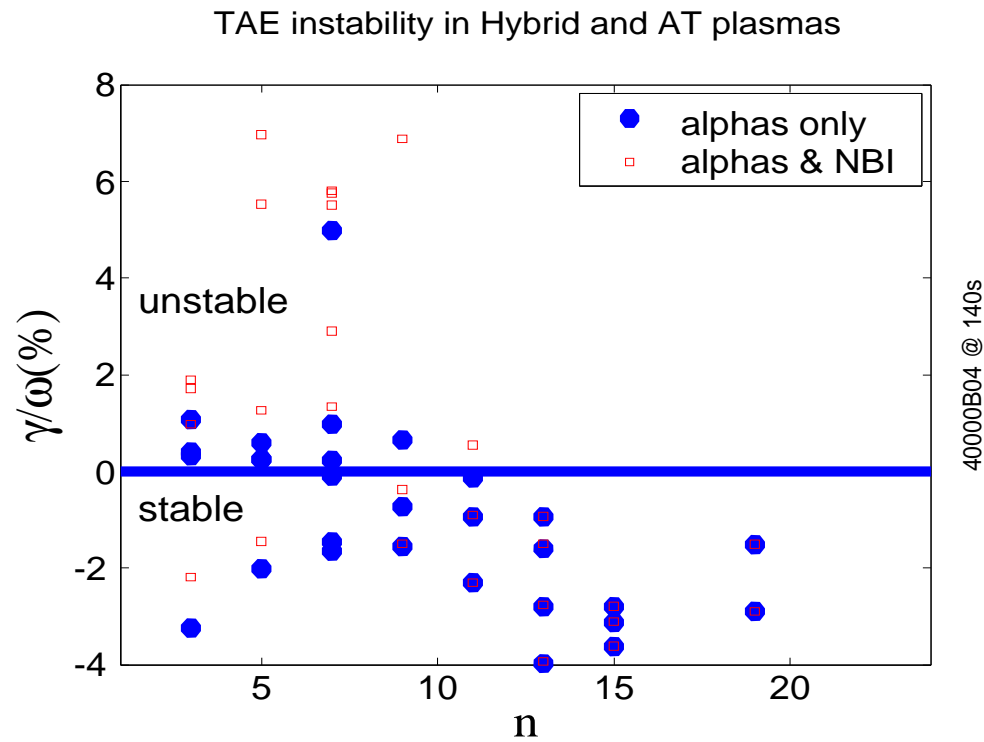
units	I_p MA	I_{boot} MA	I_{nnbi} MA	I_{Oh} / I_p	$n_e(0)$ $10^{20}/m^3$	f_{GW}	T_e keV	P_{dt} MW	$\beta_\alpha(0)$ per cent
Steady-State	9	4.3	4.3	0.0	0.6	0.63	33	305	1.3
Hybrid	12	2.8	2.4	0.50	0.8	0.64	24	333	1.0
ELMy	15	2.7	1.1	0.70	1.1	0.80	22	403	0.6

Examples of Findings

- High pedestal temperatures required by GLF23 in TSC to achieve $P_{DT} \simeq 400\text{MW}$ with the planned ITER auxiliary heating
- Good NNBI penetration and current drive
- Modest toroidal rotation from NNBI torques if $\chi_{mom} \approx \chi_i$
- Intense TAE activity predicted

Example of down-stream analysis

- NOVA-K analysis of TAE modes in ITER Steady-State / Hybrid plasmas

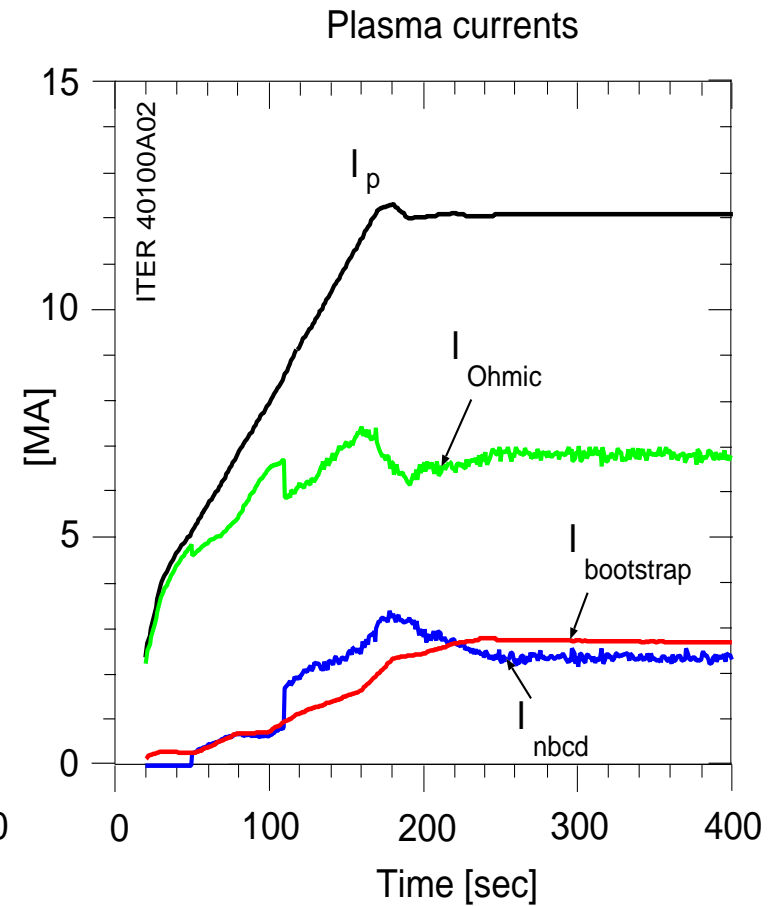
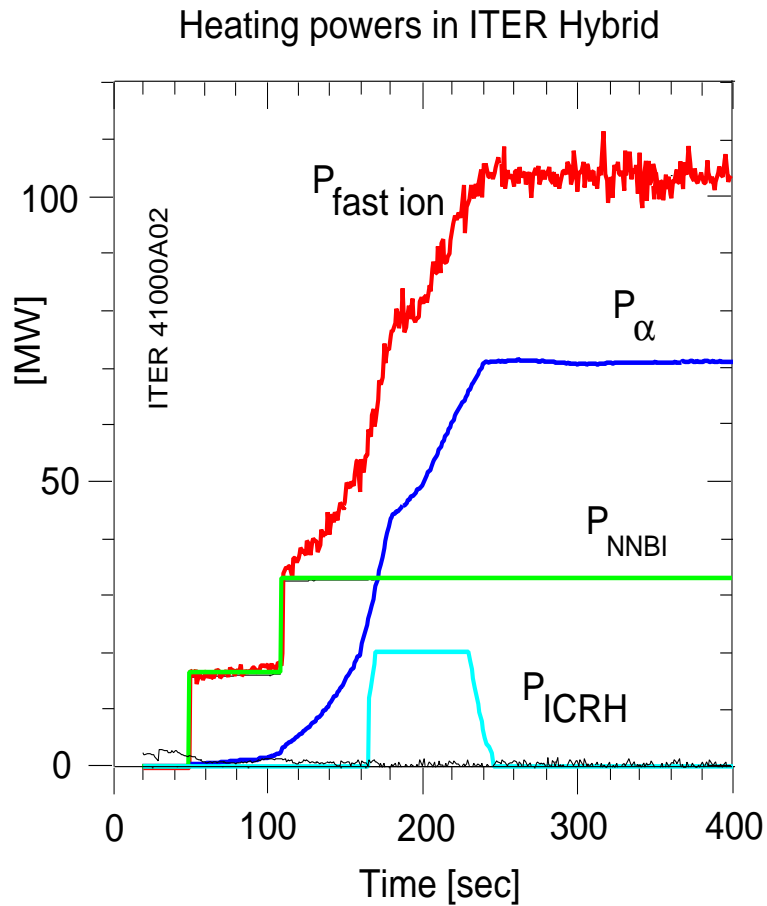


N. Gorelenkov

Construction of the Hybrid plasma

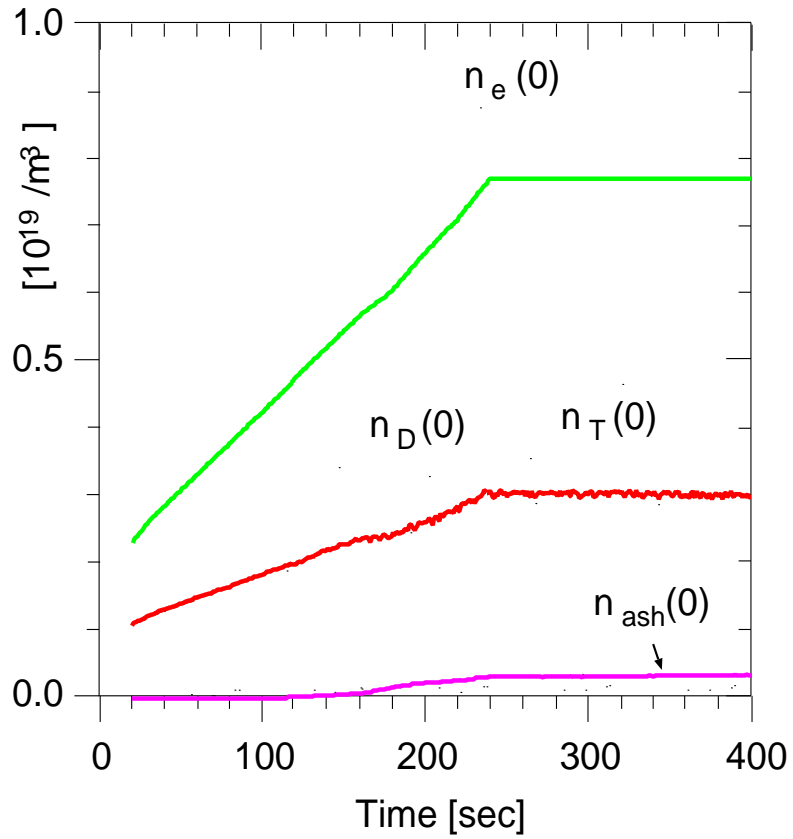
- Use GLF23 model to predict temperatures
- High pedestal temperatures to achieve $P_{DT} \simeq 400$ MW
- Reduced I_p (12 MA) to decrease inductive-current fraction
- Moderate density for good NNBI penetration
- Sufficient current drive to keep $q(0)$ above unity

Heating powers and plasma currents in the Hybrid plasma

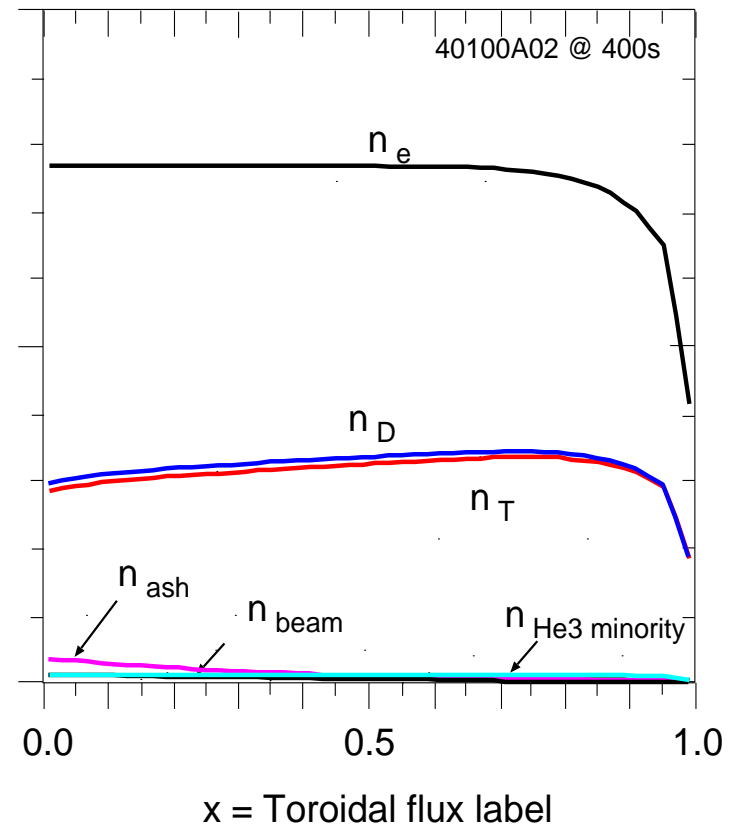


Densities in the Hybrid plasma

Central density evolution in ITER Hybrid

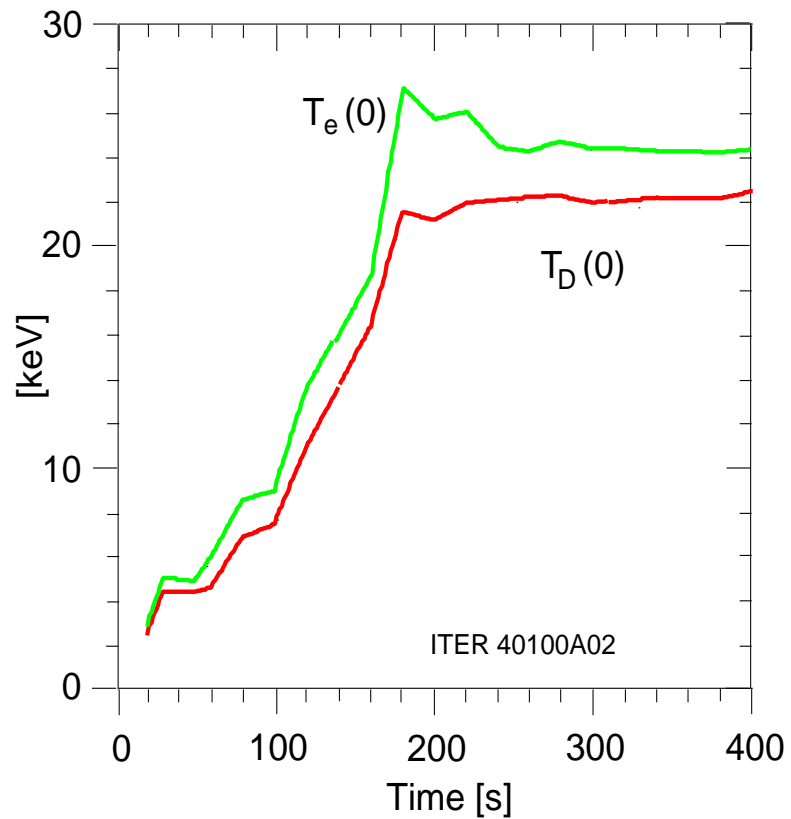


Steady state density profiles

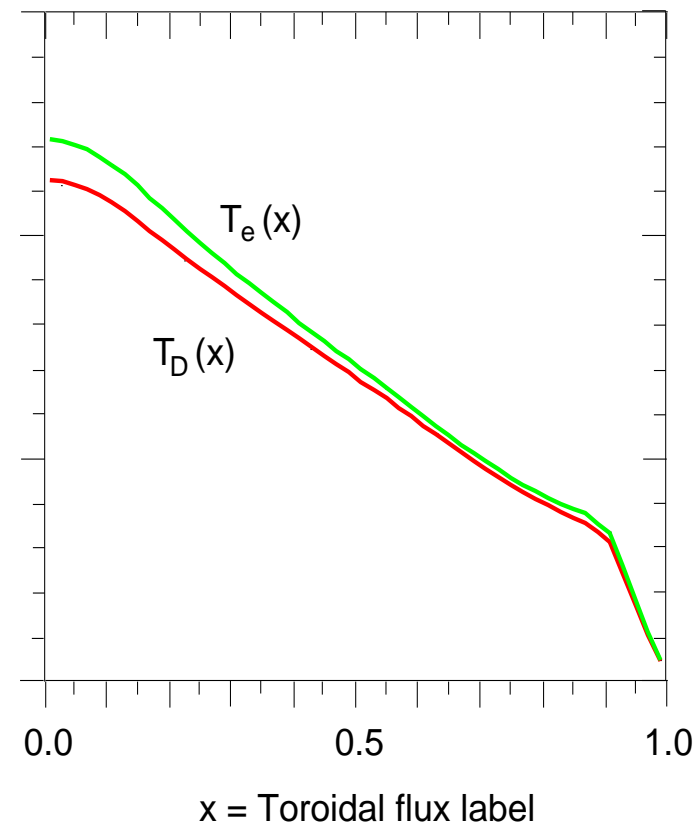


Temperatures in the Hybrid plasma

Central temperature evolution in ITER Hybrid

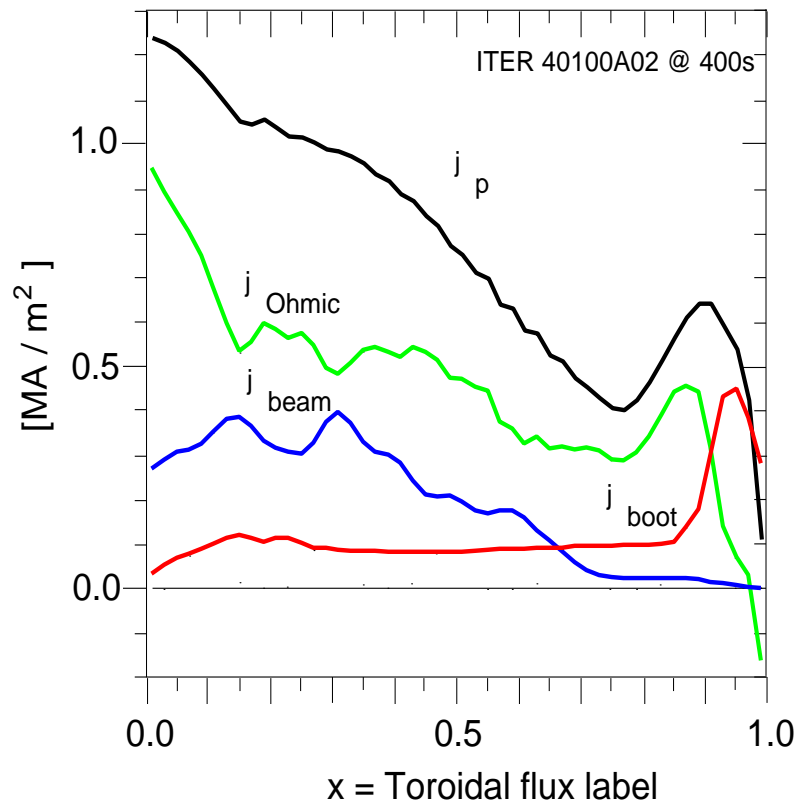


Steady state temperature profiles

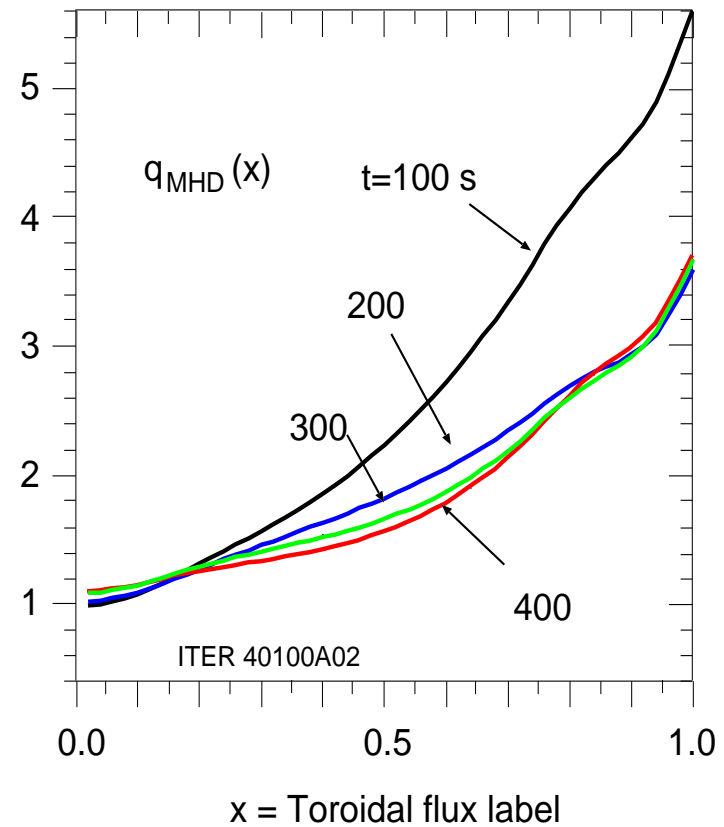


Sustained $q_{MHD} > 1$ with evolving reversal in Hybrid plasma

Current profiles computed by TRANSP

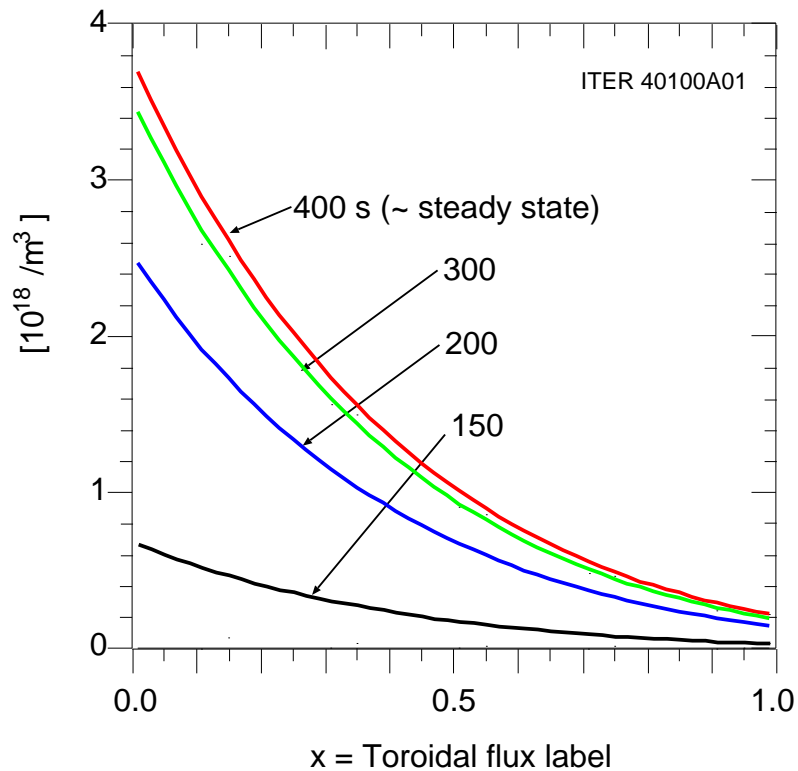


Slow evolution of q in ITER Hybrid plasma



Example of benign ash accumulation in the Hybrid plasma

He ash accumulation in ITER Hybrid plasma



Sources:

Core - Compute He^4 thermalization

Edge - Assume ash recycl coeff = 0.7

Transport assumptions

$$\Gamma = -D \nabla n_{\text{He}^4} + V n_{\text{He}^4}$$

$$D = 1.0 \text{ m}^2 / \text{s}$$

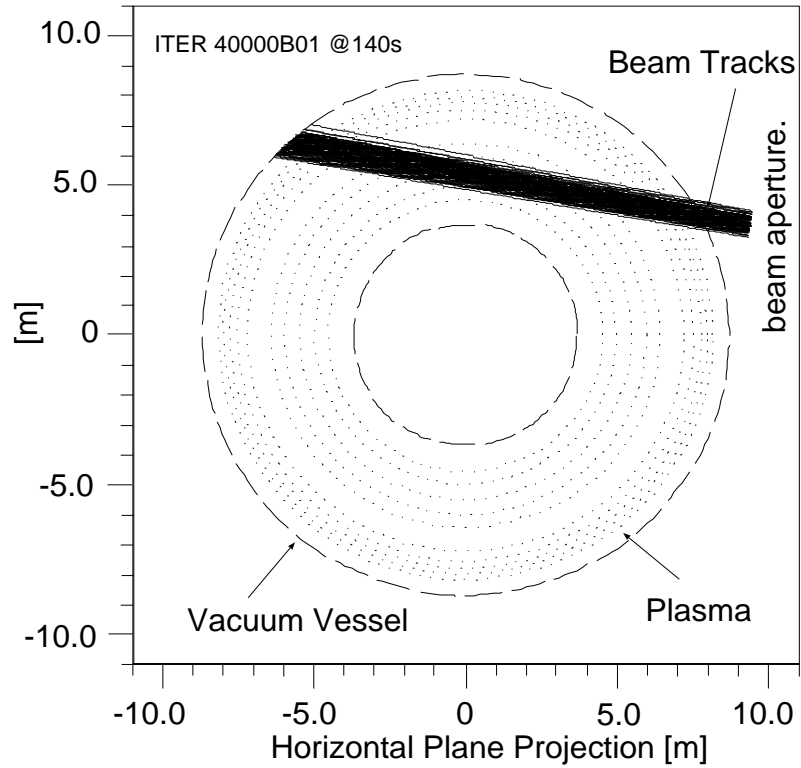
$$V = -1.0 \text{ m} / \text{s}$$

Calculate confinement

$$\tau_{\text{He}^4} = 5.3 \text{ s}$$

$$\tau_{\text{He}^4}^* = 16.0 \text{ s}$$

TRANSP Diagnostics verify NNBI aiming



Inputs

3D geometry of sources

focal lengths

apertures

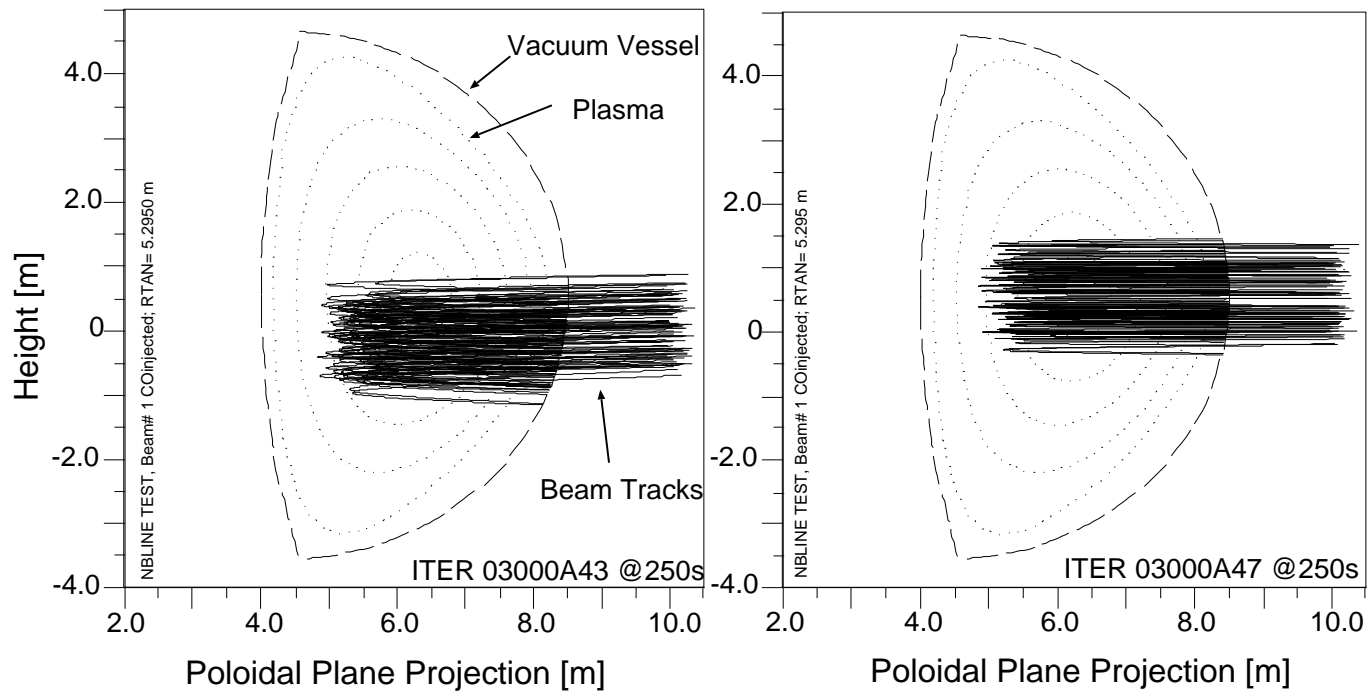
$E = 1 \text{ MeV}$

TRANSP diagnostics check vertical swing of NNBI

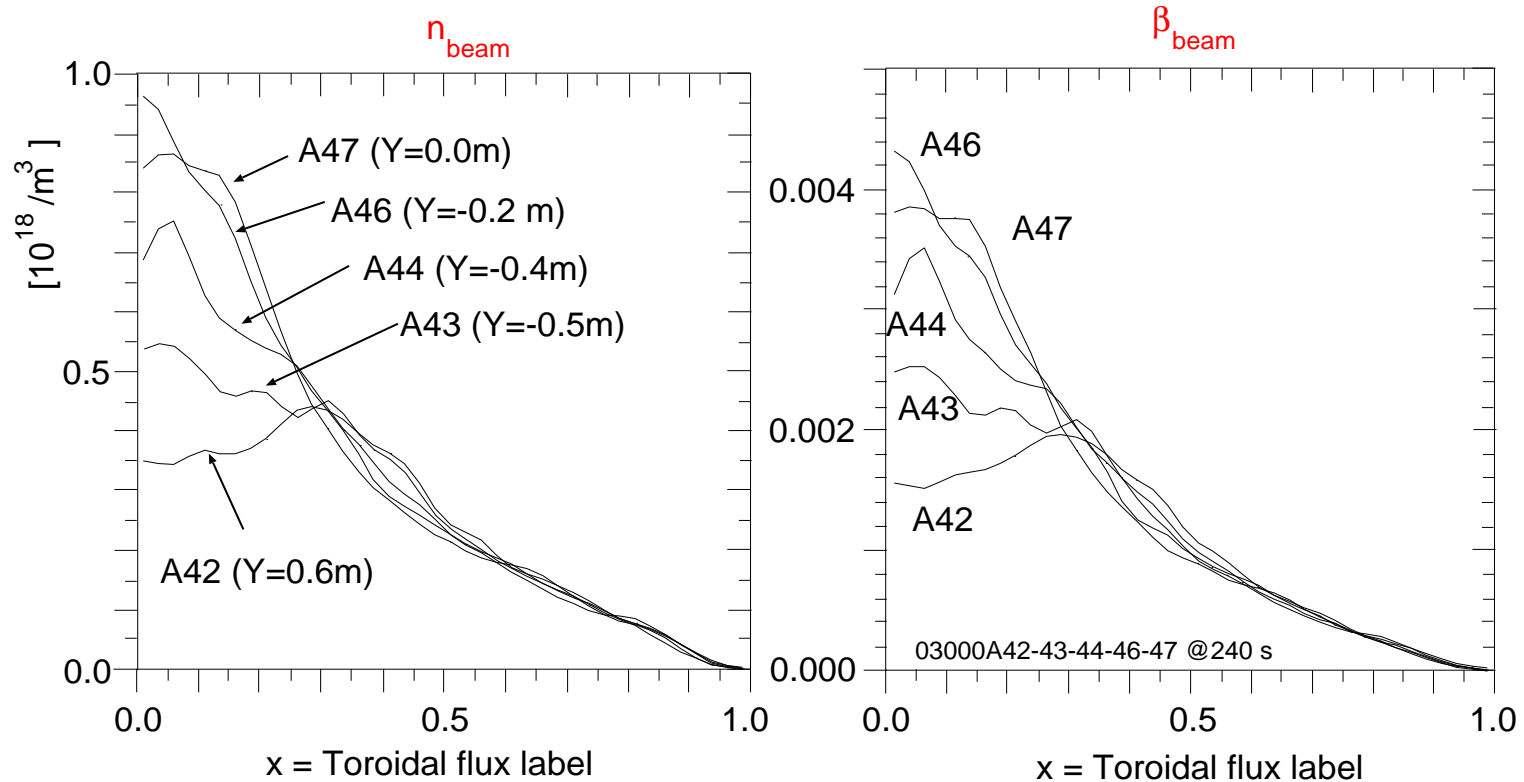
Effects of changing NNBI aiming

0.5 m below magnetic axis midplane

along magnetic axis midplane



Core beam parameters affected by NNBI aiming



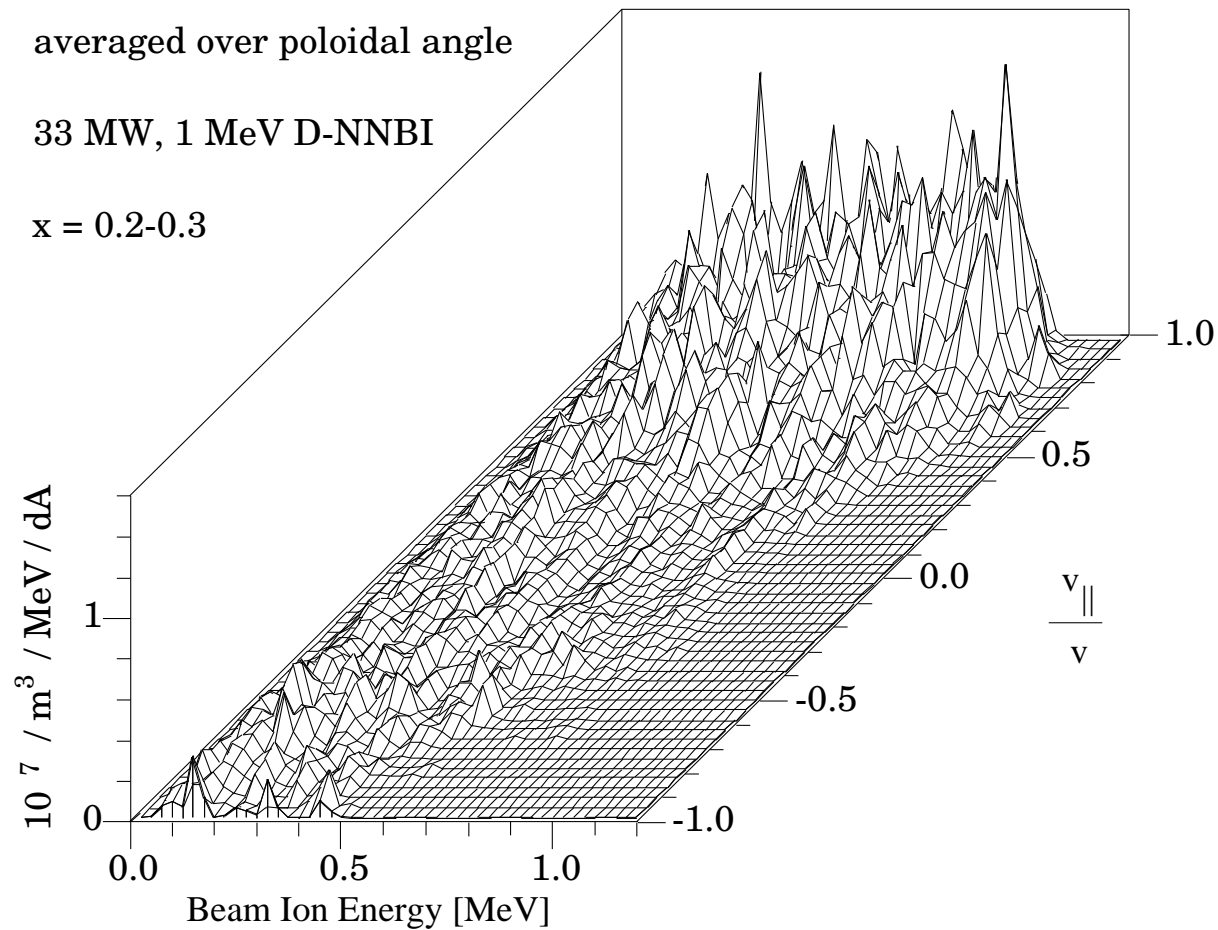
TRANSP computes distributions of fast ions

Beam ion distribution in ITER Hybrid shot 40000B09

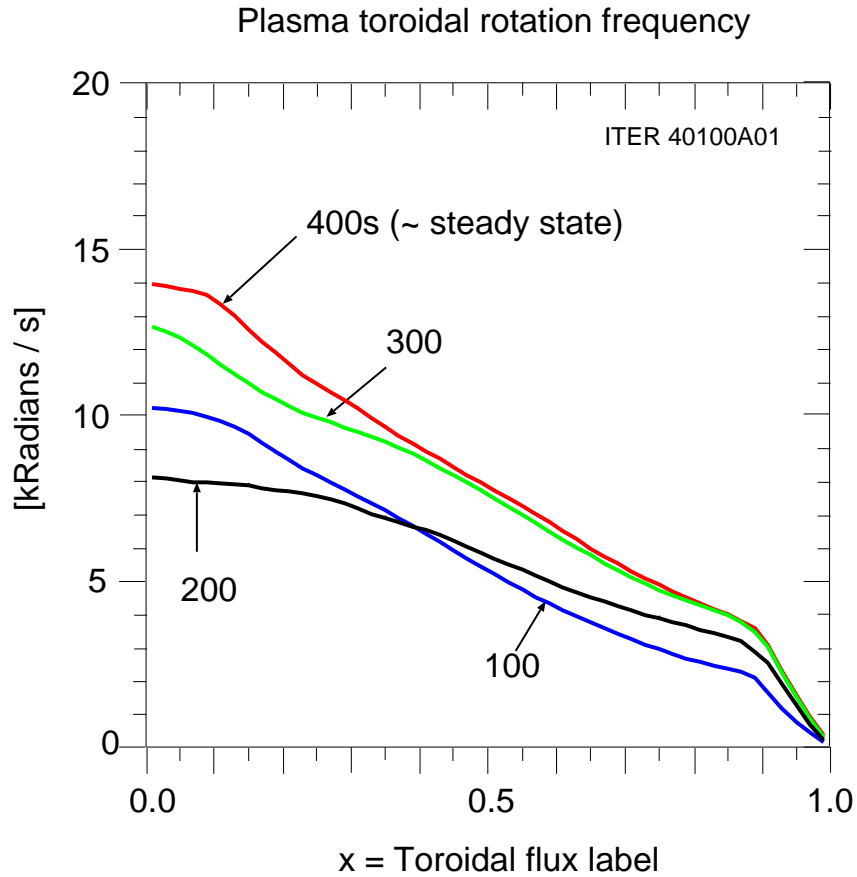
averaged over poloidal angle

33 MW, 1 MeV D-NNBI

$x = 0.2-0.3$



Estimate modest toroidal rotation in the Hybrid plasma



Assume:

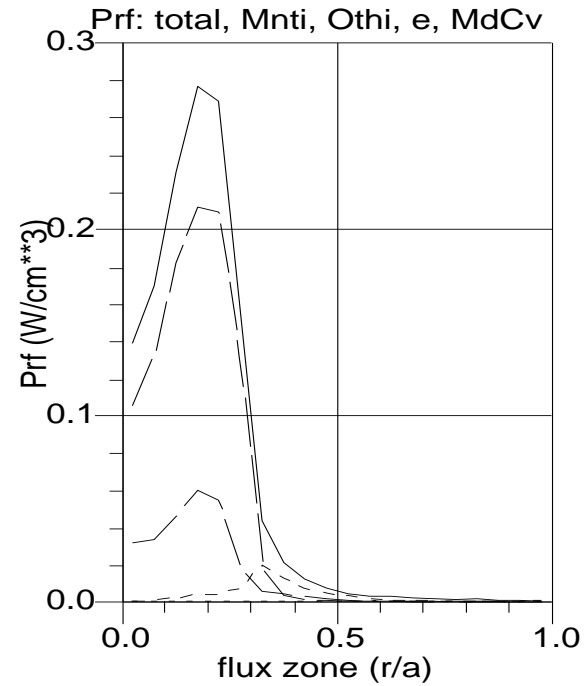
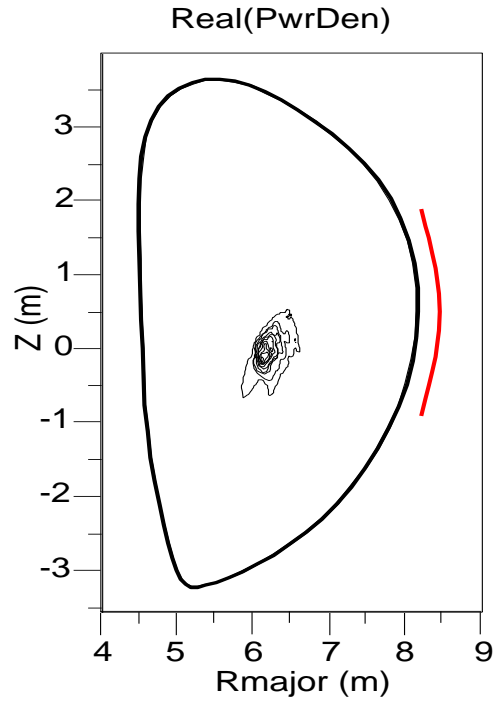
$$\chi_{\text{mom}} = \chi_i$$

$$P_{\text{NNBI}} = 33 \text{ MW}$$

Torques from NNBI

He³ minority ICRH in the Hybrid plasma

ITER 40100A01 at 209.101 sec; f= 52.500 MHz



power in = 20 MW

total Prf= 20 MW
minorities: 13.78 MW
other ions: 3.895 MW
electrons: 2.327 MW
mode conv.: 0.0 MW

T : 8.00 %
D : 5.72 %
He4 : 0.64 %
Be9_4 : 0.88 %
D_MCfi : 1.42 %
He3_mino : 68.89 %
He4_MCfi : 2.81 %
electrons : 11.64 %
mode conv.: 0.00 %

Plans for Integrated Modeling using P-TRANSP

- New PPPL - LeHigh - GA - LNL Collaboration
- Planned near-term upgrades to P-TRANSP
 1. Ability to stop, steer, and restart
 2. Free boundary adjusted by varying coil currents
 3. Improved temperature predictive capabilities
 4. Improved Verification and Validation
- Planned long-term upgrades to P-TRANSP
 1. Scrape-off model
 2. density prediction

Conclusions

- The TSC-TRANSP codes have been used to prototype time-dependent integrated modeling of burning plasmas
 1. Steady-State, Hybrid, and ELMy H-mode ITER plasmas
- moderate toroidal rotation estimated from NNBI
- LHCD effective at altering q around $x=0.8$
- TAE activity is predicted for ITER
- High pedestal temperatures required by the GLF model in TSC
- ash accumulation modeled for various transport assumptions
- sawtooth mixing of fast alphas, beam ions, and ash predicted for ELHy H-mode
- Upgrade (P-TRANSP) in progress