TRANSP Update

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(S. Jardin, F. Poli)

TRANSP User's Group Meeting
4-5 May 2017

PPPL
PRINCETON
PLASMA PHYSICS
LABORATORY

Office of Science
U.S. DEPARTMENT OF ENERGY

Purpose of User's Group meeting

- Update users on TRANSP development progress and plans
- Hear from users about uses and needs
- Discuss long-range plans and issues
- Modify short-, long-term development plans accordingly

- **System issues over last several weeks attempting to be resolved (it is now better than it was!)**

TRANSP Development Personnel Update

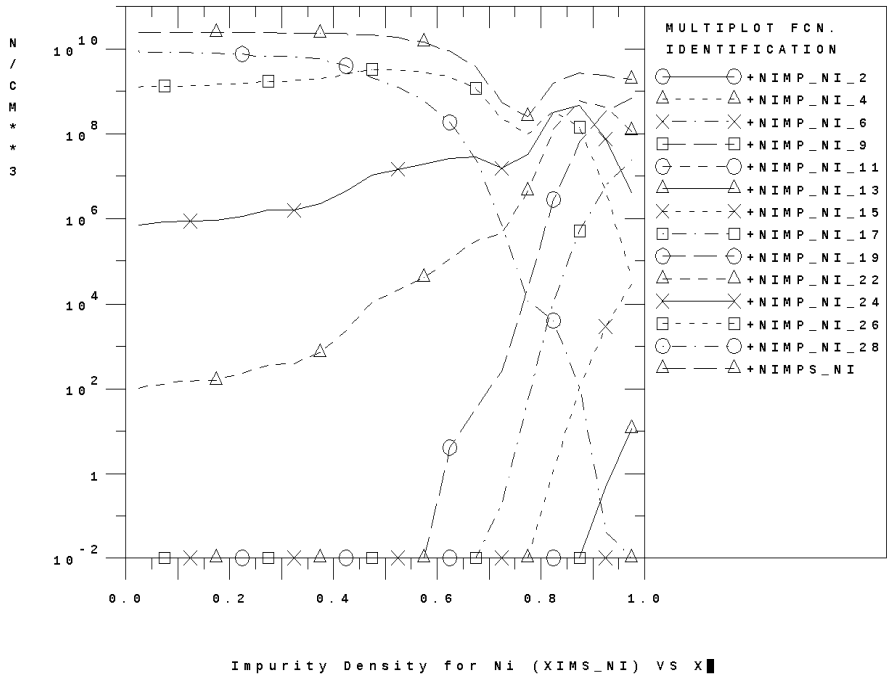
- Present personnel
  - Marina Gorelenkova (8 yrs): NUBEAM, ADAS, RF-NUBEAM coupling
  - Xingqui Yuan (6 yrs): PT_SOLVER (predictive), core-edge coupling, Linux system admin
  - Johan Carlsson (2/16 start): RF codes, IMAS framework development
  - Jai Sachdev (9/16 start): Comp. Fluid Dynamics background: pellet ablation, framework development
  - Josh Breslau (2/17 start): Macrostability codes in Theory Dept. – transfer to CPPG; fast ions, ISOLVER equilbrium
- Will focus only on highlights from last few months

Multi-impurity species transport (X. Yuan)

- Impurity density prediction capability implemented in PT_SOLVER
  - Particle conservation equation for individual impurities solved
  - TGLF/NEO used to calculate fluxes and impurity transport
  - Coronal equilibrium assumed
  - Use ADAS ionization and recombination coefficients
- Density profiles, line and bremsstrahlung radiation computed fore each charge state
  - Can self-consistently predict power radiation loss, $T_{e,l}$, etc
- Presently benchmarking against expt'l data

JET 51976

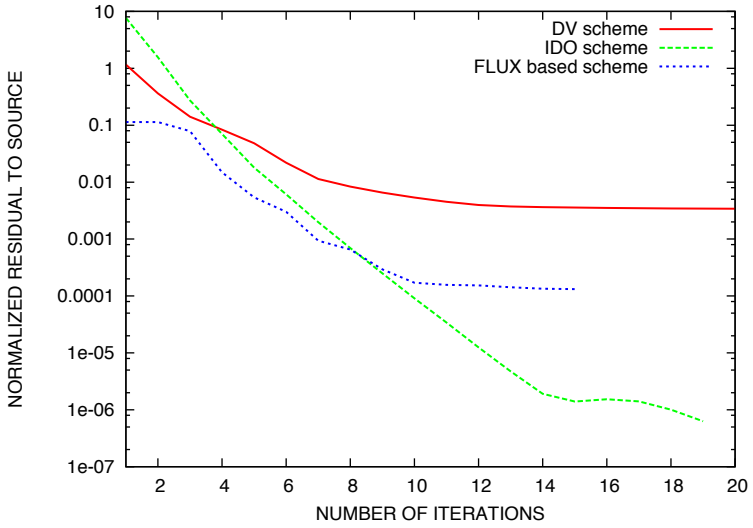
Ni impurity profiles for individual charge states

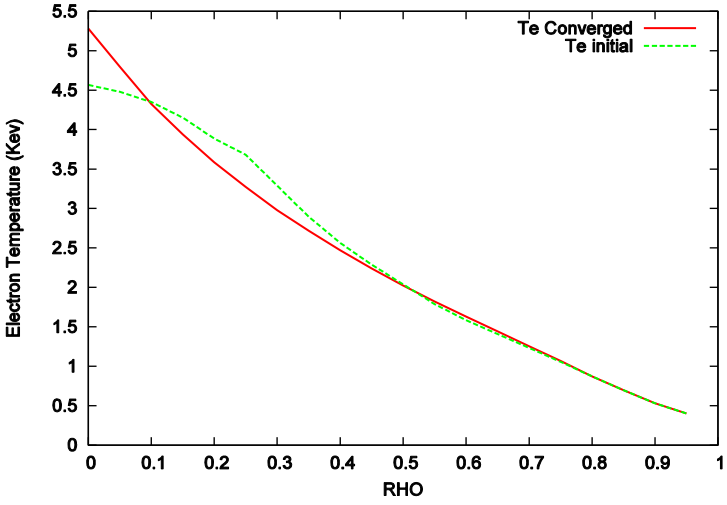


IDO solver implemented in PT_SOLVER (X. Yuan)

- Interpolated differential operator (IDO) scheme implemented
  - Test as replacement for present PT_SOLVER algorithm in an attempt to speed up (e.g., TGLF) predictions
  - Newton iteration method used to reach convergent solution
  - No additional numerical diffusivity required
  - IDO as been tested in FASTRAN code (J.M. Park, ORNL)
- IDO "robust" (stably convergent)
  - Reached steady-state in 150 timesteps, each requiring several Newton iterations to reach residual levels of 1.e-6
  - Good convergence near boundary
- IDO scheme ~30 to 40% faster than present PT_SOLVER algorithm (in time-dependent mode)
  - Also has issues with discontinuous fluxes from TGLF
  - Exploring ways to smooth TGLF fluxes (10X speedup?)
- Deep learning (Neural Net) can yield much faster solutions

TFTR Test Case

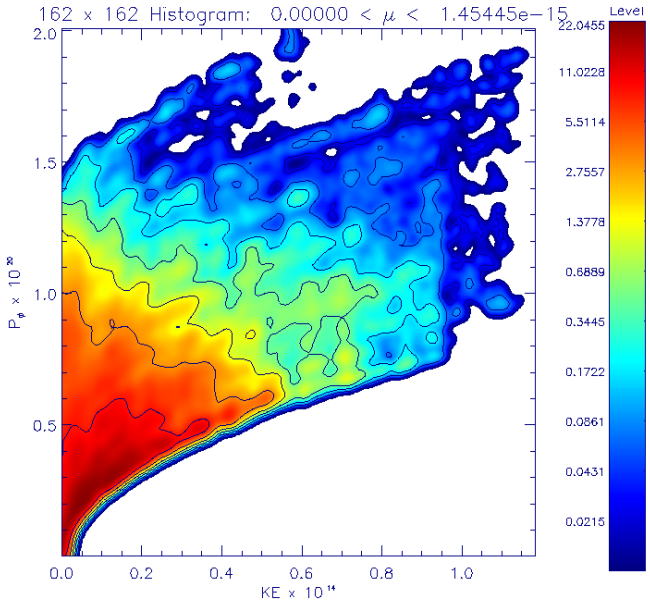


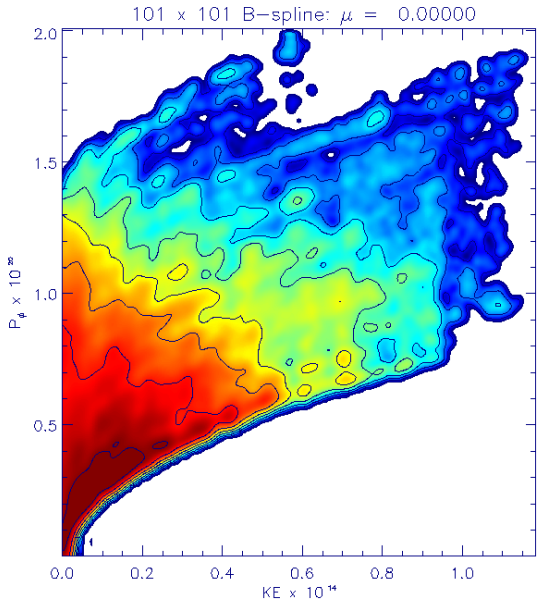


Fast ion distribution function (J. Breslau)

- Script written to convert fast ion ensembles generated by NUBEAM to analytic d.f. of particle constants of motion for use by kinetic stability codes
  - Particle coordinates converted to E, μ, P_Φ, then sorted into bins and smoothed
  - Process repeated iterativel to estimate Jacobian of the coordinate transform
  - For each μ range, 2D cubic B-splines are fit to the smoothed E, P_Φ distributions and stored in a file
  - A utility library provides fast evaluation of the d.f. and its derivatives suitable for invocation by delta-f codes

Sample particle histogram, ~1M particles.

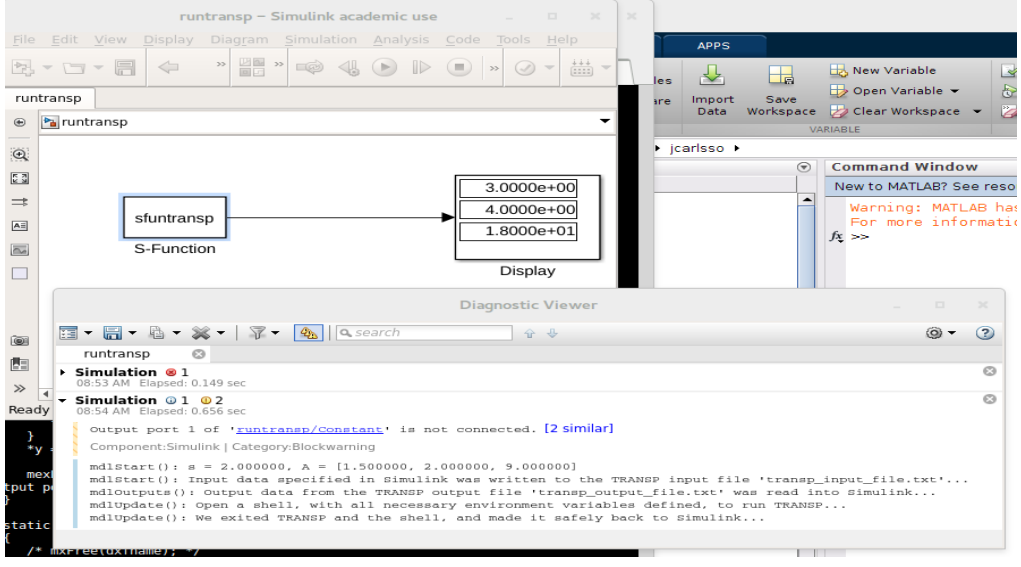




Spline reconstruction of distribution.

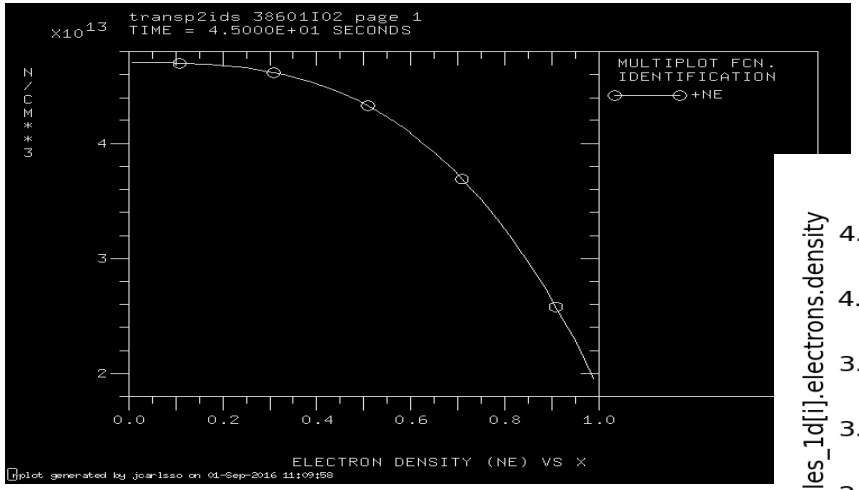
TRANSP in Simulink framework (J. Carlsson)

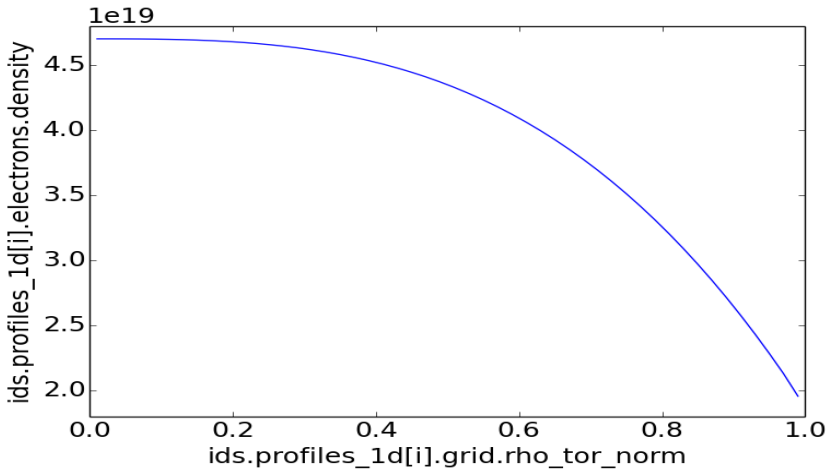
- TRANSP as a plasma proxy for developing control algorithms in Simulink
  - Simulink is the standard framework for control system development
  - Of interest for NSTX-U, KSTAR, DIII-D, ITER
- Enabling TRANSP in piecemeal and general approach
  - Useful also for other frameworks
- A couple of basic Simulink models are done: launching process (ultimately full TRANSP), writing input / reading output, pausing until output file is updated…
- The current file-based communication will be upgraded to IPC (Inter Process Communication); other protocols are being evaluated



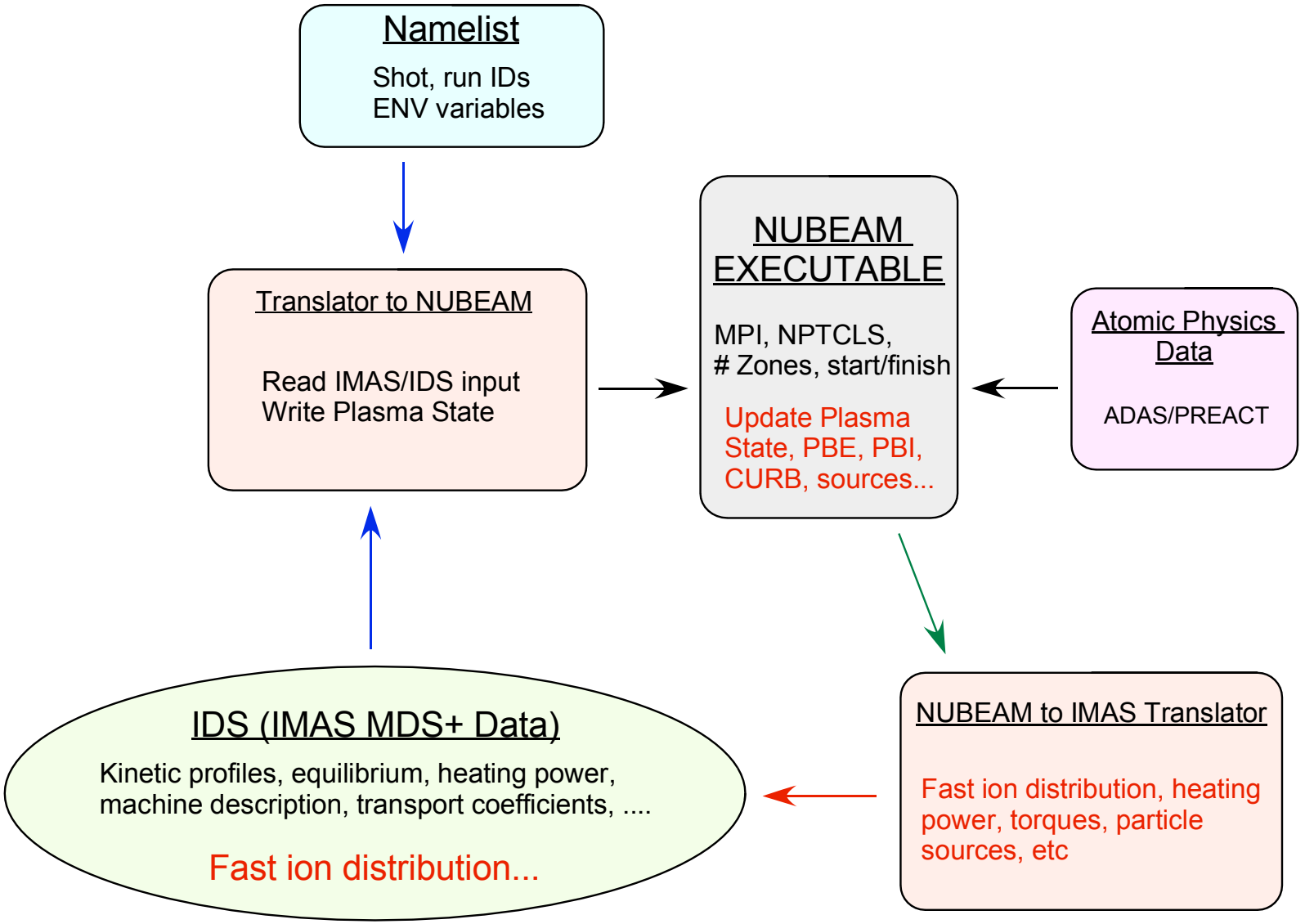
TRANSP and IMAS (J. Carlsson)

- Data translators between TRANSP and IMAS (Iter Modeling and Analysis Suite) formats have been developed and are becoming ready for use
- Currently implemented as standalone executables, to be used pre- and post-process, respectively
- Source code available at: https://github.com/transp/transp-imas-translator
- NUBEAM has been run with IMAS input data translated from TRANSP output



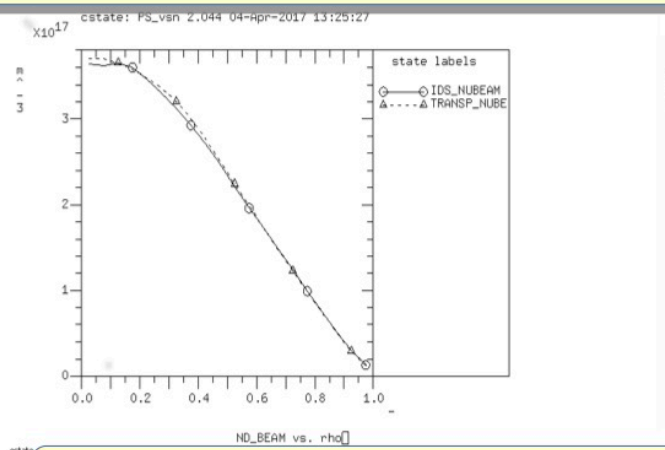


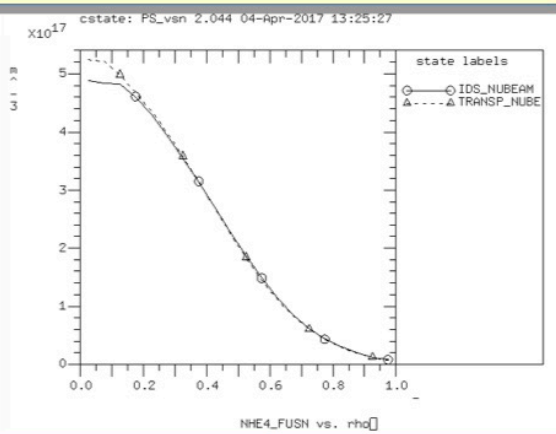
NUBEAM component added to IMAS (M. Gorelenkova)



IDS_NUBEAM vs TRANSP_NUBEAM (M. Gorelenkova)

Fast ion (D_beam & He4-fusion) density





ITER.11
TRANSP RUNID 38530B10
IDSID/input 3850030
IDSID/output 3850035
t_start=100 sec
t_finish=105 sec

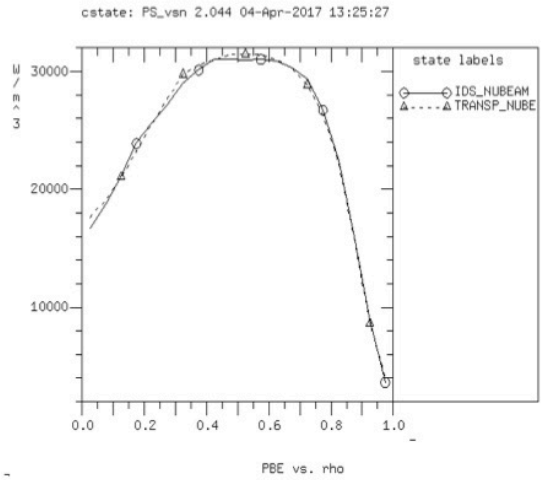
sold line – IDS-NUBEAM
dash line – TRANSP-NUBEAM

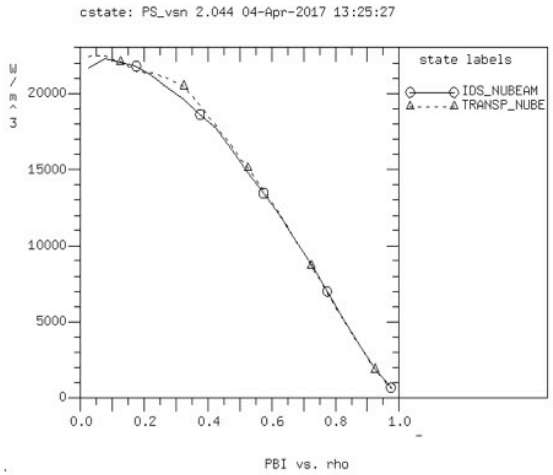
Fast ion heating

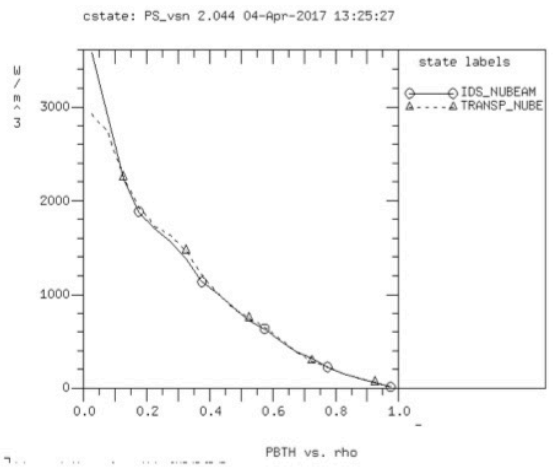
Electrons

thermal ions

thermalization power







Pellet ablation model (J. Sachdev)

Objective:

- Reinstate pellet ablation model
- Extend to more modern models

Status:

- Using a pellet ablation module developed by Parks at GA
- Extending input parameters to allow specification of pellet injectors instead of just individual pellet events
- Currently undergoing basic testing and validation

Pellet Injection:

- Inputs include direction of the pellet injector, injection frequency, pellet material, ablation model
- Treated and scheduled as discrete events, similar to TRANSP s-t treatment
- Pellet trajectories are traced through the plasma and electron density and temperature profiles are compiled along the path
- Pellet ablation is computed along the trajectory (size is reduced accordingly)
- Net change to electron density and temperature is computed and added to the plasma as the pellet ablates

Ablation Model:

- Form of base model for hydrogenic and impurity pellets:

$$\frac{\mathrm{d}N}{\mathrm{d}t} = \alpha\, n_e^{0.333}\, T_e^{1.64}\, r_p^{1.333}\, M_i^{-0.333}$$

TRANSP in OMFIT (J. Sachdev)

Development:

- CPPG will directly be involved with the TRANSP/OMFIT development
- Ensure new capabilities are added to the TRANSP module inputs
- Extend capabilities as required (e.g., new plotting tools, additional consistency checks, …)
- Will also help extend to other devices as needed

Support:

- Help users get started with TRANSP in OMFIT
- Help users trouble shoot issues they are having with TRANSP in OMFIT

TRANSP framework development (J. Carlsson, J. Sachdev)

Objective:

- Improve and modernize the code architecture of TRANSP
- Streamline TRANSP integration into other frameworks
- Allow for straightforward testing/integration of user's own codes that are not part of TRANSP

Other Frameworks:

- Develop driver routines that can guide TRANSP runs as part of other frameworks (e.g., Kepler, Matlab/Simulink)
- File-based communication at first, socket or MPI communication in future

TRANSP as a Framework:

- Split code into physics-based modules
- Compile these modules dynamically and link at run time
- Allows for swapping of models and easy testing/integration of user defined models, for example:
  - The TRANSP standard RF heating module, librfh.so, can be swapped out for a user's own code, librfuser.so
  - The hooks required to connect to TRANSP will be provided
  - User's will then have to compile their code as a shared library
- This effort is still going through planning and experimentation
- Could require significant upgrading of the TRANSP build system

RF code development status

- TORIC extension completed for both HHFW and ICRH (Bertelli, Valeo, Bonoli)
  - Can use either analytic or numerical distribution functions
  - Not yet implemented in TRANSP
- RF Q-L operator in TORIC to couple to CQL3D (Lee, Wright, Bertelli)
  - Valid only for minority heating schemes (e.g., ITER)
  - CQL3D can be used instead of FPPRF
  - Not yet implemented in TRANSP
- RF kick operators in NUBEAM being validated
  - Critical for NB-ICRH/HHFW modeling (fast ion tail determination)
  - Needs to be made self-consistent
  - TORIC/NUBEAM self-consistent coupling can be used to verify amount of fast ion heating due to (e.g.) HHFW

Short-term (0 – 2 yrs) plans

- Continue and 'finalize'
  - Impurity transport benchmark with STRAHL using C-Mod data
  - IMAS/TRANSP workflow and translators, NUBEAM as IMAS module
  - Exploration of PT_SOLVER speedup
    - Incorporate TGLF NN (DIII-D based)
    - Extend NN
  - Implementation/support of TRANSP in OMFIT (w/GA) and SIMULINK frameworks
    - Latter can serve as basis for code modernization
- Incorporate RBQ-model for fast ion diffusion due to AE, when available
- Extend Parks' pellet model
- Incorporate extended TORIC, TORIC CQL3D QL operator
- Implement implicit coupling of GENRAY/CQL3D & ISOLVER for self-consistent calculation of E-field and runaway tail in LHCD

Short-term (0 – 2 yrs) plans cont'd

- Support implementation of BEAST (BEtween and Among Shots Transp) on DIII-D, KSTAR, (JET, EAST)?
  - Already available and running on NSTX-U
- Standalone ISOLVER (IMAS component) and PT_SOLVER (already in OMFIT via Brian G.)
- Incorporate simple NTV model based on EMP coil currents into momentum balance
  - Already exists in rotation control scheme
- GRE/NTM island model implementation and validation (F. Poli, E. Fredrickson)
- Diagnostic ballooning stability calculation
- Initial core-pedestal coupling model
  - EPED lookup table/Neural Net (discussion with Brian G.)

Longer-term (2+ yrs) plans

- Optimize and fully implement TRANSP on NERSC for V&V/UQ
- Develop plans and initiate implementation of 1D SOL model
  - Based on OEDGE?
  - 2d neutrals package necessary?
  - Discussion near end of TUG
- Continue development of pedestal model
  - Extended range of equilibria/profiles for NN
  - Explore different NN approaches
- Initiate/continue TRANSP framework modularization
  - Legacy code will not go away!
- Incorporate pressure anisotropy into ISOLVER
  - Low R/a application

Backup

ISOLVER equilibrium solver (J. Breslau)

- The free boundary equilibrium code ISOLVER is a tightly bound component of TRANSP
  - Uses Picard iteration to update from an initial plasma current distribution until convergence is achieved to a target *q* profile
  - Part of the core of the TRANSP time advance loop

- Plan: extract ISOLVER as a standalone NTCC module for equilibrium solves with prescribed *q* profiles outside of TRANSP
  - Requires isolation of library dependencies to compile independently
  - Requires isolation of data structures to enable user input of initial guesses, profiles
  - Work in progress

- Plan also for tight coupling between ISOLVER and GENRAY/CQL3D for self-consistent calculation of E-field and runaway tail in LHCD

Pellet ablation (cont'd)

- (Very) preliminary result for the ablation model for an ITER scenario: Pellet inputs not realistic for test
- Flux surface contours shown at 1.5 s
- The arrow indicates the pellet injector location
- Figure at bottom left shows the electron density before (purple) and after (green) the pellet ablation
  - Asymmetry due to cell centered values plotted at the cell exit position
  - Significant ablation at center possibly exaggerated due to not realistic inputs