Kinetic-Kinetic Plasma-Neutral Simulations with XGC0-DEGAS2*

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Outline

- Background on XGC0 kinetic neoclassical code
- Introduction to XGC0-DEGAS2 kinetic-kinetic plasma-neutral code
- Example application: core particle fueling

What is Role of Neoclassical Processes in Pedestal?

- ITER performance sensitive to height of H-mode pedestal
  $\Rightarrow$ extensive efforts to understand governing processes.

- Neoclassical effects significant in H-mode due to reduced anomalous transport.

- Pedestal characteristics complicate analytic model development:
  - Gradient scale lengths $\sim$ banana orbit width,
  - Proximity of separatrix,
  - Loss holes in ion velocity space.

- $\Rightarrow$ kinetic, guiding center ion neoclassical PIC code, XGC0 [Chang2004].

Physics Capabilities and Accomplishments of XGC0

- Effect of consistent E_r & collisions on pedestal examined in [Chang 2004],
- Demonstrated pedestal build up with simplified neutral routine.
- Subsequent extensions: kinetic electrons, impurity ions, logical sheath, anomalous transport models, RMP.
- Recent applications:
  - ELM cycle by coupling to M3D [Park 2007],
  - Divertor heat load width [Pankin 2010].
- Planned upgrades: multiple charge state impurities, 2-D ϕ.

Improve XGC0 Neutral Treatment with DEGAS2 Routine

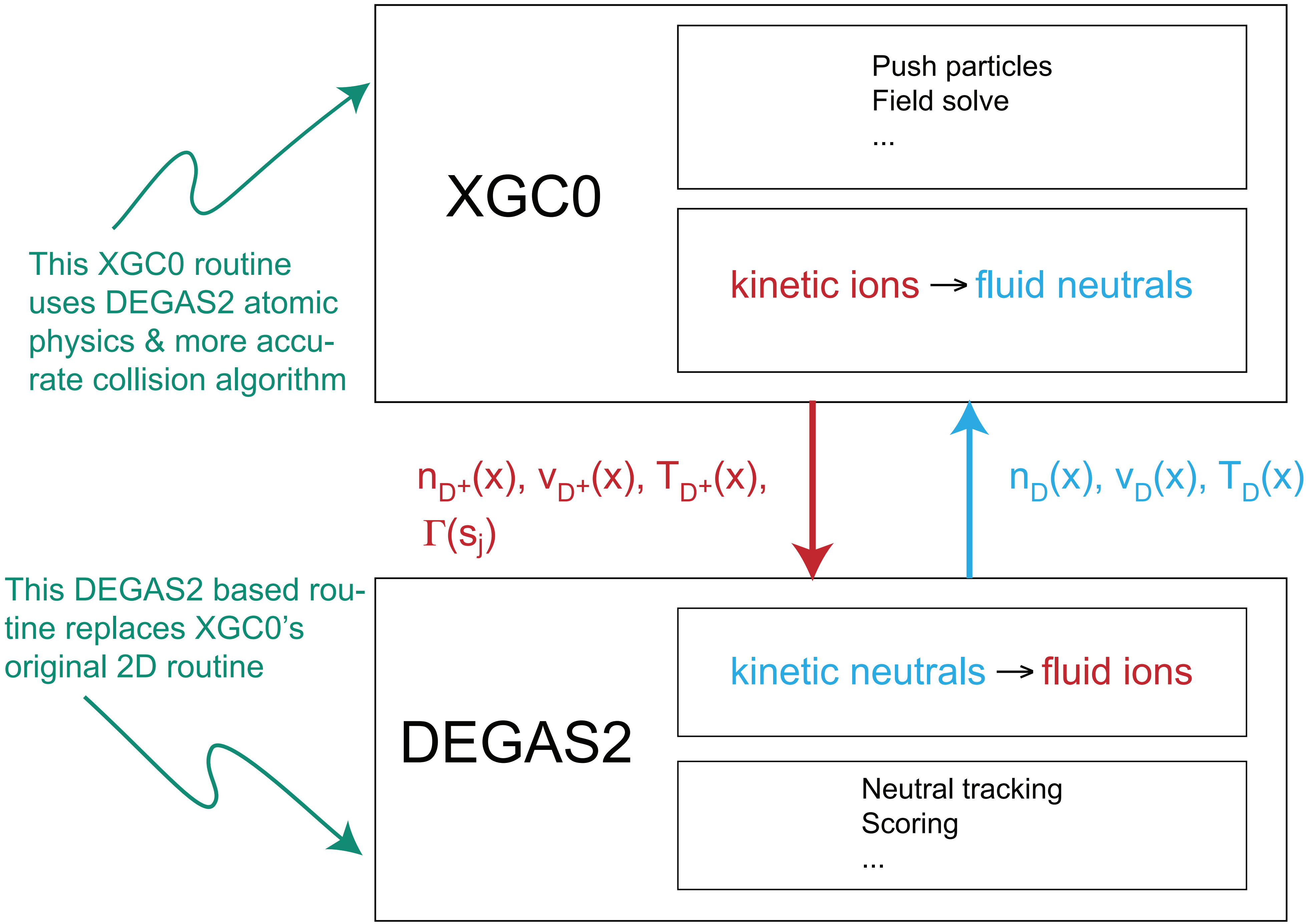
- Bring XGC0 neutral model up to level of B2-EIRENE, UEDGE-DEGAS2, etc.
  - Resolve neutral quantities throughout vacuum vessel,
  - Neutral sources & PMI at wall,
  - Use DEGAS2's atomic physics machinery & database,
  - Synthetic diagnostics, e.g., visible cameras.

- Kinetic electrons & impurities not enabled in XGC0-DEGAS2 since verification is ongoing.

Approach to Kinetic-Kinetic Plasma-Neutral Coupling

- Fluid plasma - kinetic neutral coupling: latter computes plasma sources due to neutrals,
  - $\Rightarrow$ "right hand sides" of plasma equations.
- Kinetic data lost $\Rightarrow$ need different mechanism for kinetic plasma code.
- Fully kinetic Direct Simulation Monte Carlo requires too many computational resources.
- Instead use "test particle Monte Carlo":
  - Developed for handling nonlinear collision operator in gas simulations.
  - Kinetic test particles collide with background characterized by specified distribution.
  - Distribution updated iteratively to convergence.
  - Accuracy depends on adequacy of chosen distribution.

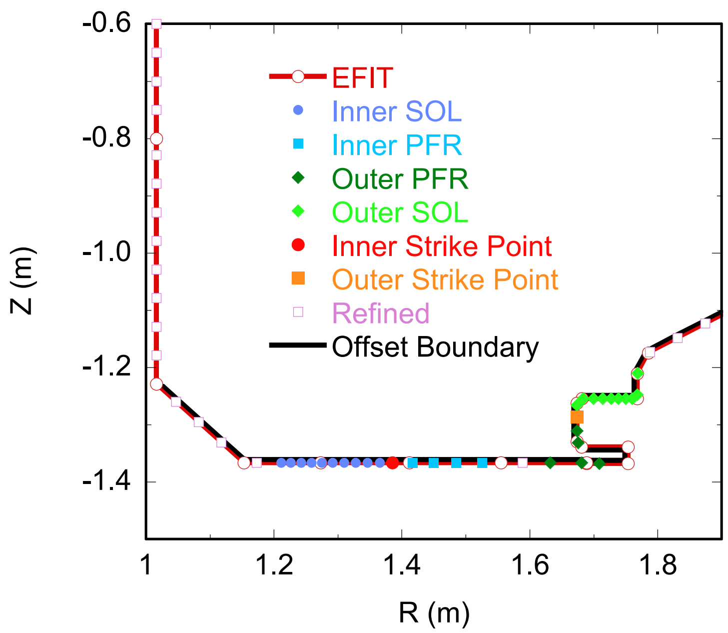
"Test Particle Monte Carlo" Technique Implemented in Two Complementary Collision Routines

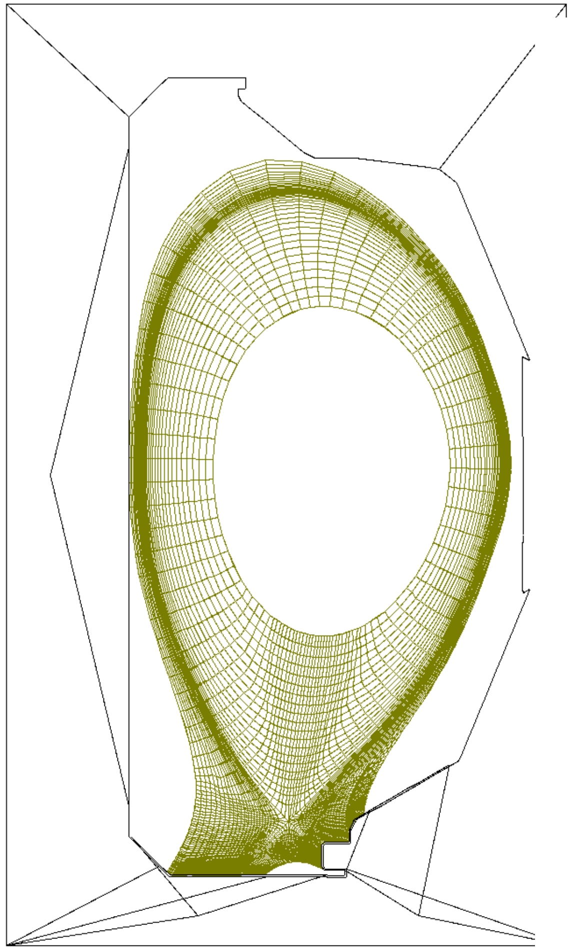


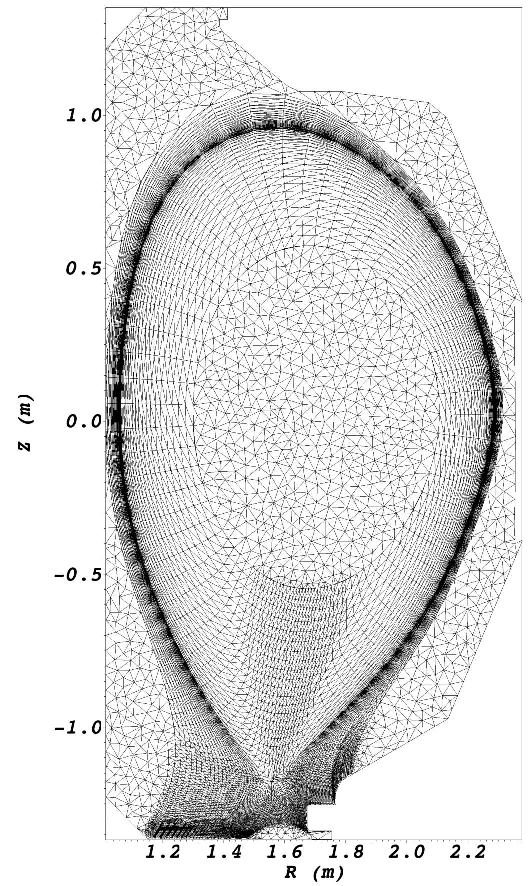
Consistent, Time-Dependent Recycling in XGC0-DEGAS2

- XGC0 ion current to boundary $\Rightarrow$ recycling neutral source for DEGAS2.
  - Poloidal distribution periodically updated.
  - Integrated source current $=$ total lost ion current since last DEGAS2 call.
- Will be adding lost ion energy distribution
  $\Rightarrow$ sample recycled ions & can use detailed PMI models.
- "PMI" here: 3 eV D atoms with cosine distribution.
- DEGAS2 routine invoked every 15 μs here,
  - $\Rightarrow$ neutrals evolved in time over interval,
  - Moments of neutral distribution time averaged.
  - Atoms left in volume at end of interval can be continued in next.

Vessel Filling Triangular Mesh with User Controlled Boundary Discretization



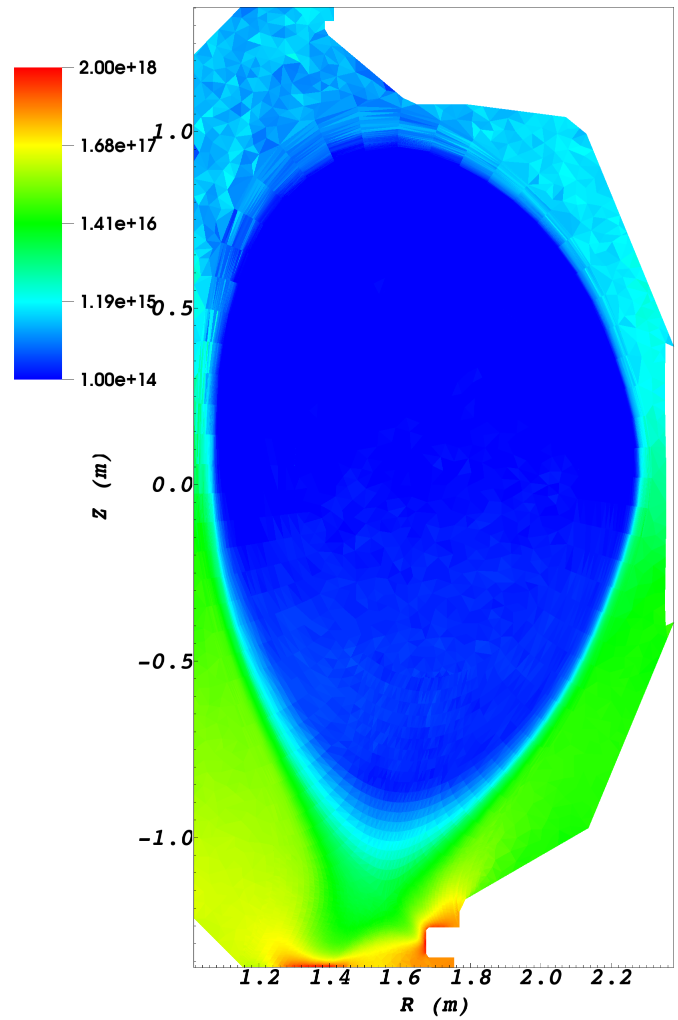




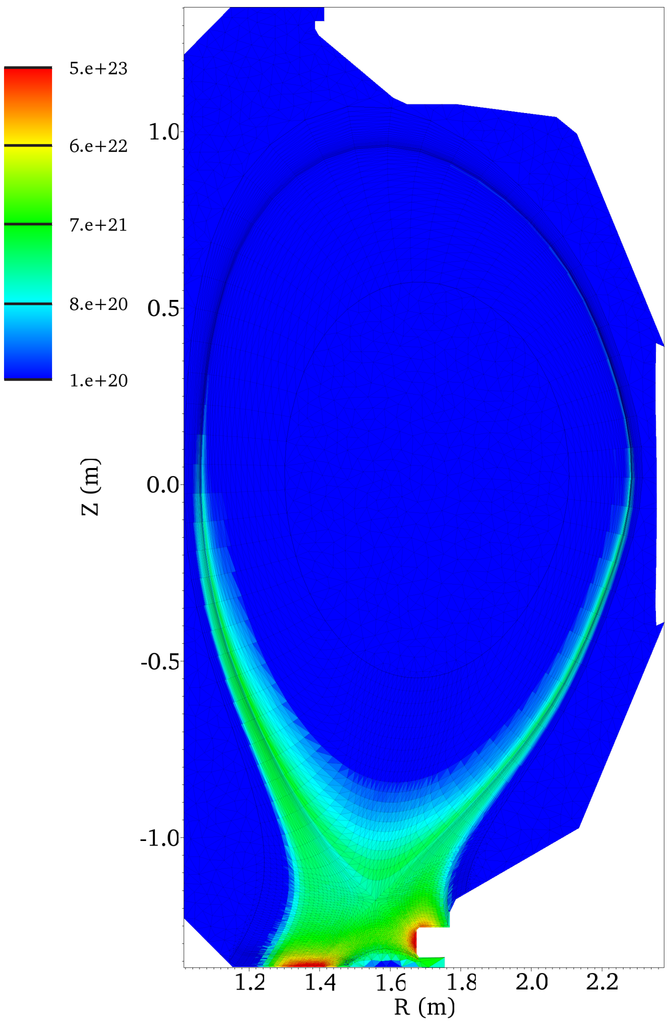
- User specifies minimum spacing on boundary and narrow flux grid around strike points.
- Boundary to be used by Carre offset by 5 mm.
- Use DG & Carre to generate flux surface mesh for given EFIT.
- Tile remainder with triangles via Triangle routine.

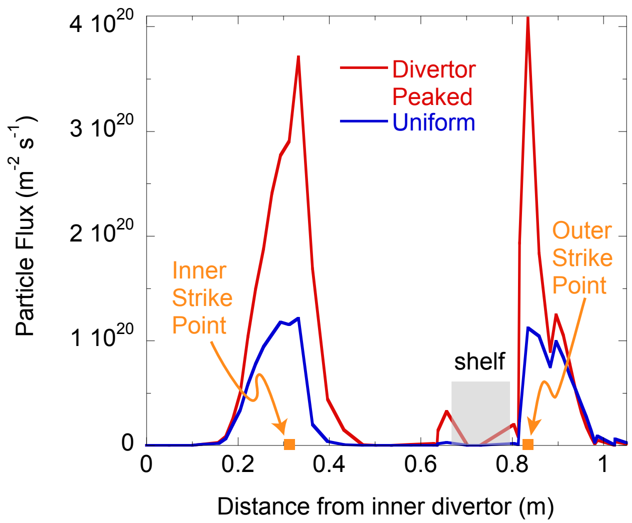
Demonstration of Coupled XGC0-DEGAS2 Code

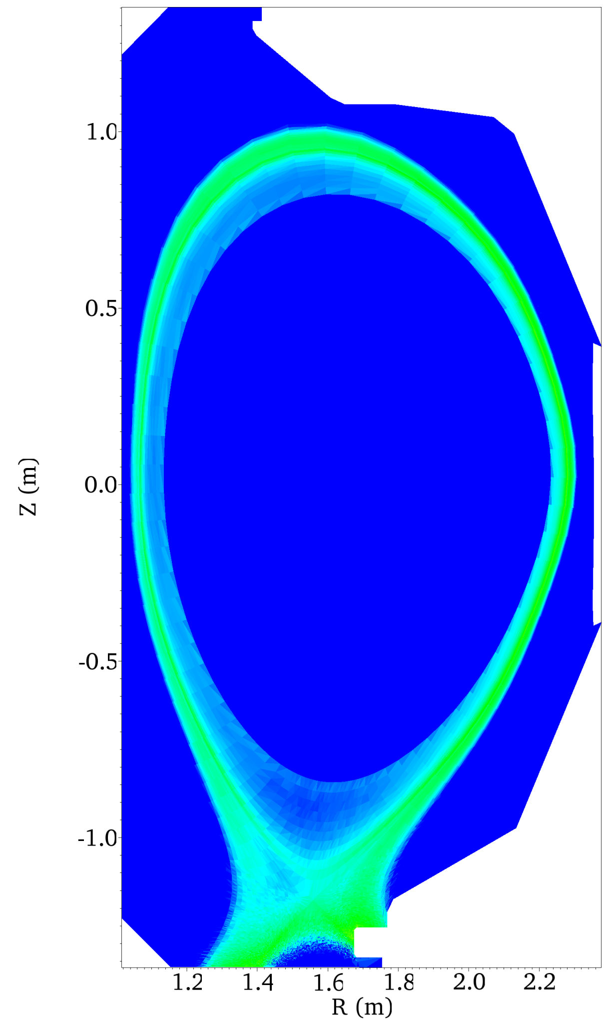
- Standard XGC0 test case:
  DIII-D shot 96333 3300 ms.
- Initial pedestal density 5×10^{19} m^{-3} & temperature 1 keV.
- Lower T_e based on more recent DIII-D data.
- Only other adjustable parameters:
  - 90% recycling coefficient,
  - Collisionless gyroviscosity coefficient 5×10^{-2} m^2/s.
- Profiles evolved for 20 ion transit times $= 1.56$ ms.
- NOTE: for validation, would add: heat source, kinetic electrons, logical sheath, turbulent diffusion.



Compare Runs with Consistent, Divertor Peaked & Poloidally Uniform Recycling







Divertor Peaked Source: 9% core ionization

Uniform Source: 47% core ionization

Summary

- DEGAS2 based Monte Carlo neutral routine coupled to guiding center, ion-electron-neutral neoclassical PIC code XGC0,
  - $\Rightarrow$ Kinetic-kinetic plasma-neutral transport code.
  - Detailed atomic physics & PMI available via DEGAS2.
  - Neutral recycling source determined from XGC0 ion currents to material surfaces.
- Demonstrate with example DIII-D H-mode particle fueling simulations:
  - Poloidally uniform “puff & pump” source yields much higher core ionization fraction relative to consistent, divertor peaked source.