

3-D Source, Neutron Wall Loading & **Radiative Heating** for ARIES-CS Paul Wilson Brian Kiedrowski Laila El-Guebaly

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- Motivation
- Methodology
- Source Map
- Results
  - Neutron Wall Loading
  - Radiative Heating



- 1-D modeling
  - Uniform source acceptable approximation

- 3-D modeling enabled by new neutronics tool, MCNPX-CGM
  - Source distribution becomes limiting approximation in model analysis



- Generate hex mesh in real space from uniform mesh in flux coordinate space
- Generate cumulative distribution function for source density in hex mesh
- Sample hex mesh and mesh cells for source position



#### Generate Hex Mesh

- Uniform spacing in
  - -1 field period in toroidal direction
  - $-2\pi$  in **poloidal** direction
  - Flux plasma surfaces in *radial* direction
- Use Fourier expansion to convert
  - First to  $(r,z,\phi)$
  - -Then to (x,y,z)
- Note: Degenerate hexes along magnetic axis



 Mesh vertices are indexed to increase most rapidly in the poloidal direction, then the radial direction and finally in the toroidal direction

 Mesh hexes are numbered to correspond to the lowest numbered vertex that forms that hex



- Use extra storage to simplify calculations
  - Extra vertices are stored for  $\theta=2\pi$  even though these points are redundant with  $\theta=0$
  - Extra hexes are indexed at the maximum in each dimension even though there is no space there
    - Since they are defined to have 0 volume these hexes won't interfere with the probabilities



#### Fundamental Source Density

Note: based on Data from J. Lyon (ORNL)



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## Source Strength on Mesh

- Evaluate source density at each mesh vertex, s<sub>vi</sub>
- Define mesh cell source strength as simple mean of associated mesh vertex source densities
- Define mesh cell probability as normalized source strength
- Evaluate CDF for this discrete PDF

$$S_{hi} = \frac{1}{8} \sum_{\nu j} S_{\nu j}$$







#### **ARIES-CS** Parameters

- Major radius, R = 7.75 m
- Fusion power, P = 2355 MW
  - Radiative power,  $P_h = 354 \text{ MW}$
- 5cm SOL everywhere
- 727 m<sup>2</sup> FW area





#### Source Probability Map



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Peak source density is identical, as expected!



13

# Peak source probability lower at 60°

Source volume is smaller because of lower major radius. (ignore artifacts of interpolation at domain boundary)





Peak source probability is lower because of volume.



15



- Know vertex coordinates and CDF of source strength
- Find *hi* such that  $P_{hi-1} < \xi < P_{hi}$  for random variable  $\xi$
- Sample trilinear coordinate system of mesh cell *hi* uniformly
- Map trilinear coordinates to real coordinates for origin



• For comparison, an artificial *unphysical* source was contrived



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#### **Radiation Heating Source**







## **Results and Analysis**

- Calculate NWL on surface grid
  - Some statistical variation
- Transform (x,y,z)coordinates of each patch to  $(\theta_P, \phi_T)$
- Interpolate results on 200 x 200 uniform grid in  $(\theta_P, \phi_T)$



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#### NWL Summary

	Peak (Min)	Toroidal Angle	Poloidal Angle
	[MW/m <sup>2</sup> ]	(degrees)	(degrees)
Real 3-D	5.26	-11	-18
Source	(0.32)	(-4)	(-116)
Broadened Source	4.38	-33	-11
Uniform Source	3.56	-49	-21
Rad. Heating	0.68	-34	-17
	(0.2)	(11)	(-117)







### Neutron Wall Loading Profiles



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#### **Radiation Heating Profiles**



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## Note: all figures use consistent scale for NWL (on left) and for Rad. Heating (on right)





- 3-D Source methodology provides generic mechanism for neutronics source term
- Areas of improvement/research
  - Mesh spacing in minor radius dimension
  - Calculation of hex-averaged source density
  - Sampling of hex



#### 3-D modeling of plasma source is important for accurate determination of NWL

#### Paul Wilson 608-263-0807 wilsonp@engr.wisc.edu

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