Research Overview for Neutronics Group

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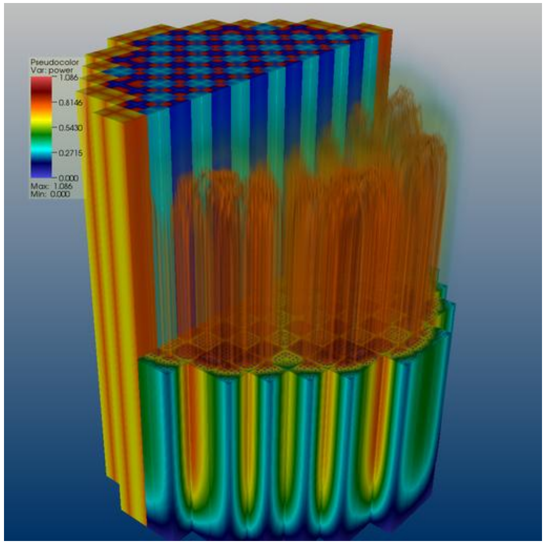
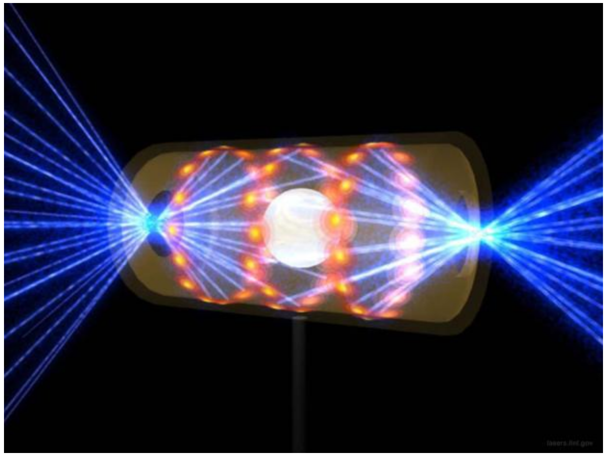
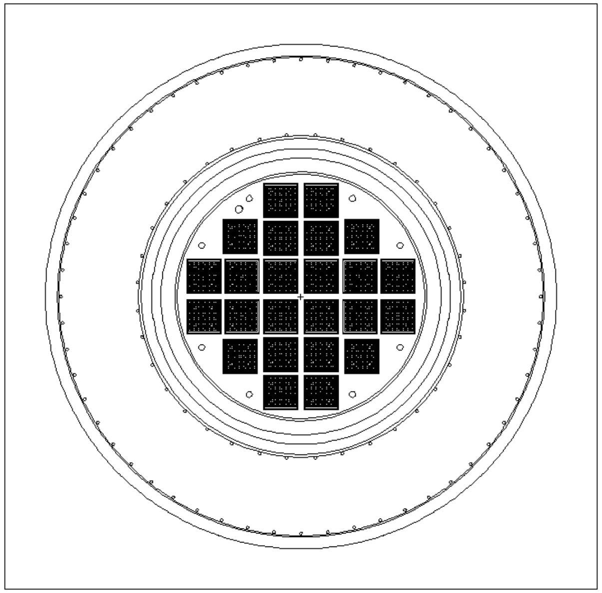
What exactly do you do?

$$
\begin{aligned}
&[\hat{\Omega} \cdot \nabla + \Sigma(\vec{r}, E)]\psi(\vec{r}, \hat{\Omega}, E) = \\
&\quad \int dE' \int d\hat{\Omega}' \, \Sigma_s(\vec{r}, E' \to E, \hat{\Omega}' \cdot \hat{\Omega}) \psi(\vec{r}, \hat{\Omega}', E') \\
&\quad + \frac{\chi(E)}{k} \int dE' \, \nu\Sigma_f(\vec{r}, E') \int d\hat{\Omega}' \, \psi(\vec{r}, \hat{\Omega}', E')
\end{aligned}
$$







How do you do it?

- Deterministic methods require discretization of phase space
  - discretize more finely to improve solution quality
  - use advanced solvers to converge solution more quickly
- Monte Carlo (MC) treats phase space continuously
  - accuracy depends on number of particles simulated
  - often requires variance reduction (VR)
- Hybrid methods: create MC VR parameters using deterministic solutions

Algorithms + Architecture


Current Projects: WARP

- "Weaving All the Random Particles" (Bergmann)
- GPU-Based Monte Carlo
- Kelly has implemented and is completing testing of Woodcock Delta-tracking
- Next up: adaptation for MICs (Multi Integrated Cores, e.g. Intel XeonPhi)

Current Projects: Angle-Informed Hybrid Methods

Use adjoint relationship to create VR parameters for MC

$$\int\int q^{+}(r,E)\phi(r,E)drdE = \int\int q(r,E)\phi^{+}(r,E)drdE$$

$$\boxed{q^{+}(r,E) = f(r,E)}$$

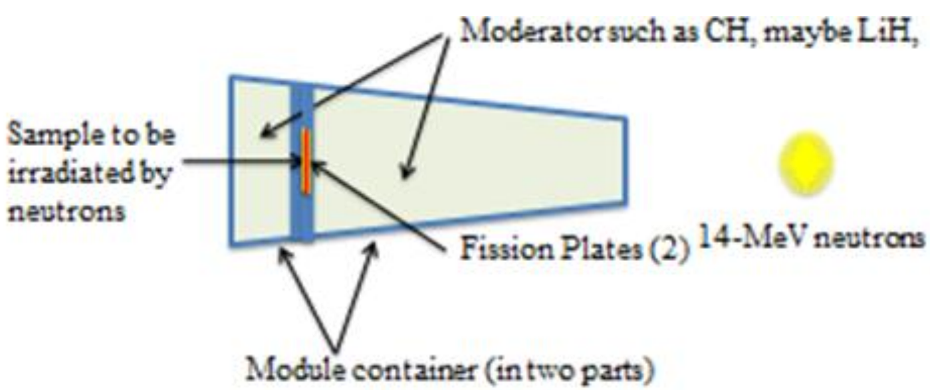
$$R = \int_{E}\int_{V_f} f(r,E)\phi(r,E)drdE \longrightarrow R = \int_{E}\int_{V_S} q(r,E)\phi^{+}(r,E)drdE$$

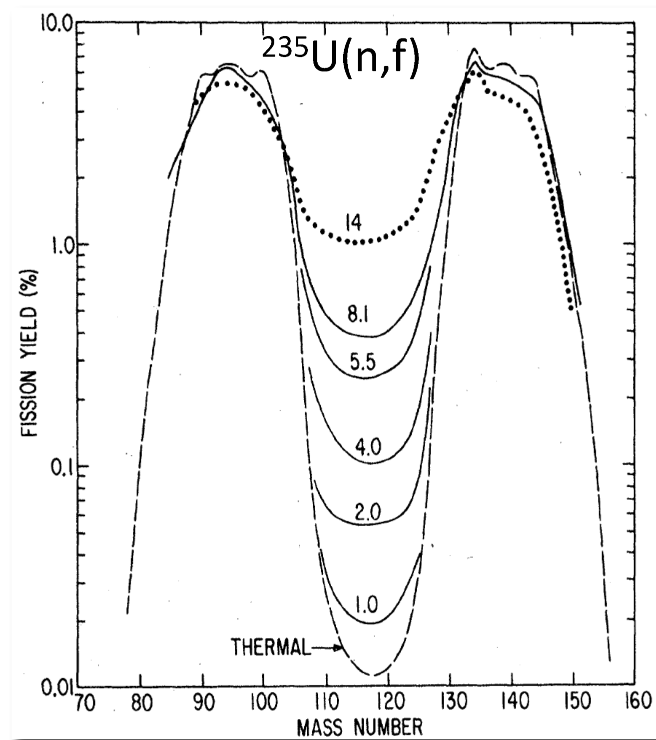
Create an importance map augmented by angular information

$$\phi^{\dagger}(\mathbf{r},E) = \frac{\int \psi(\hat{\Omega},\mathbf{r},E)\psi^{\dagger}(\hat{\Omega},\mathbf{r},E)d\hat{\Omega}}{\int \psi(\hat{\Omega},\mathbf{r},E)d\hat{\Omega}}$$

Current Projects: Energy Tuning Assembly

- Develop a tailored spectrum irradiator for forensics applications at NIF
- Constraints
  - Thermonuclear weapon-like spectra
  - Geometry: ~7.5% solid angle
  - ~10^{12} fissions
  - Minimize fertile/fissile material





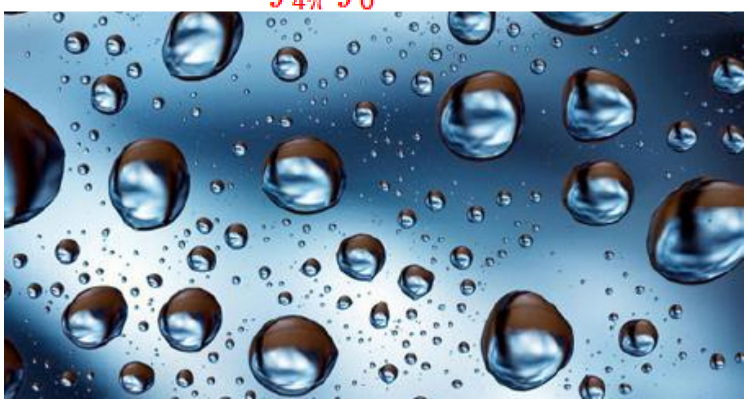
[8] Gene Henry and Bill Dunlop

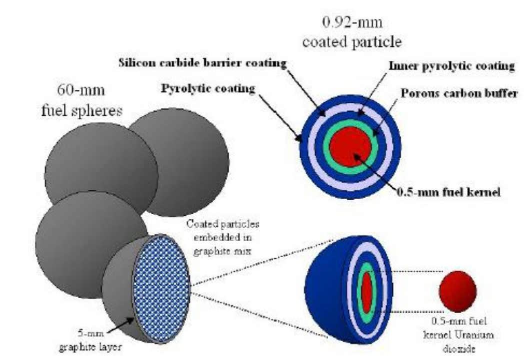
[9] J.E. Gindler et al.

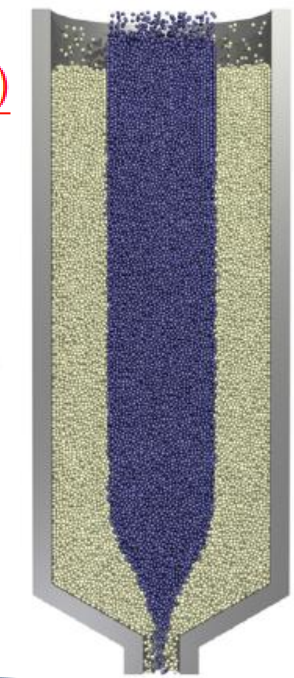
Upcoming Projects: non-classical transport

- Classical Transport inherently assumes that the distances between collisions are exponentially distributed: $p(s)=\Sigma_t e^{\Sigma t}$
- Non-Classical Transport drops this assumption, generalizing the linear Boltzmann equation

$$\frac{\partial\psi}{\partial s}(\mathbf{x},\boldsymbol{\Omega},s)+\boldsymbol{\Omega}\cdot\nabla\psi(\mathbf{x},\boldsymbol{\Omega},s)+\Sigma_t(\boldsymbol{\Omega},s)\psi(\mathbf{x},\boldsymbol{\Omega},s)$$
$$=c\delta(s)\int_{4\pi}\int_0^\infty P(\boldsymbol{\Omega}'\cdot\boldsymbol{\Omega})\Sigma_t(\boldsymbol{\Omega}',s')\psi(\mathbf{x},\boldsymbol{\Omega}',s')\,ds'\,d\Omega'+\delta(s)\frac{Q(\mathbf{x})}{4\pi}$$







Full PWR-900 Details

2 x 2 spatial cells/pin

17 x 17 pins/assembly

289 assemblies (132 reflector,
159 fuel of varying enrichment)

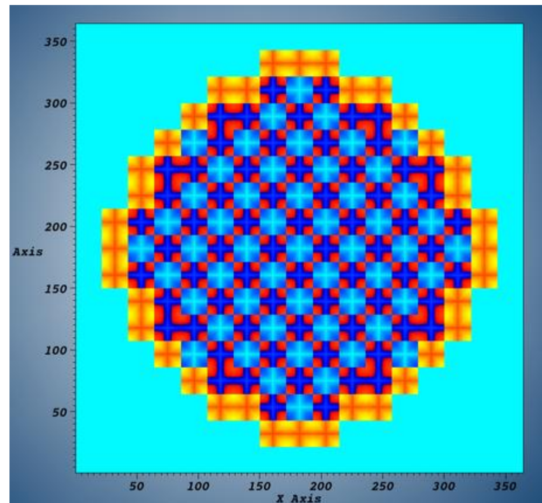
P_0: 1 moment

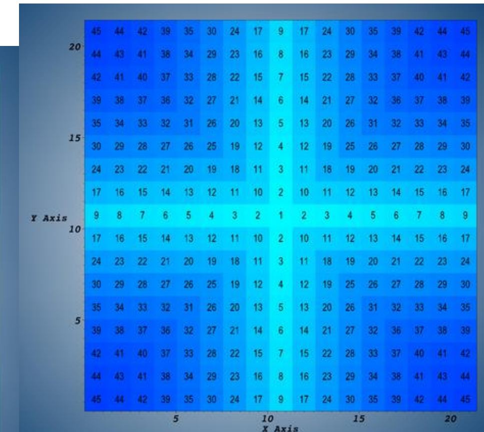
S_{12}: 168 angle sets (MGE: S_2)

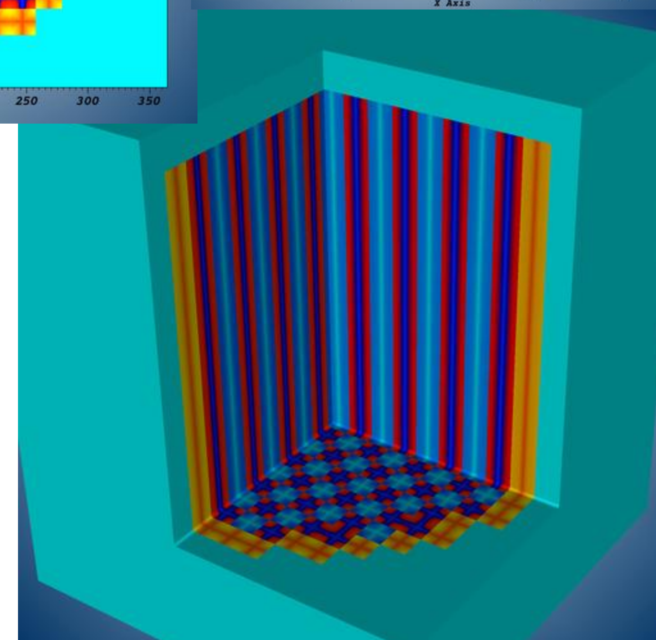
233,858,800 cells; 1 unknown/cell

44 groups: *1.73 trillion unknowns*

12,544 blocks; 137,984 cores (11 sets)







RQI Can Beat PI

- RQI needed **less time** and **fewer iterations**

Solver	Precond	Krylov	Eigen	Time (m)
PI	none	5.602	149	612.2
PI	w1r2v2	946	86	720*
PI	w1r3v3	111	11	480*,+
RQI	w1r2v2	70	5	54.8
RQI	w1r3v3	76	6	330.4+

*Exceeded wall time limit

+S_{12} in MGE; different tolerances and decomposition

RQI+MGE Strong Scaling