Cross Section Generation Strategy for High Conversion Light Water Reactors

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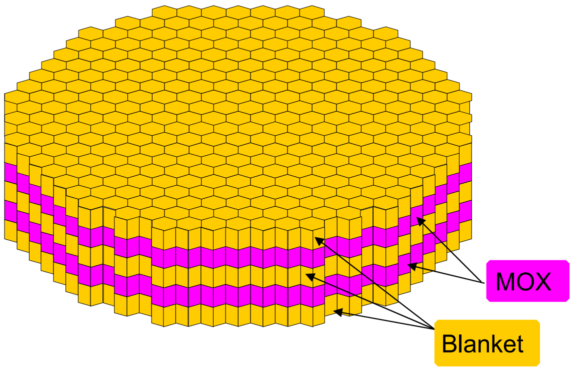
Outline

- High Conversion Water Reactors
- Cross Section Homogenization Process
- Branch Cases
- Application of Discontinuity Factors
- Conclusions/Future Work
- Serpent Wish List

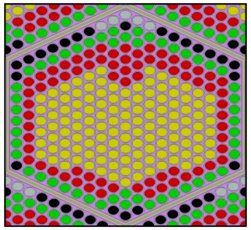
High Conversion Water Reactors

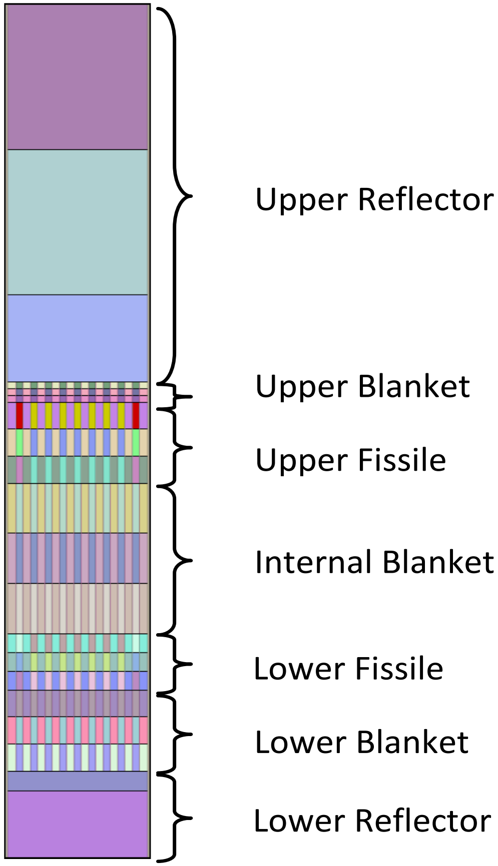
- Parfait core
- Axial blankets are used to achieve BR~1.01
- Blankets: Depleted or Natural Uranium
- Fissile zones: TRU (Pu+MA) MOX
- Examples:
  - Hitachi – Resource Renewable Boiling Water Reactor (RBWR)
  - JAEA – Reduced Moderation Boiling Water Reactor (RMWR)



Hitachi RBWR

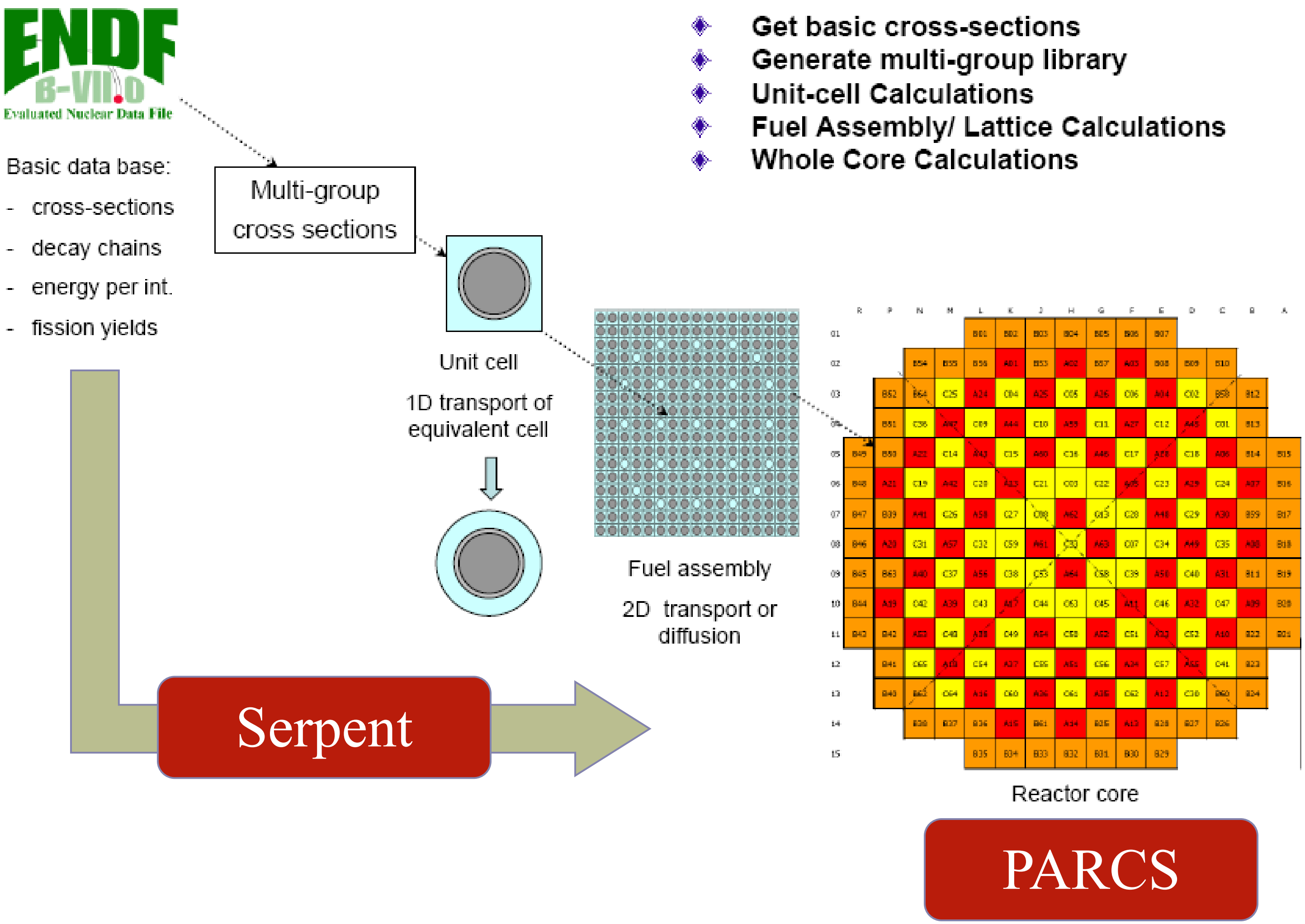
- Assemblies are axially heterogeneous
- Core average void fraction ~60%
  - vs. typical BWR ~40%
- Fissile zones produce neutrons while blanket zones absorb them
- Significant axial streaming of neutrons





Cross Section Homogenization

- Get basic cross-sections
- Generate multi-group library
- Unit-cell Calculations
- Fuel Assembly/ Lattice Calculations
- Whole Core Calculations



Obtaining Homogenized XS

- PARCS solves multi-group diffusion eq.:

$$\underbrace{-\nabla\cdot D_g\nabla\phi_g}_{\text{leakage}} + \underbrace{\bar{\bar{\Sigma}}_{ag}^{*}\,\phi_g + \upsilon\bar{\Sigma}_{sg}\phi_g}_{\text{interactions}} = \underbrace{\sum_h \upsilon\bar{\bar{\Sigma}}_s^{h\to g}\,\phi_h}_{\substack{\text{scattering production}\\ \text{w/ (n,xn) production}}} + \underbrace{\frac{\chi_g}{k_{eff}}\sum_h \nu\bar{\Sigma}_{f,h}\phi_h}_{\substack{\text{fission}\\ \text{production}}}$$

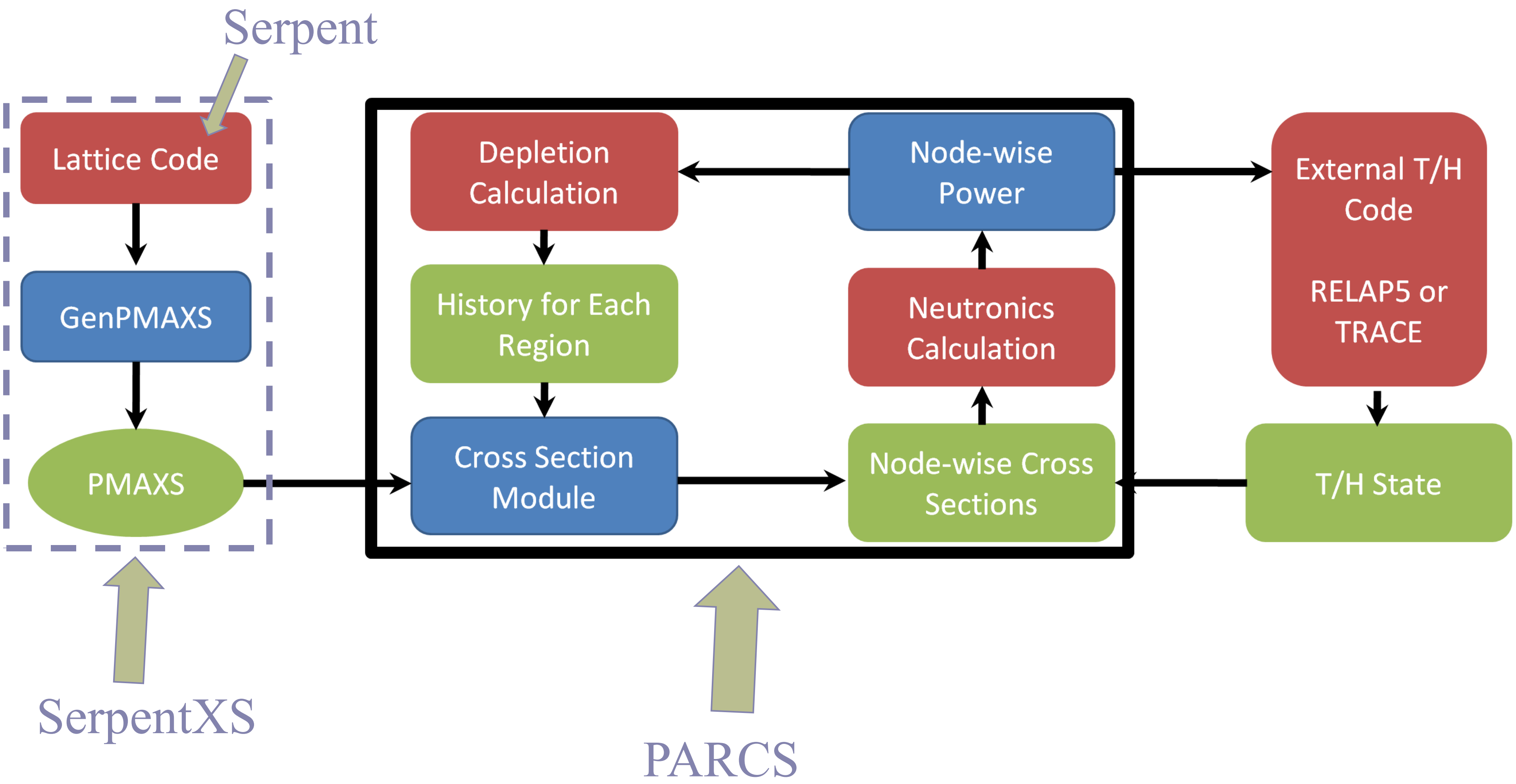
- macroscopic cross sections are flux weighted:

$$\bar{\Sigma}_{\alpha g} = \frac{\int_{E_g}^{E_{g-1}} dE\int_V d^3r\,\Sigma_\alpha(\vec{r},E)\phi(\vec{r},E)}{\int_{E_g}^{E_{g-1}} dE\int_V d^3r\,\phi(\vec{r},E)}$$

Monte Carlo Estimation of D

- Diffusion coefficient must be current-weighted
  - Usually it is just flux-weighted and a B_1 calculation is performed to adjust it
- For RBWR we would like to have directional diffusion coefficients
- Instead we use discontinuity factors to preserve neutron balance

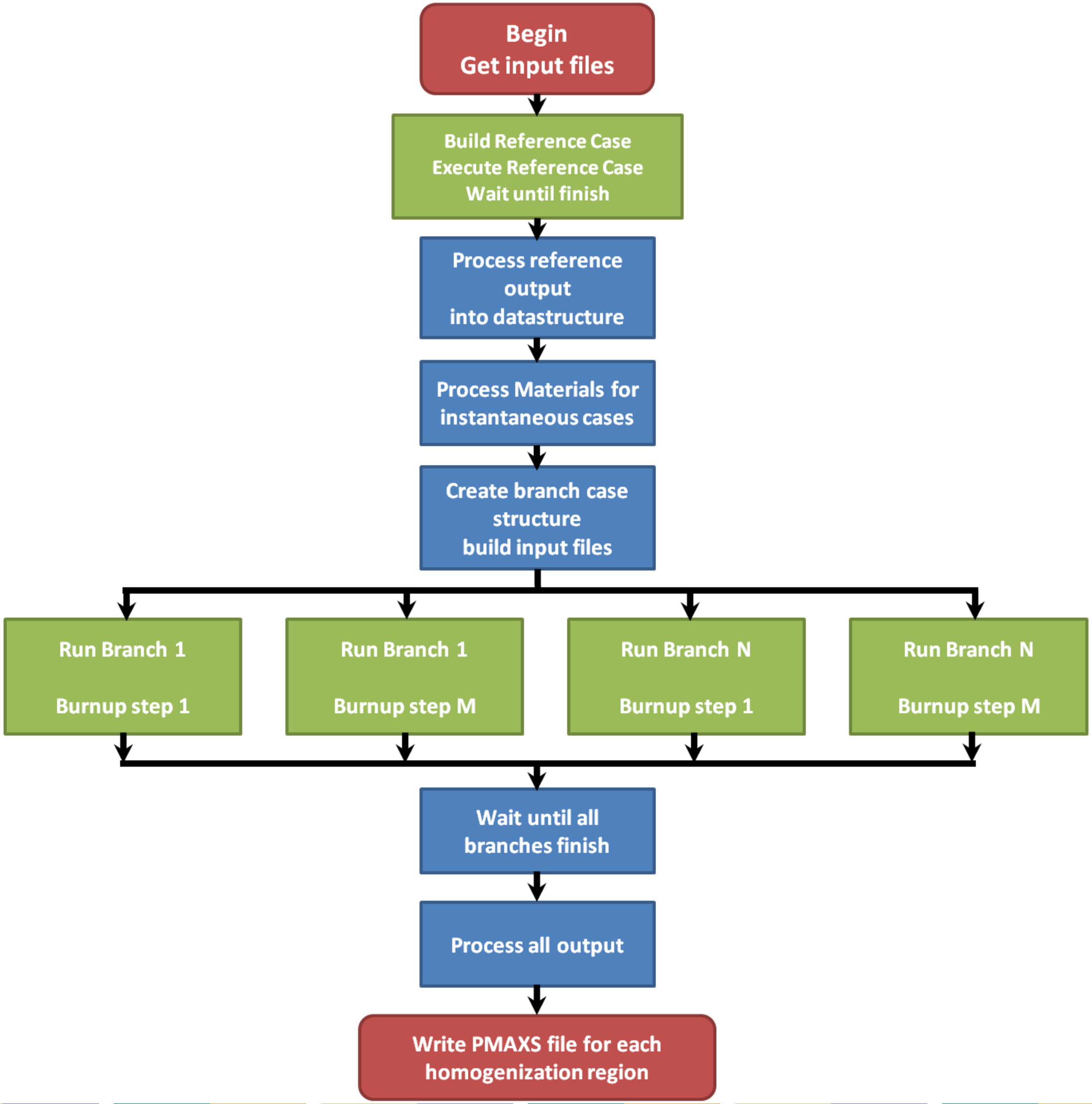
PARCS Overall Methodology



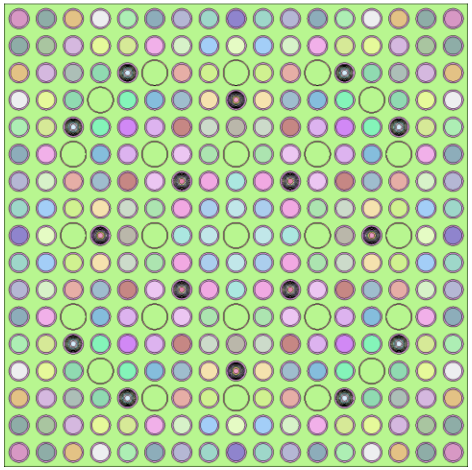
Branch Cases

- Must account for a range of operating conditions
  - unknown beforehand
- Cross sections are therefore parameterized over instantaneous values and time-averaged (history) operating conditions
- Instantaneous conditions – control rod, poison conc., coolant density, fuel temp, coolant temp
- Histories – burnup, control rod, density …

SerpentXS Code

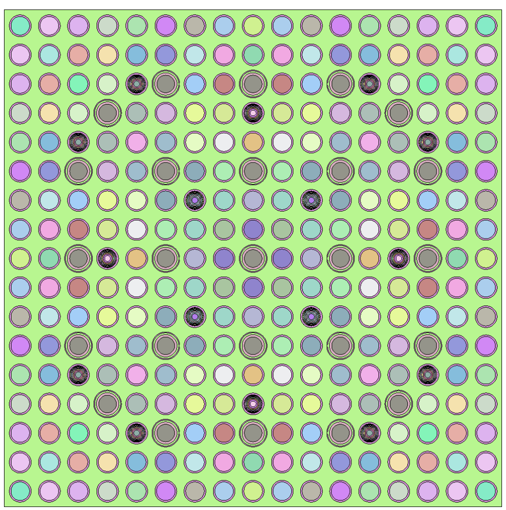


PWR Test Problem



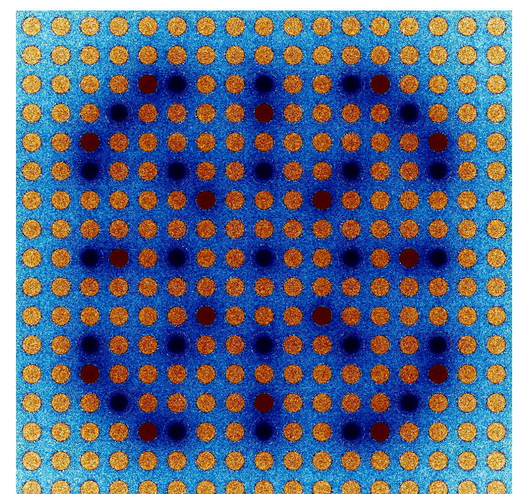
Reference Geometry

Branch	Indx	CR	DC [g/cc]	PC [pcm]	TF [K]	TC [K]
Refer.	1	0	0.707	1000	900	582
CR	1	1	0.707	1000	900	582
DC low	1	0	0.594	1000	900	582
DC high	2	0	0.740	1000	900	582
TF low	1	0	0.707	1000	582	582
TF high	2	0	0.707	1000	1500	582

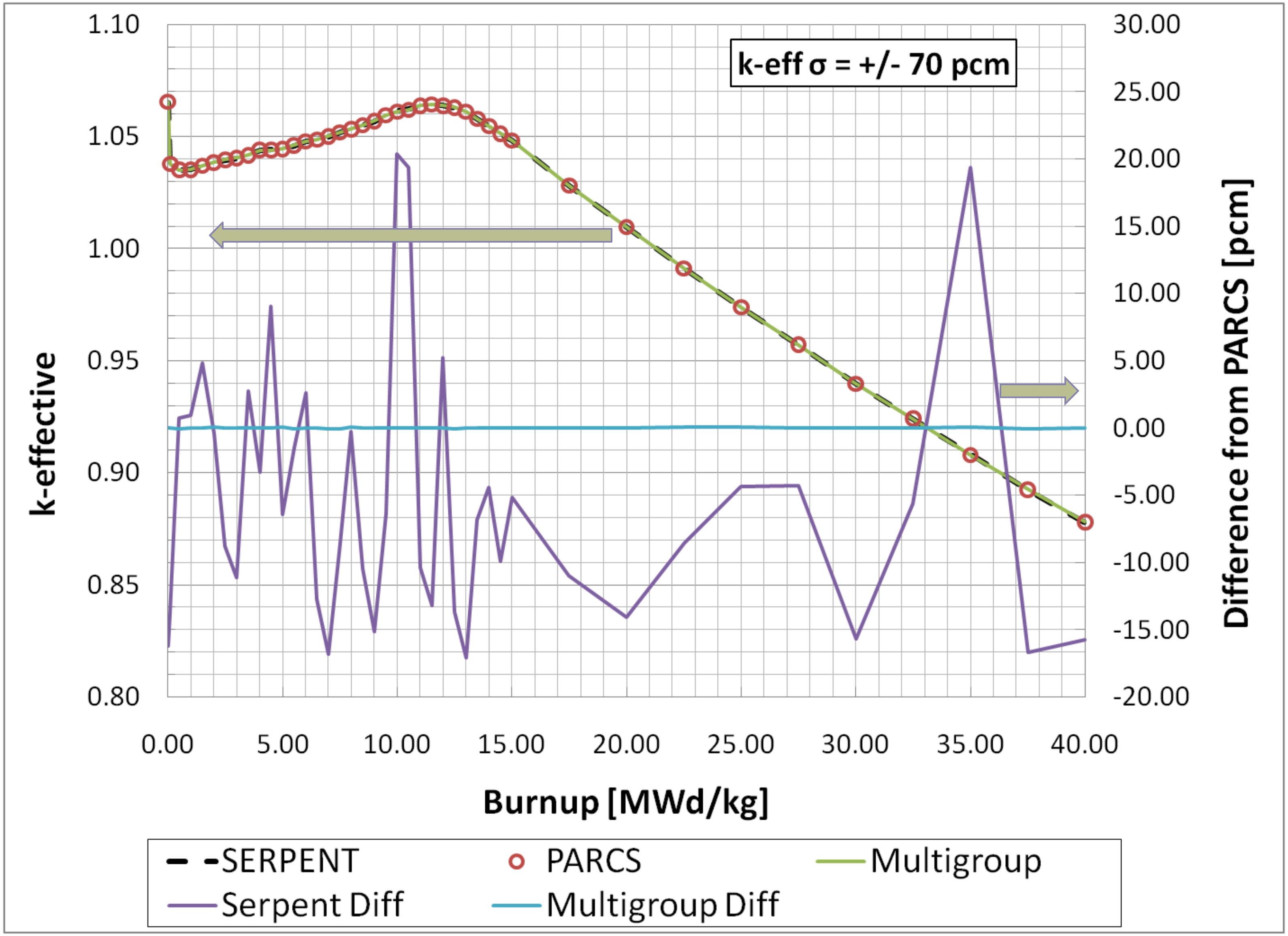


Rodded Geometry

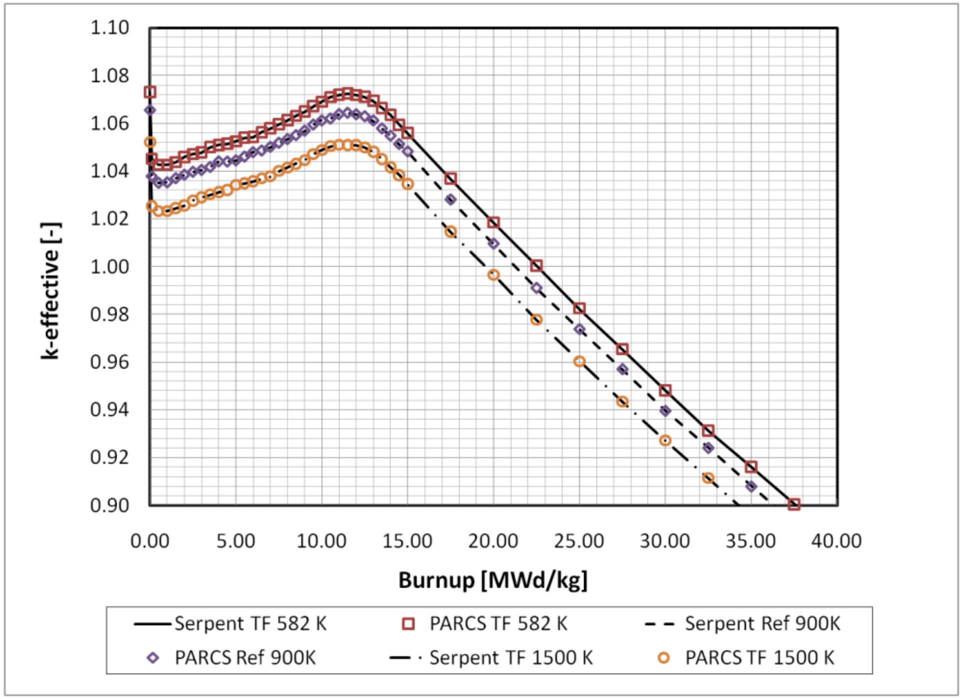
Power Distribution

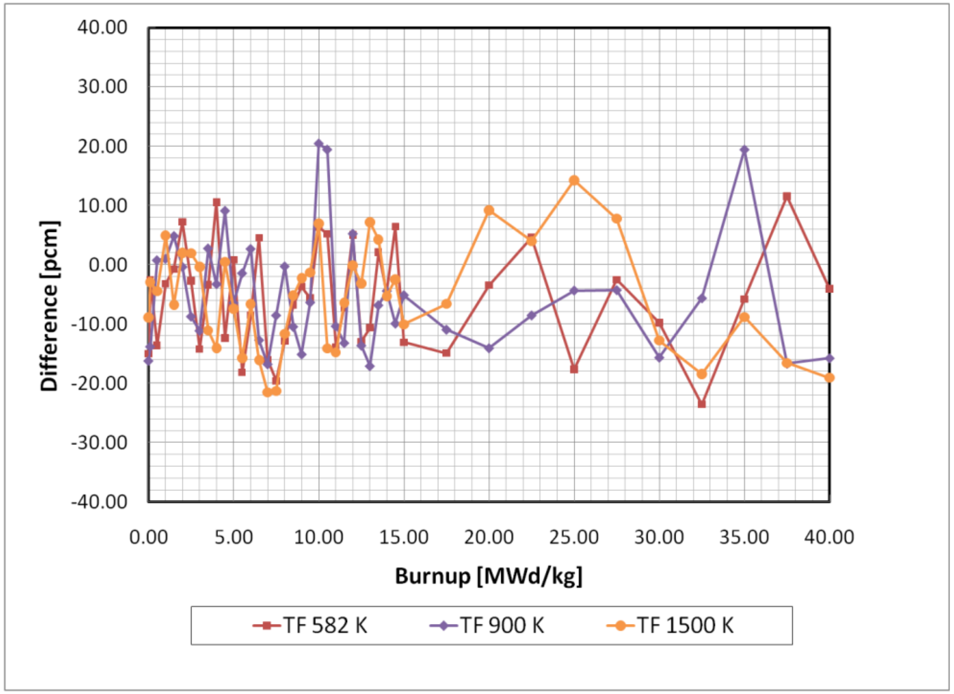


Reference Case



Fuel Temperature Branch



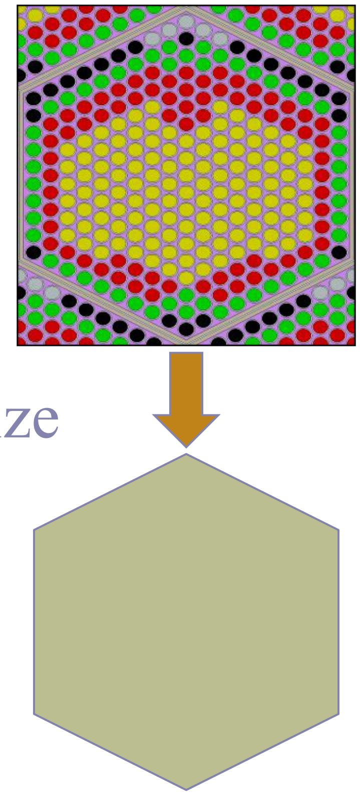


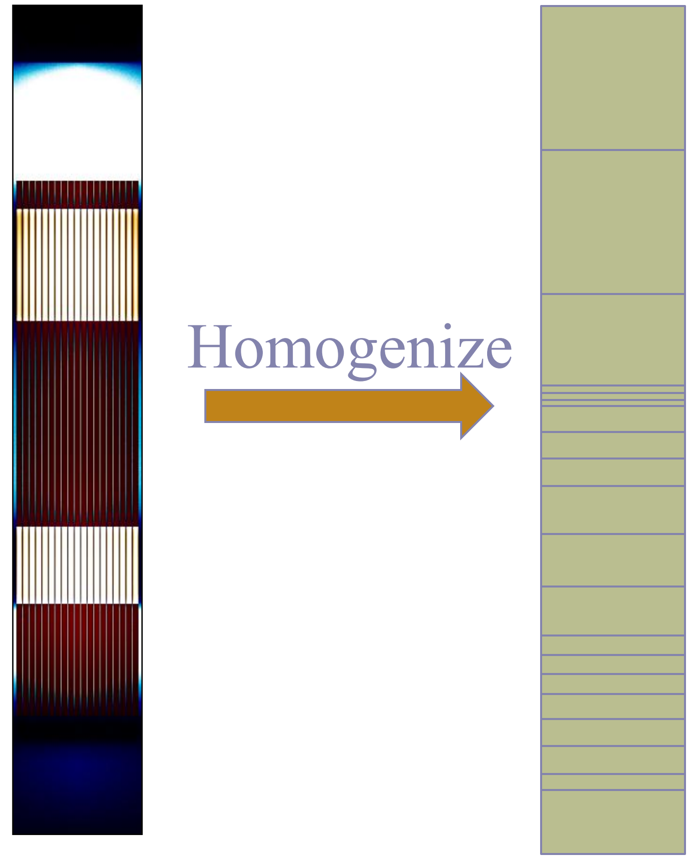
2-D vs. 3-D Generated XS

- Strong axial material discontinuities
- Obtain XSs generated in conventional 2-D geometry (denoted as 2-D XSs)
  - Surrounded by zero-net current boundaries
- Compare to XSs generated for axial zones surrounded by neighbors (denoted as 3-D XSs)
- Serpent makes this relatively **simple**

2-D vs. 3-D XS

Homogenize



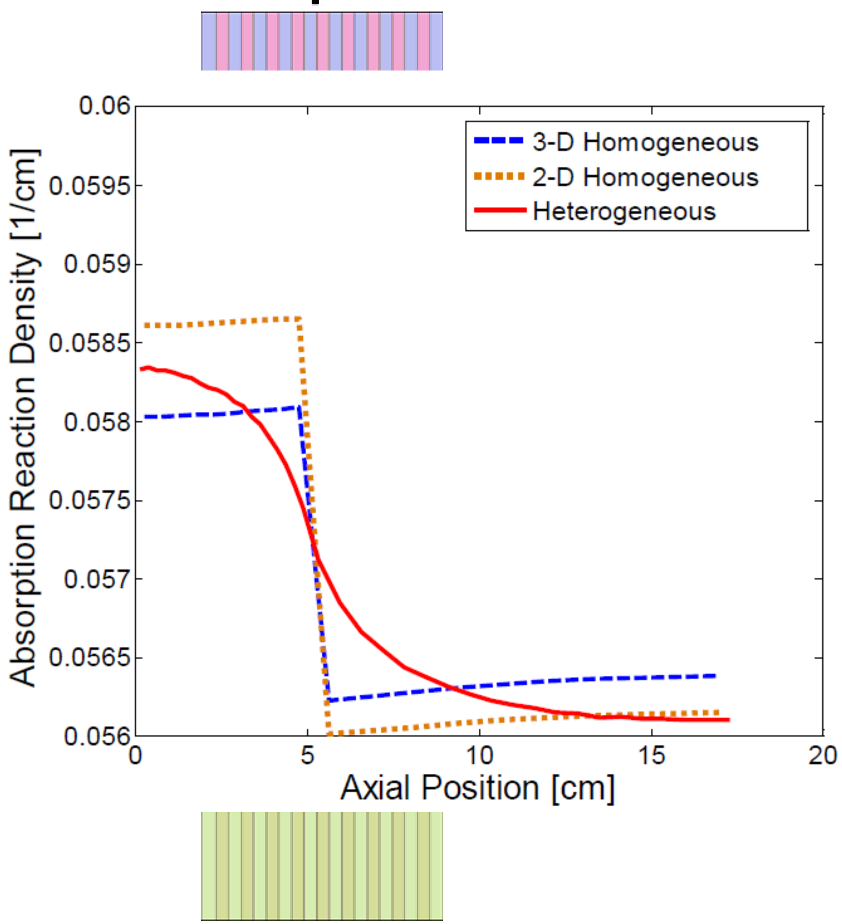


2-D

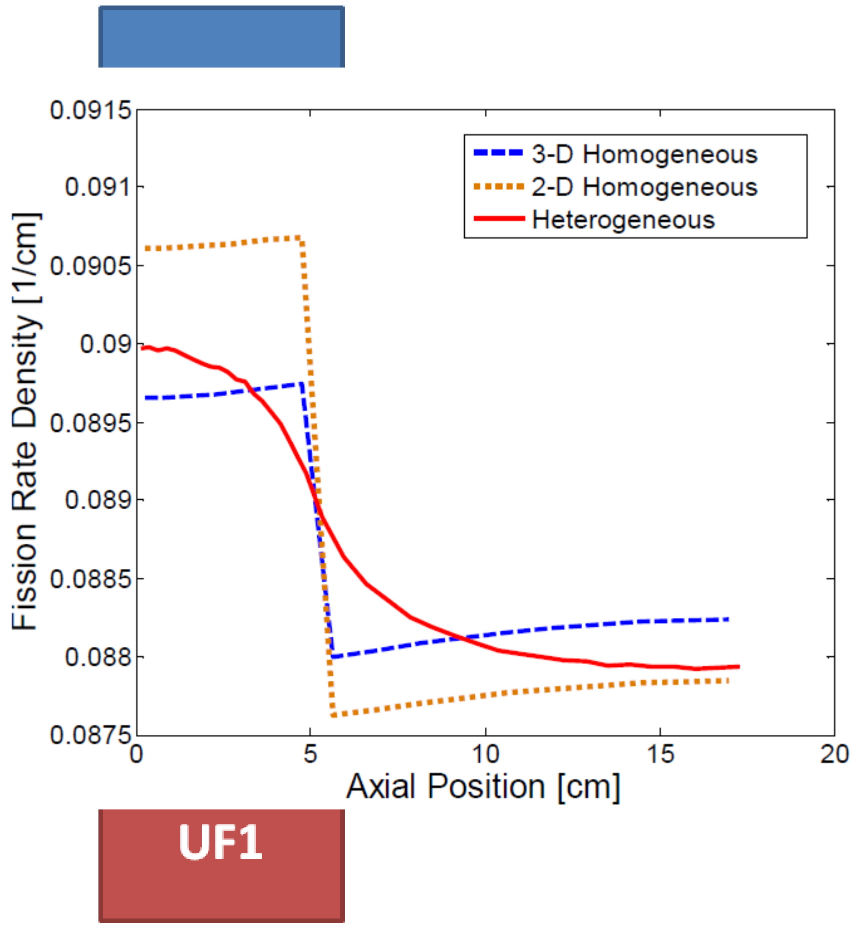
3-D

Fissile-Fissile Two-Zone Results

Serpent

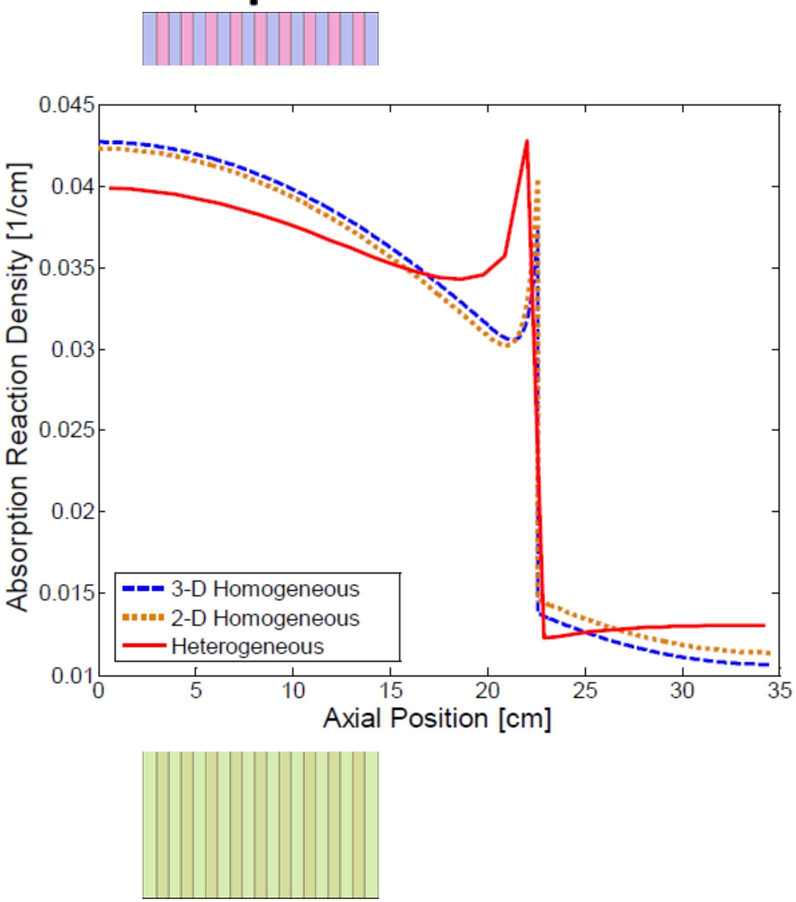


PARCS

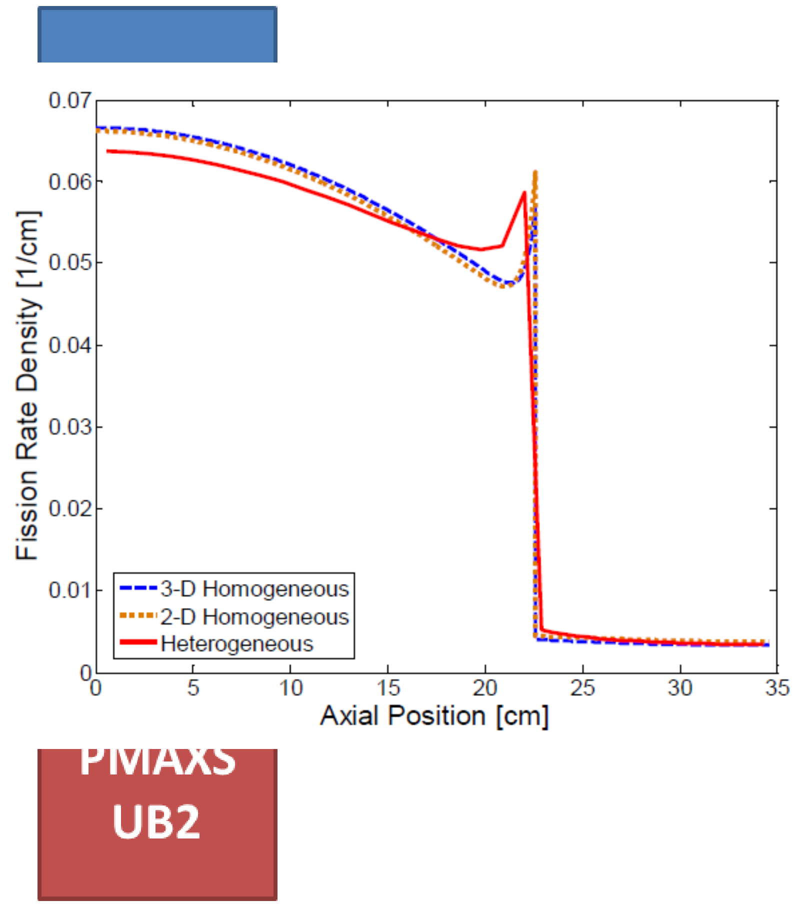


Fissile-Blanket Two-Zone Results

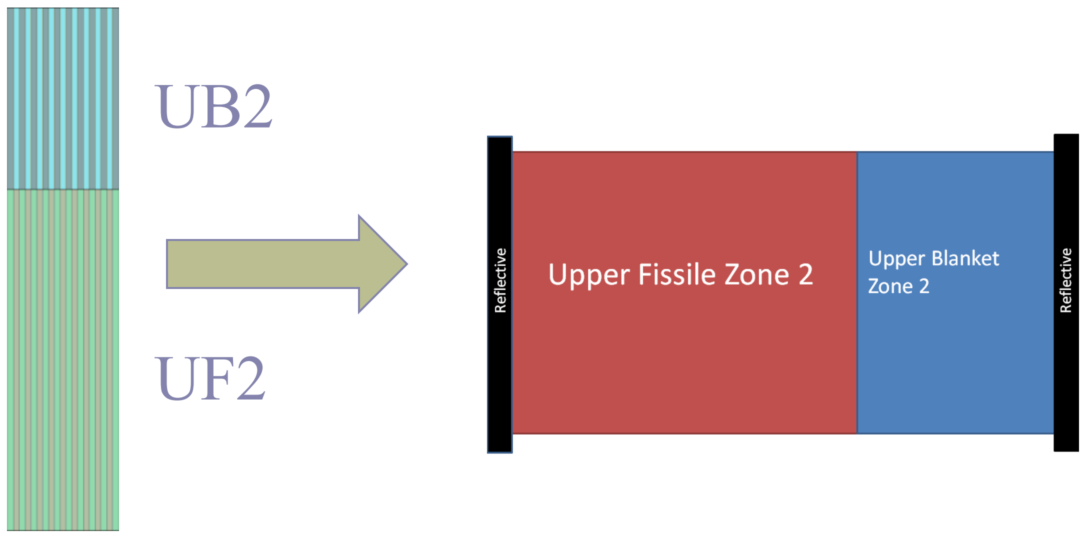
Serpent



PARCS



Axial Discontinuity Factors

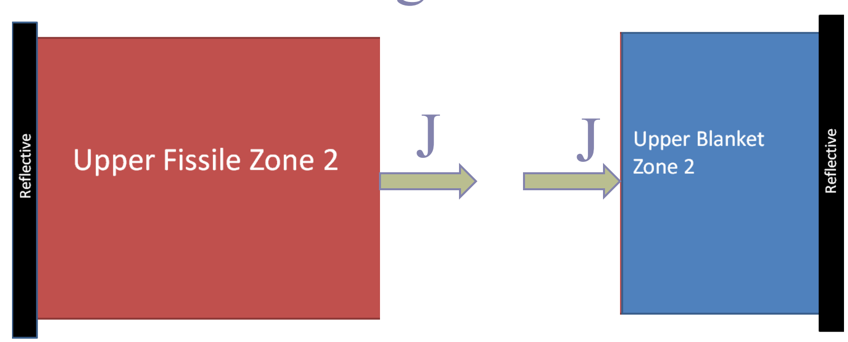


K-eff: 1.36620

Two-Zone Problem

Get Homogeneous Flux

PARCS (No ADFs):
K-eff: 1.38312



Discontinuity factors: Background

- Real flux has to be continuous
- Homogeneous flux does not
- ADF: Ratio of heterogeneous-to-homogeneous surface flux

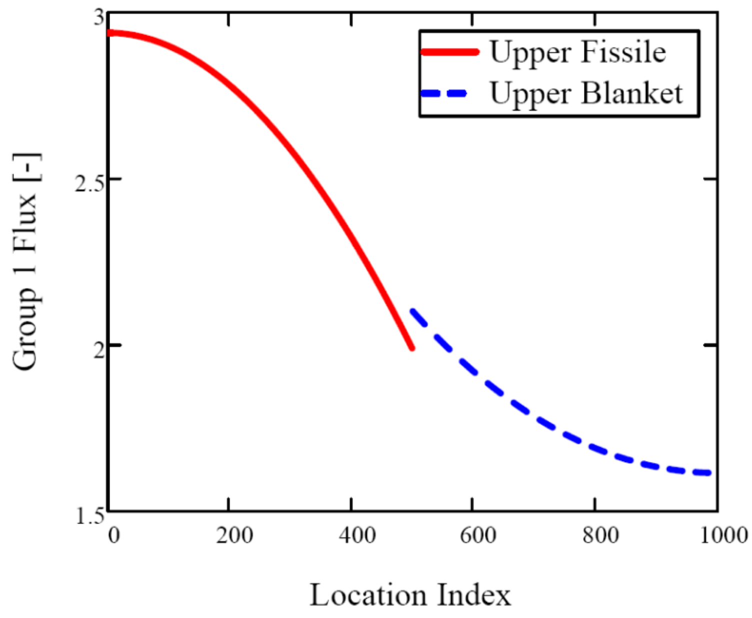
$$f_g^{\pm} \equiv \frac{\phi_{g,het}^{\pm}}{\phi_{g,hom}^{\pm}}$$

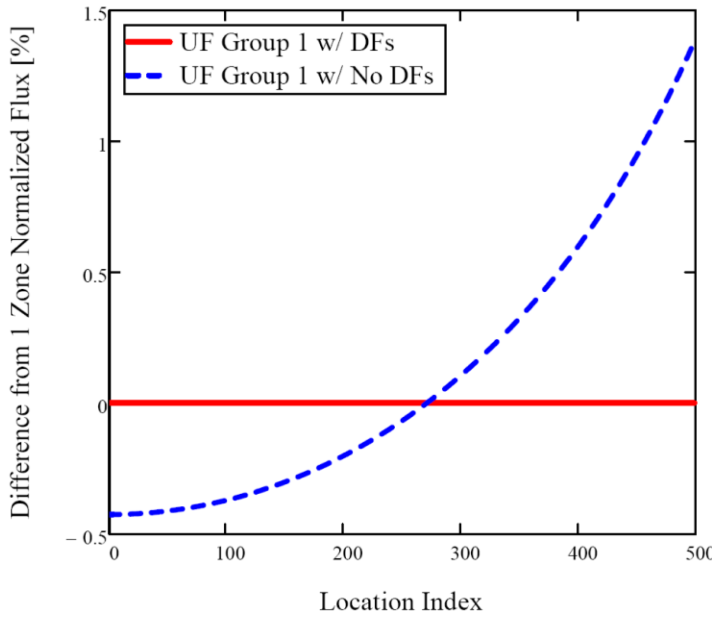
- Conventional process: 2D reflected assembly
  - Homogeneous surface flux = nodal flux
  - Surface current is zero
  - NOT the case in RBWR

Procedure for toy problems

- Obtain the heterogeneous solution with Serpent
  - Global reflective boundaries,
- Extract homogenized parameters from Serpent
- Compute interface currents using neutron balance
- Perform fixed source 1D diffusion calculation for each coarse region
- Compute discontinuity factors using surface fluxes:
  - Heterogeneous (Serpent)
  - Homogeneous (Fine mesh 1D diffusion)
- Run the entire homogeneous geometry (1D diffusion + ADFs)
  - To verify that homogeneous and heterogeneous setups are equivalent

Axial Discontinuity Factors





Discontinuity Factors

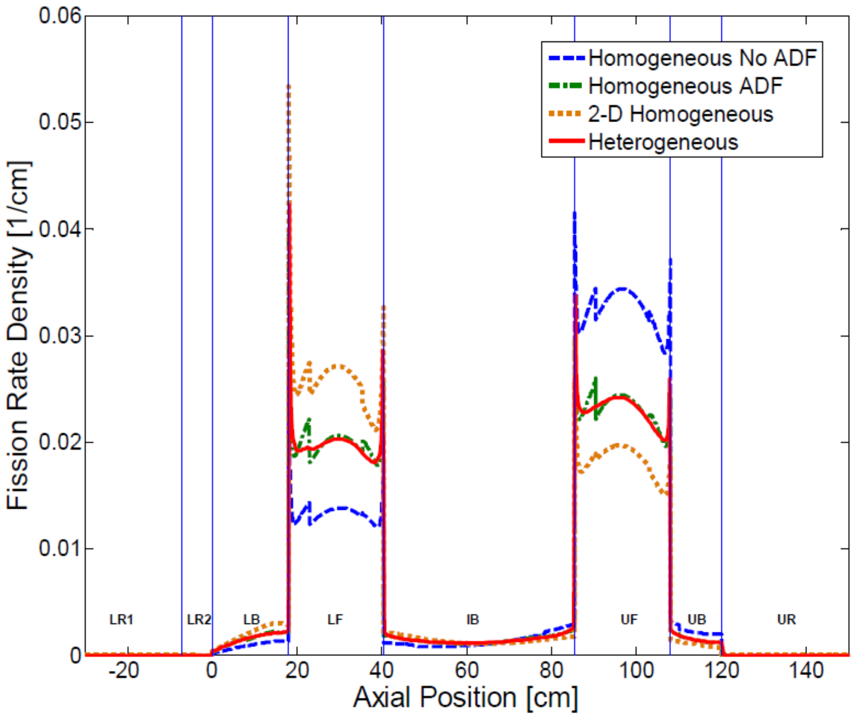
$f_1^{UF} = 1.028$	$f_1^{UB} = 0.966$
$f_2^{UF} = 0.972$	$f_2^{UB} = 1.034$

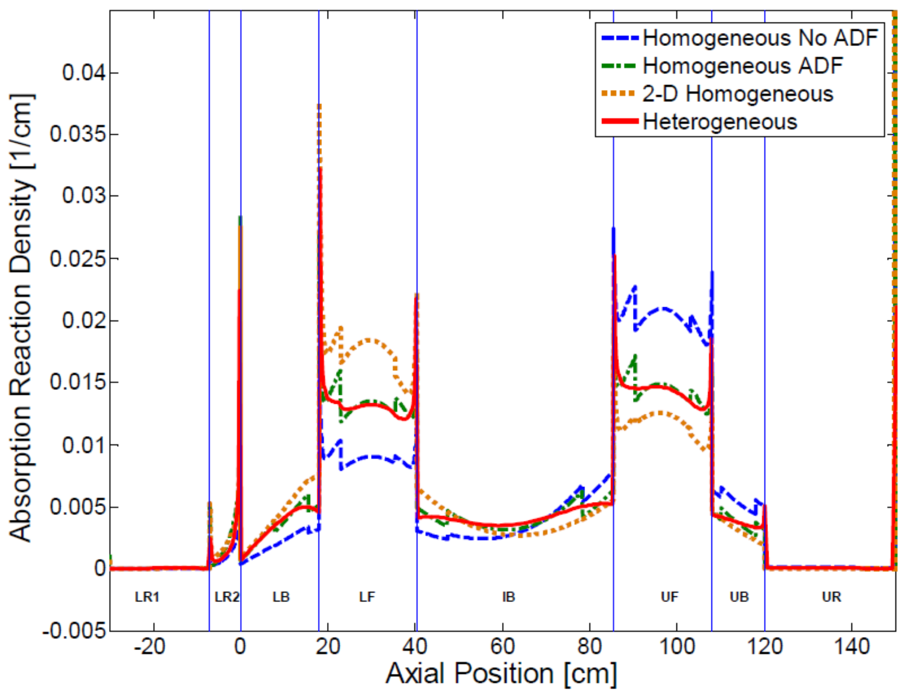
PARCS (ADFs):
K-eff: 1.36620

The need for surface current tallies…

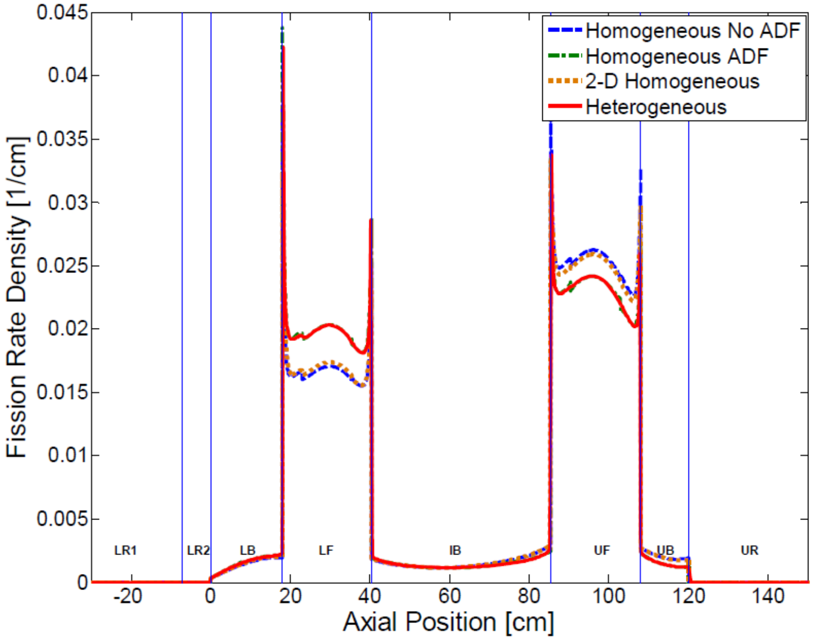
- To generate the exact discontinuity factors (e.g. in reflector) surface currents are needed
- Homogeneous flux is determined from fixed source diffusion equation with current boundary conditions
- Currently we use global reflective boundary conditions to back out surface currents using neutron balance

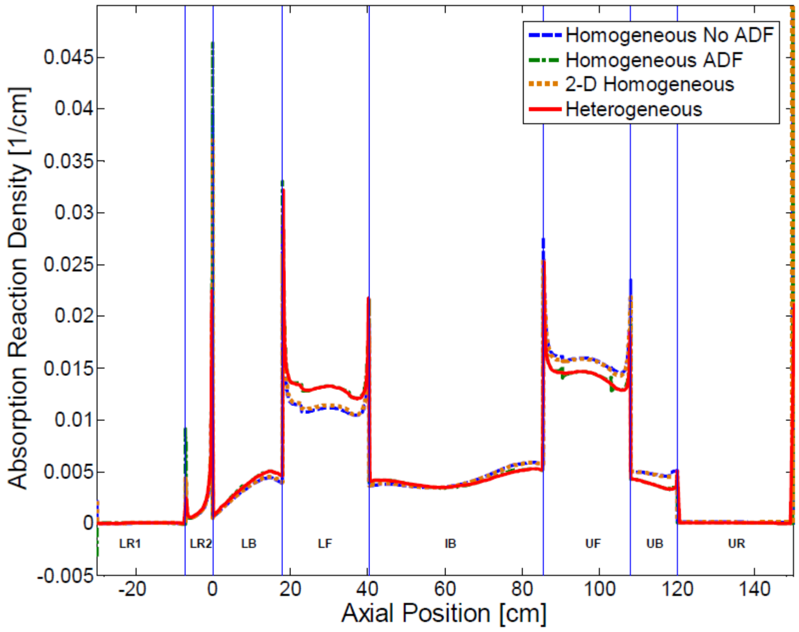
2-G Single Assembly Calculations





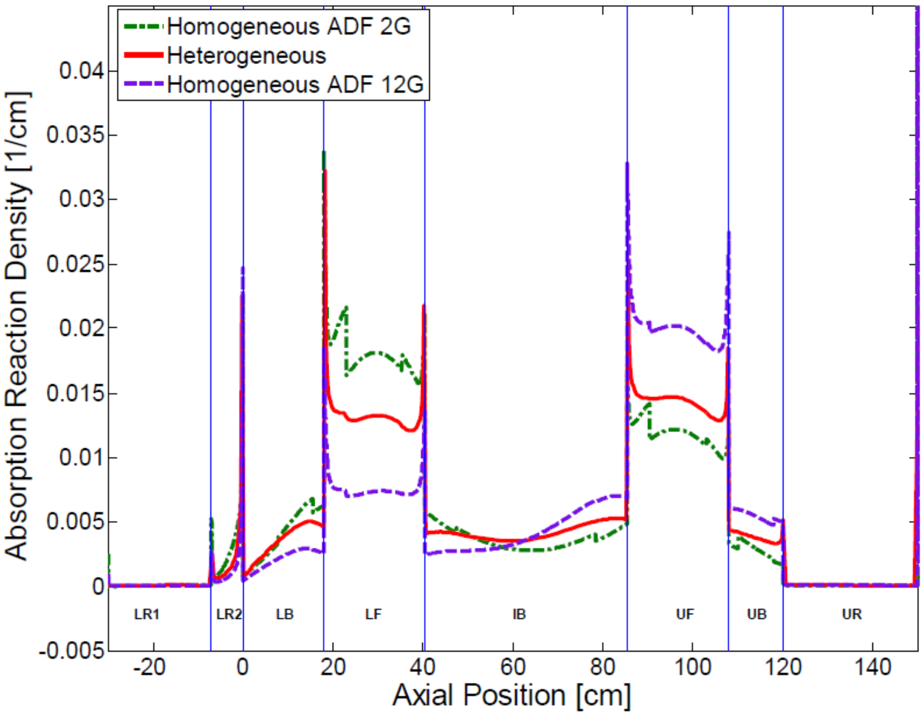
12-G Single Assembly Calculations





Approximation of ADFs

- Can we get away with just homogenizing over two-zone problems



Conclusions

- Observed large differences between Serpent and PARCS calculations using conventional approach
- Need to treat axial discontinuity for RBWR core
  - Current methods are not appropriate
- Developed methodology to generate cross section database for PARCS
- Showed applicability of axial discontinuity factors

Future Work

- Finish developing methodology for axial discontinuity factors
- Study sensitivity of discontinuity factors for different operating conditions
- Approximate discontinuity factors with:
  - Single Assembly → Full Core

Serpent "Wish List"

- Surface current tallies (a must)
- A parallel calculation method that reproduces answers w/ arbitrary number of CPUs
- Built-in method to restart calculations and perturb conditions (like in CASMO)
- Output fission product yields (I, Xe, Pm)
- Pin power and flux distribution per energy group

Acknowledgments

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- Dr. Jaakko Leppanen (VTT Finland) for Serpent

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Questions