Subcritical Secondary Source Modeling for Watts Bar 1 Cycle 8

Andrew Godfrey, ORNL

Gary Wolfram, PNNL

Ben Collins, ORNL

Eva Davidson, ORNL

Cole Gentry, ORNL

Germina Ilas, ORNL

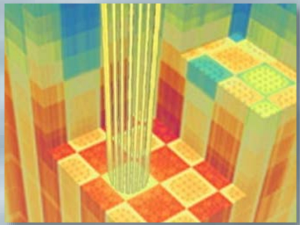
Kang Seog Kim, ORNL

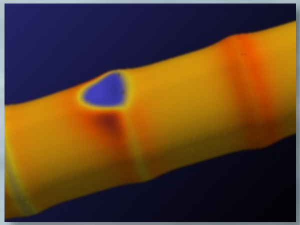
Scott Palmtag, Core Physics, Inc.

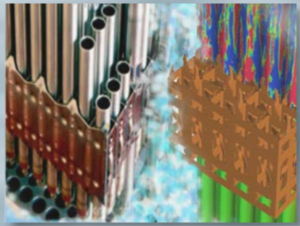
Tara Pandya, ORNL

2018 SCALE Users' Group Workshop

August 29, 2018







Motivation

- Multiple industry stakeholders have approached CASL about capability for modeling sub-critical, source driven problems
  - ICRR predictions (boron dilution accident)
  - Secondary source design and optimum placement
  - Excore detector response during core loading sequences
- VERA has potential to provide unique capability, which could impact plant operations, reduce outage times, or reduce costs associated with components
  - Better than Monte Carlo methods due to high-fidelity 3D characterization of fuel rods and components, and ability to track fuel assemblies over multiple fuel cycles
  - Better than nodal methods due to 3D neutron transport and direct modelling of the excore detectors

Secondary Source Rods

- Antimony-Beryllium (SbBe) rods provide a fast neutron source during startups to ensure adequate signal in excore detectors during fuel loading and approach to criticality

- Sb-123 is activated by neutron absorption and becomes Sb-124, which decays by gamma emission with a half-life of 60.2 days.

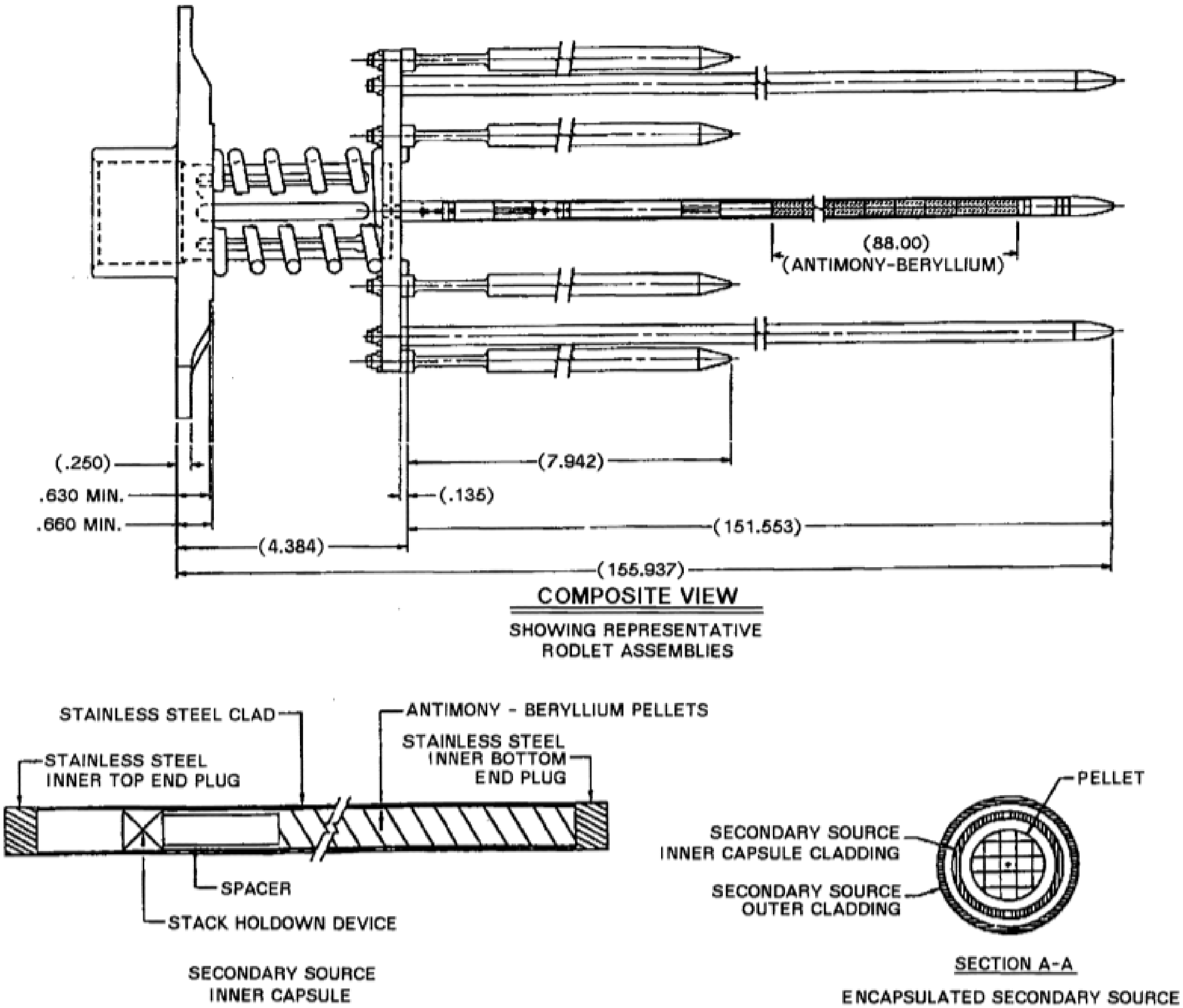
$$^{123}_{51}Sb + ^{1}_{0}n \rightarrow ^{124}_{51}Sb + \gamma$$

- Be-9 produces a photoneutron reaction from the Sb-124 gammas, releasing ‘monoenergetic’ neutrons

$$^{9}_{4}Be + \gamma \rightarrow ^{8}_{4}Be + ^{1}_{0}n$$

- Typical source rods are about 2/3rd of the active fuel height, offset toward the bottom, with 6 rods per assembly

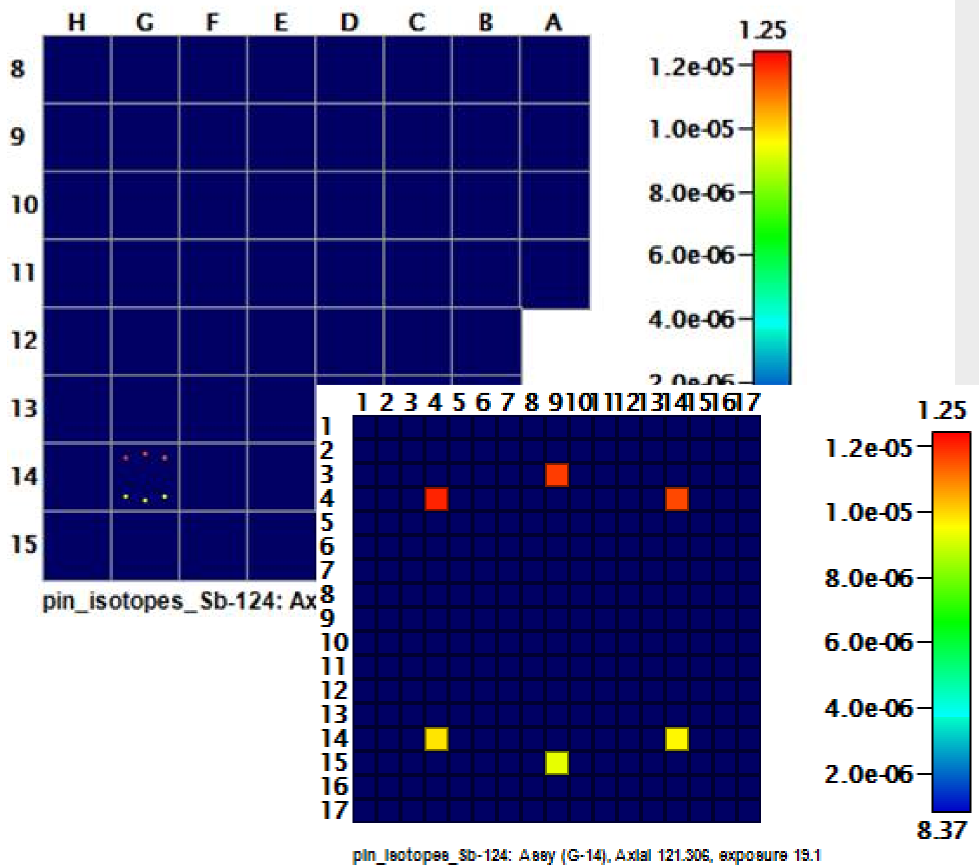
Secondary Source Rods

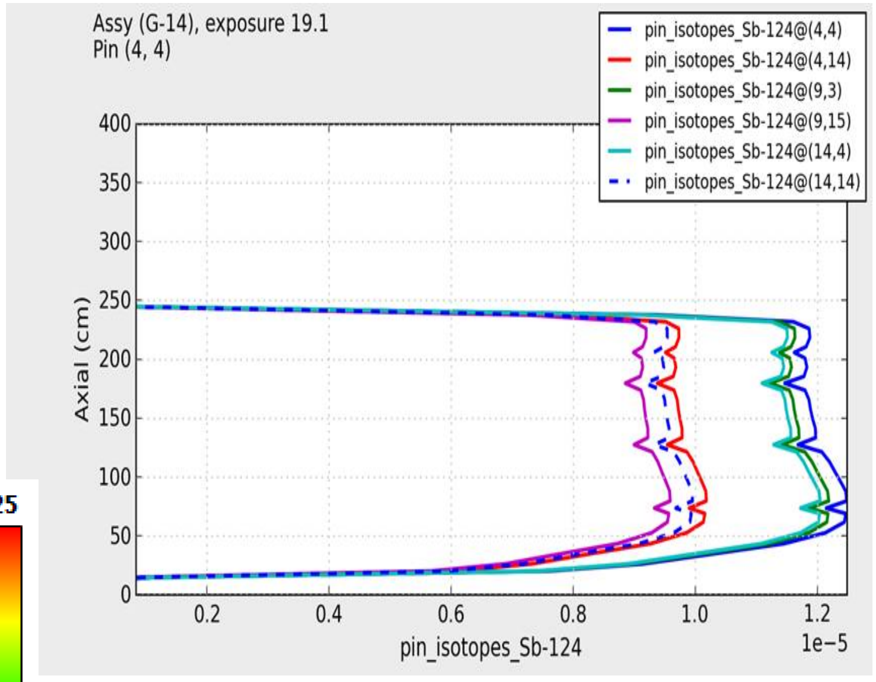


Watts Bar Unit 1 FSAR, Figure 4.2-21

SbBe Activation in VERA

- ORIGEN is used within MPACT to deplete the Sb-123 and produce/decay Sb-124 on the fine depletion mesh during a fuel cycle depletion

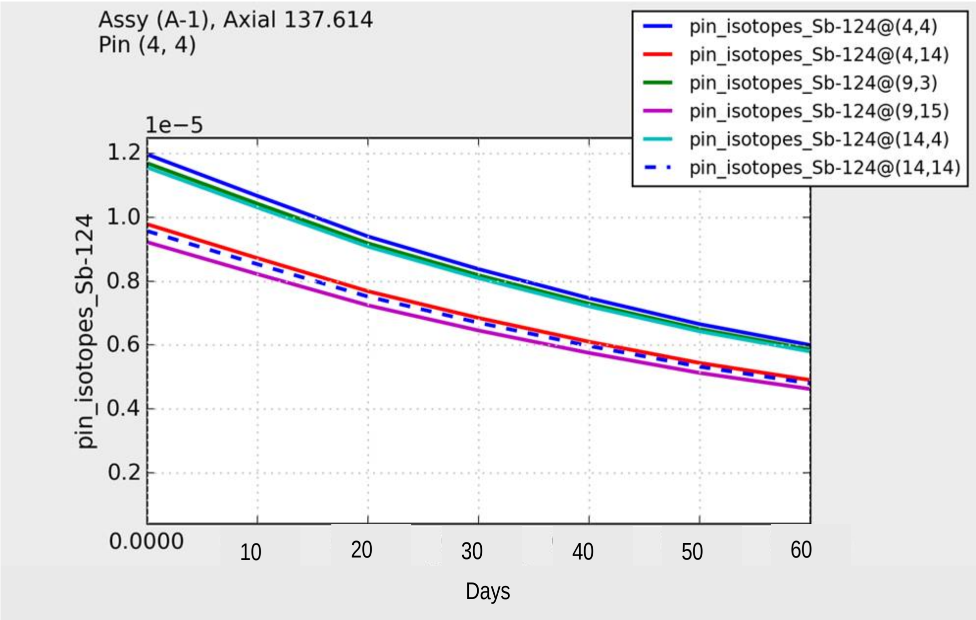




Sb-124 distributions in SbBe rod at EOC Cycle 7

SbBe Insert Shuffling

- The SbBe rods are moved into new or reinsert fuel assemblies after activation
- MPACT capability of insert shuffling during a refueling outage has been added, along with the existing ability to shuffle fuel
- Automatic decay is performed on the Sb-124 regions (60.2 day half-life) during the refueling outage



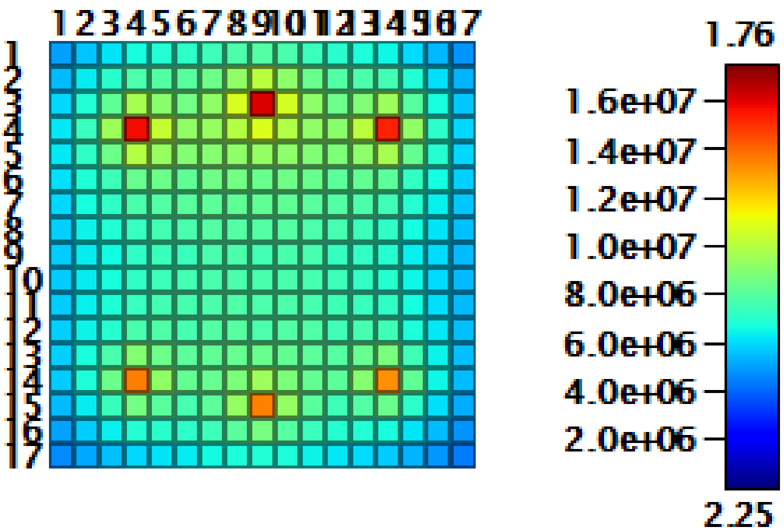
Decay in Sb-124 in the six rods as a function of outage length

Neutron Sources

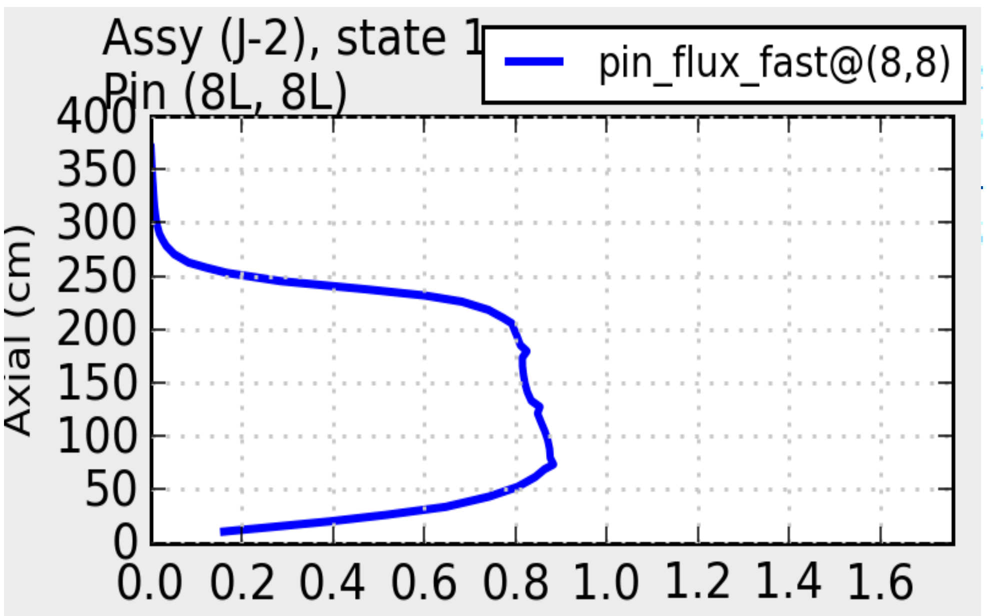
1. Be-9 photoneutrons
   - ORIGEN/SCALE does not include (gamma,n) reaction data
   - Analysis performed with MCNP to determine the Be-9 source strength as a function of Sb-124 decays
     - MPACT used to develop representative isotopics in a 2D lattice
     - ORIGEN used to determine the gamma sources from Sb-124 and depleted fuel
     - MCNP used to transport the gammas and tally the photoneutron reaction rate
   - VERA input created to provide neutron source strength and spectrum for each Sb-124 bearing region
     - Currently using 700,000 n/s/Ci of Sb-124

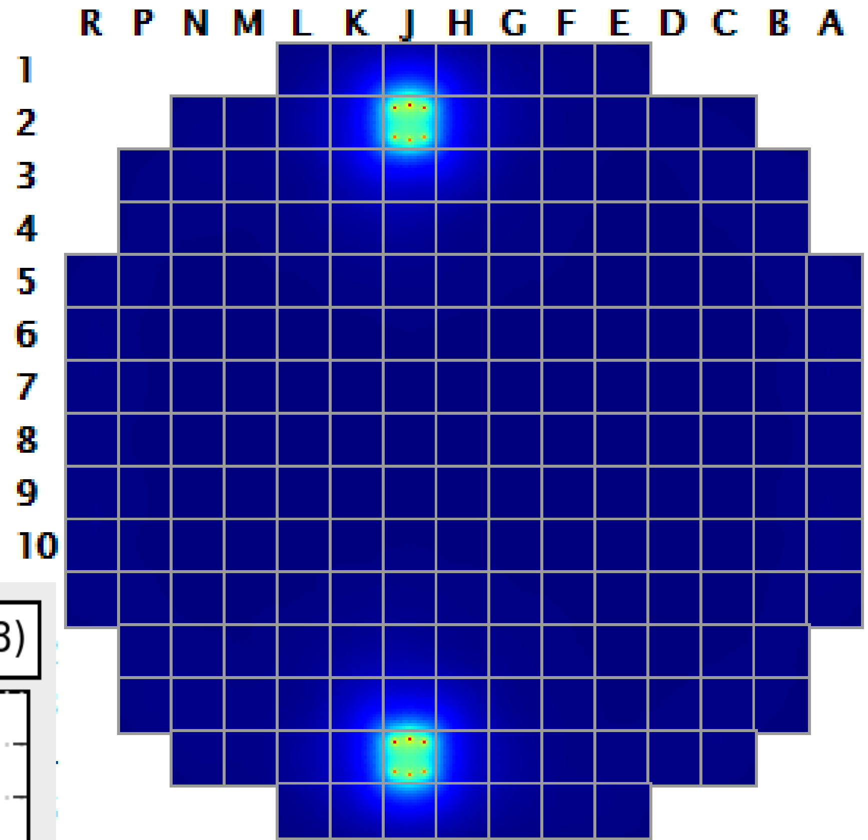
2. Neutrons emitted from depleted fuel are determined by ORIGEN for each depletion region in the core
   - Spontaneous fission, (α,n) reactions, delayed neutron sources

Detailed Source Distributions – Sb-124



pin_flux_fast: Assy (J-2), Axial 200.806, state 1

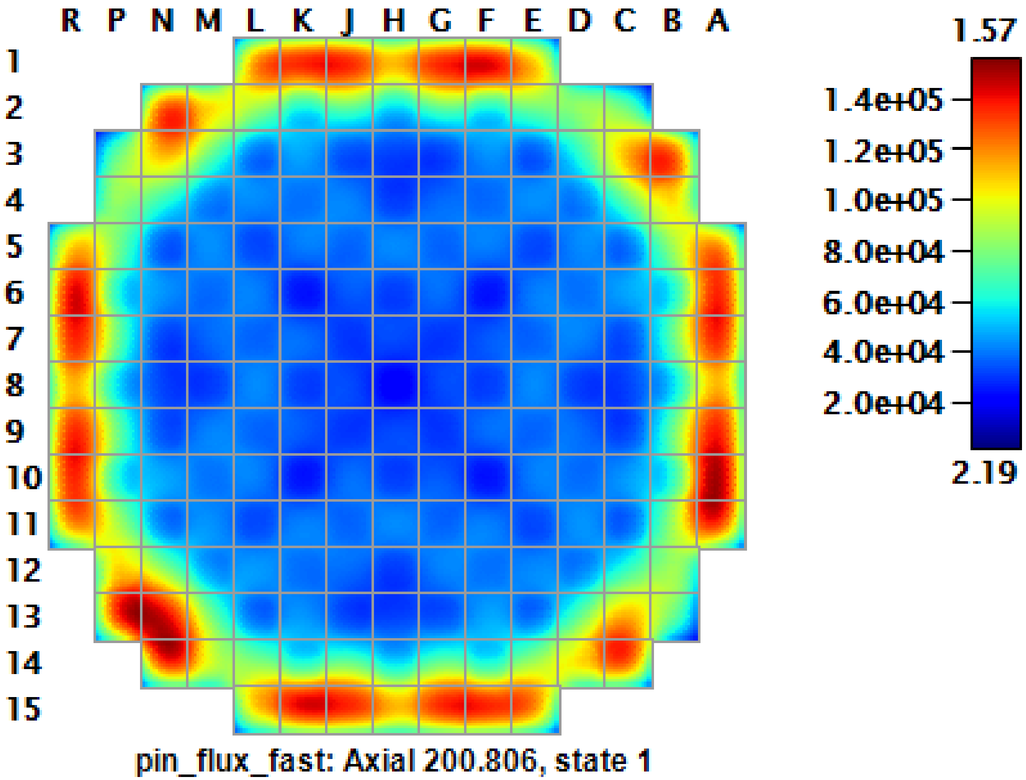


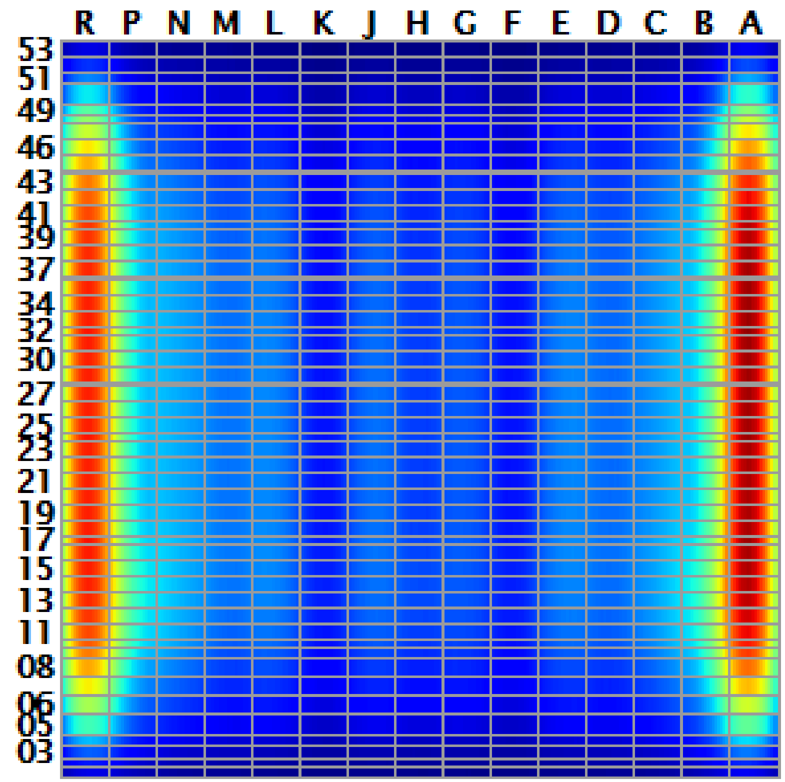


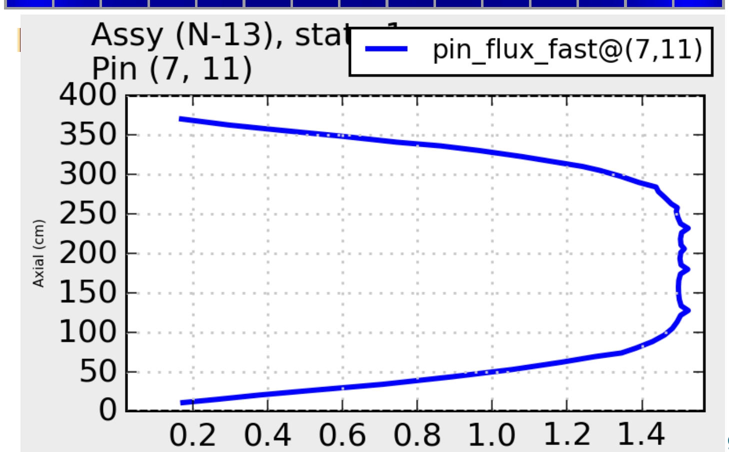
pin_flux_fast: Axial 200.806, state 1

Fast Flux Distributions near the SbBe rods at the Beginning of WB1C8

Detailed Source Distributions – Burned Fuel







Fast Flux Distributions without the SbBe rods at the Beginning of WB1C8

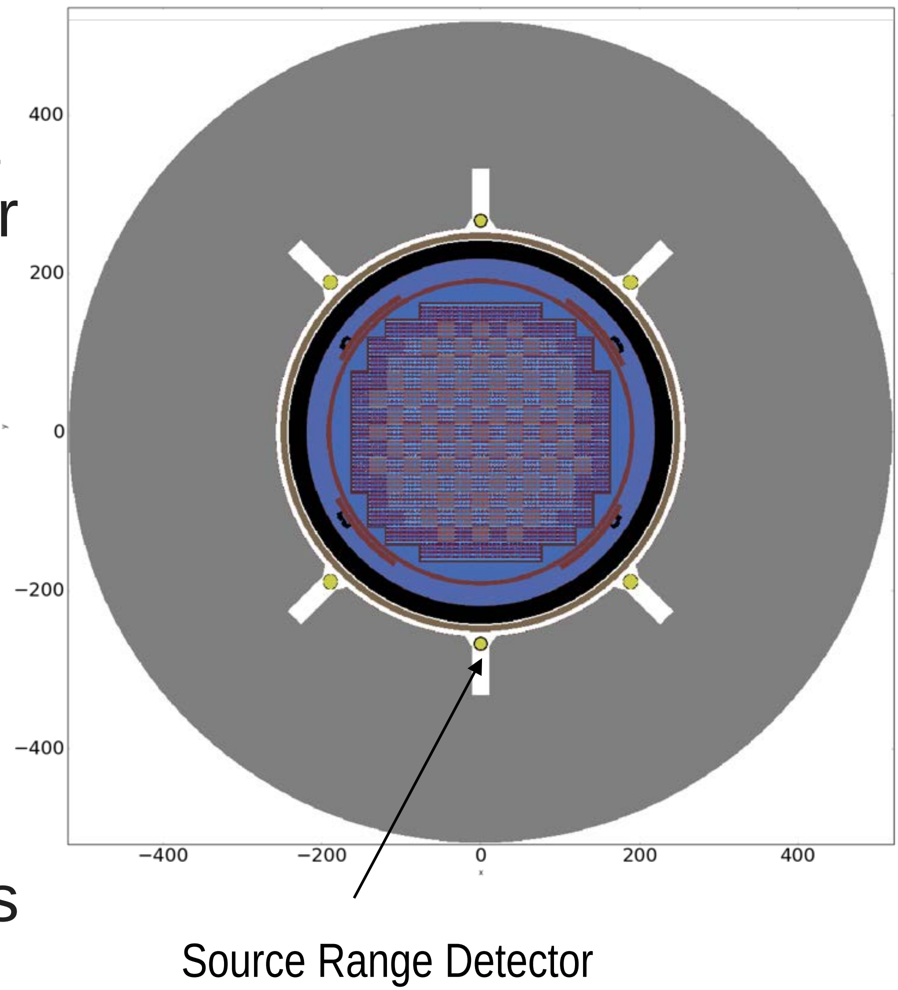
Note: In this case the source strength from burned fuel is ~1% of that from Sb-124

Sub-Critical Multiplication in MPACT

- In the short-term, a 3D pin-wise diffusion solver was implemented in MPACT to calculate the flux distribution from fixed-source problems
  - Fast and stable
  - May be accurate enough for providing the fission source to Shift
- An S_N transport solver may be available in the future through other activities
- Long term goal is to bypass this feature and give all the sources directly to Shift

Shift Excore Transport

- The detailed 3D fission source calculated by MPACT is transferred to Shift for transport out to the source range detector
- CADIS can be used to accelerate the calculation and reduce the variance of the detector tally
  - B-10 and U-235 detector types are supported
- Detailed excore model for Watts Bar created using Omnibus general geometry capability



Note: The Shift capability is not quite functional yet for this application.
Results should be available soon.

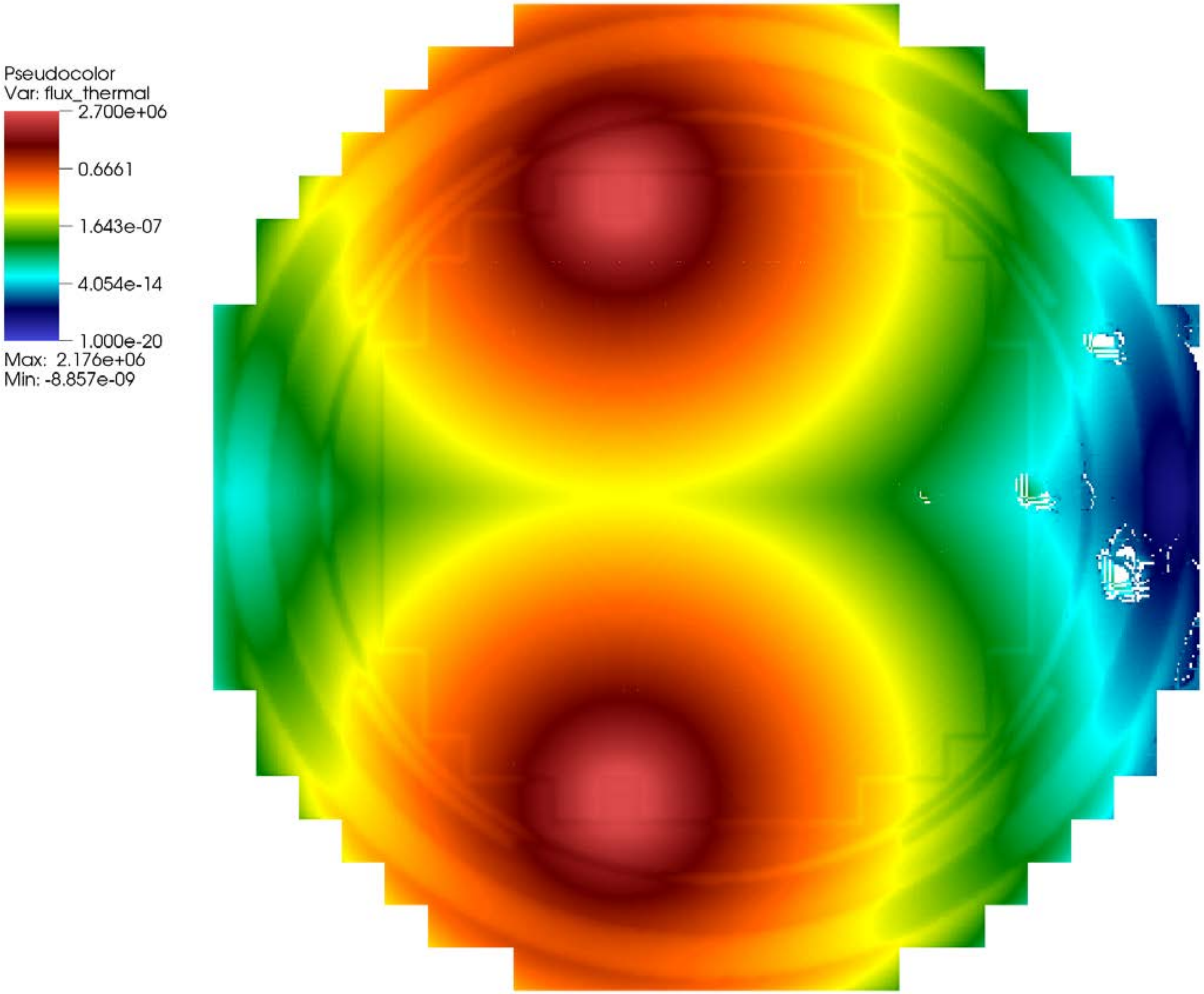
Applying to WB1C8 Refueling

- TVA provided core loading sequence and measured detector signals for WB1 Cycle 8
- Simulation includes first 10 moves
- Two secondary source assemblies
  - South assembly activated in WB1C7 (in SE quadrant of quarter-core calculation)
  - North assembly approximated as rotated version of southern
  - Sources are in fresh fuel assemblies
- Source strength and spectrum based on MCNP calculations (700,000 n/s/Ci Sb-124)
- Refueling includes all inserts (sources, WABA, RCCAs)

Preliminary Analysis

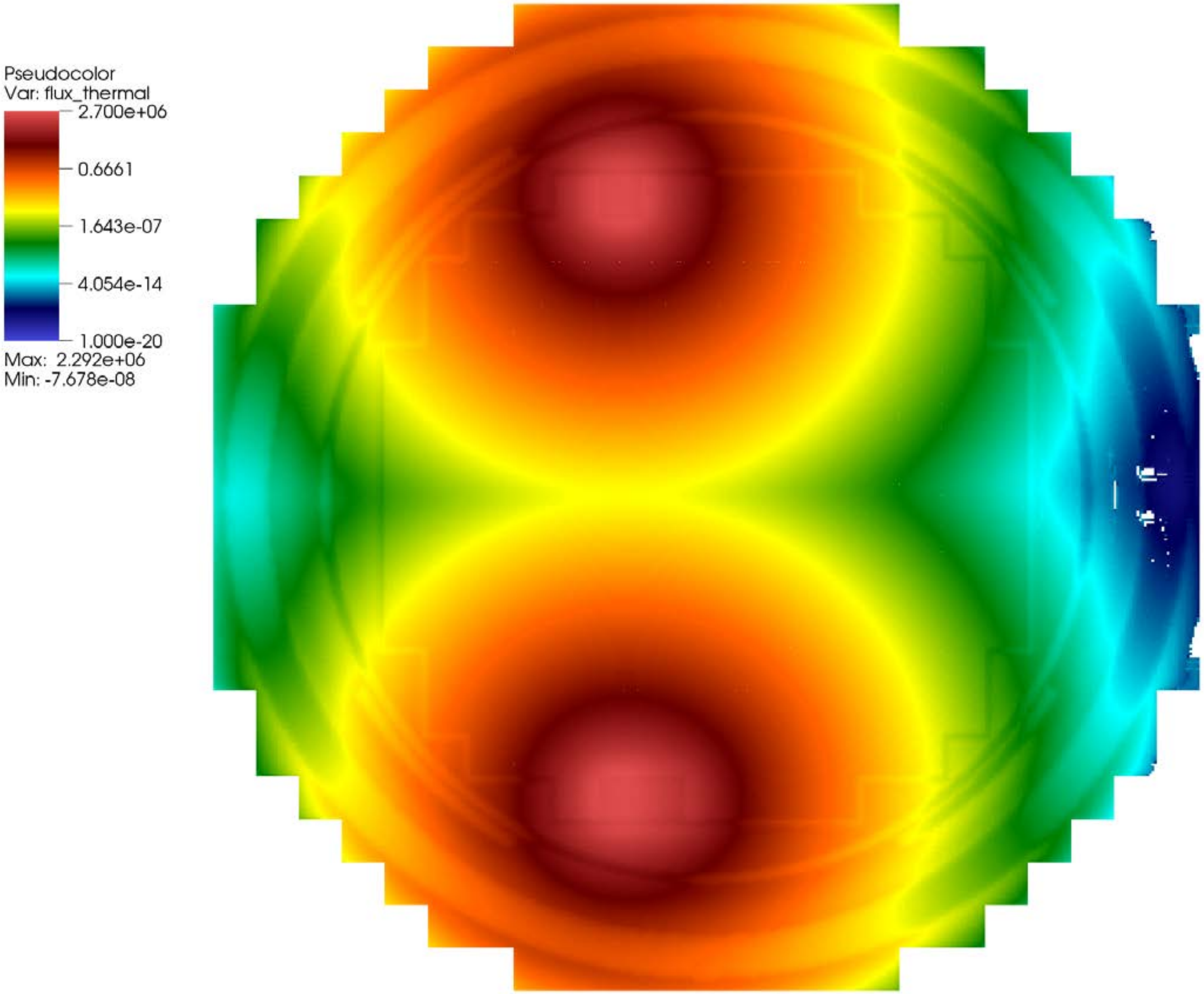
- Full Core 3D MPACT used to estimate thermal flux outside of the vessel NEAR the source range detector
  - Single point at core mid-plane is selected
- MPACT using subcritical fixed-source diffusion solver
- Expanded excore reflector model used to visualize calculated flux distribution
- Each refueling step modeled up to a 3x3 on the south side of the core
- Ran on Titan with 3600-26,220 cores
- Thermal flux response compared to measured detector signal provided by TVA (renormalized)

Step 1
Two source-bearing fresh assemblies on periphery



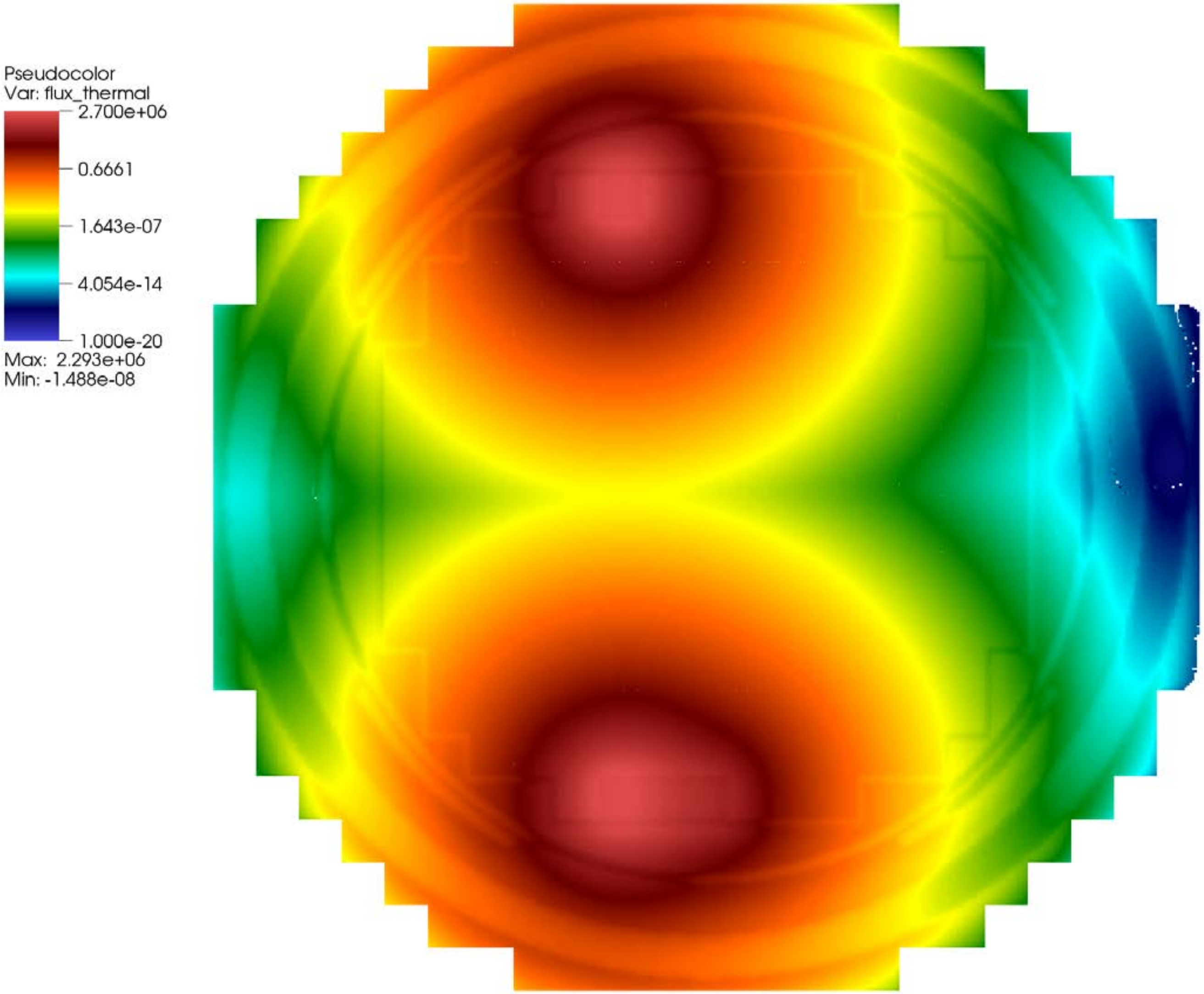
10B SS			

Step 2
Add burned fuel



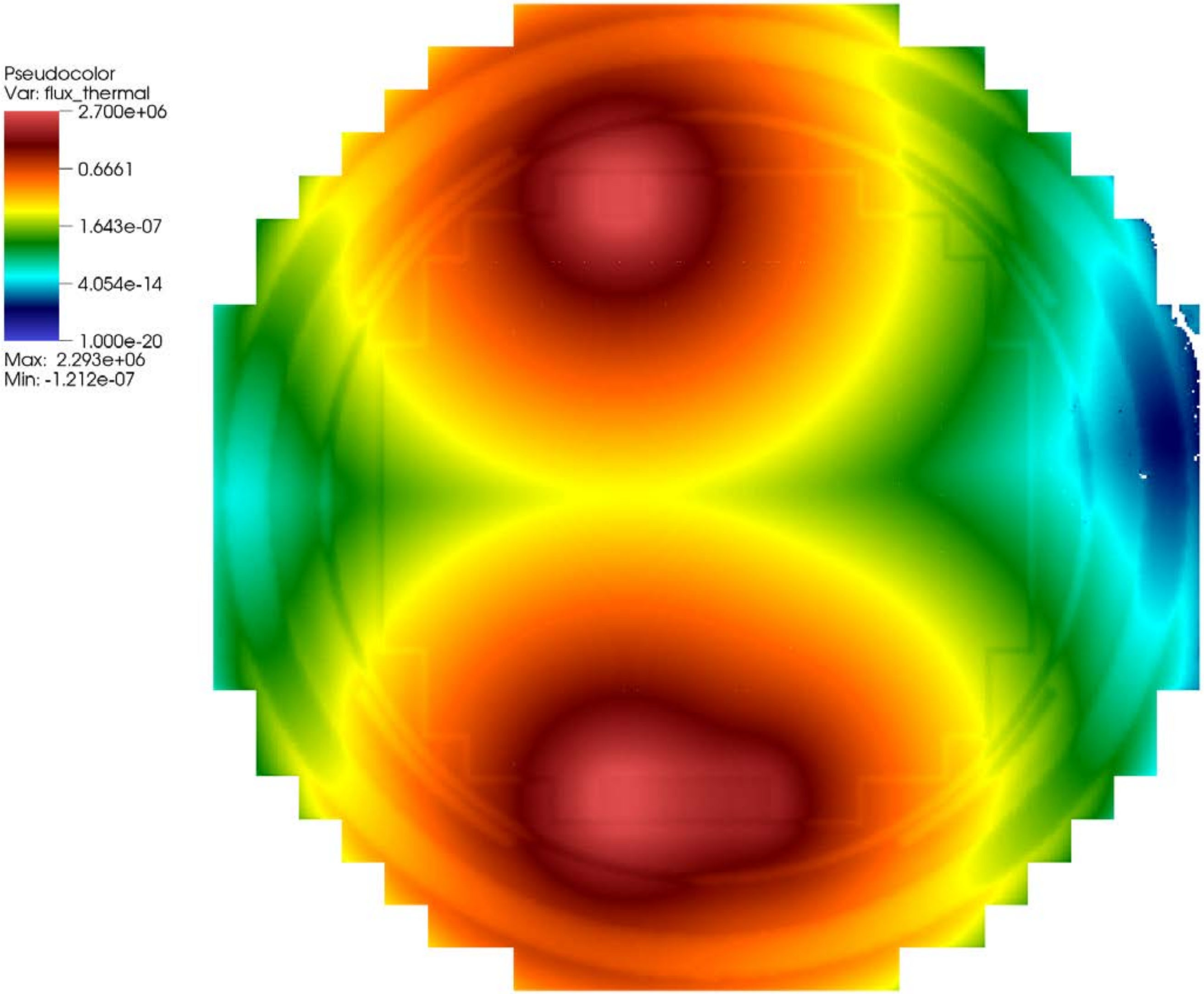
10B SS	8B		

Step 3
Add burned fuel



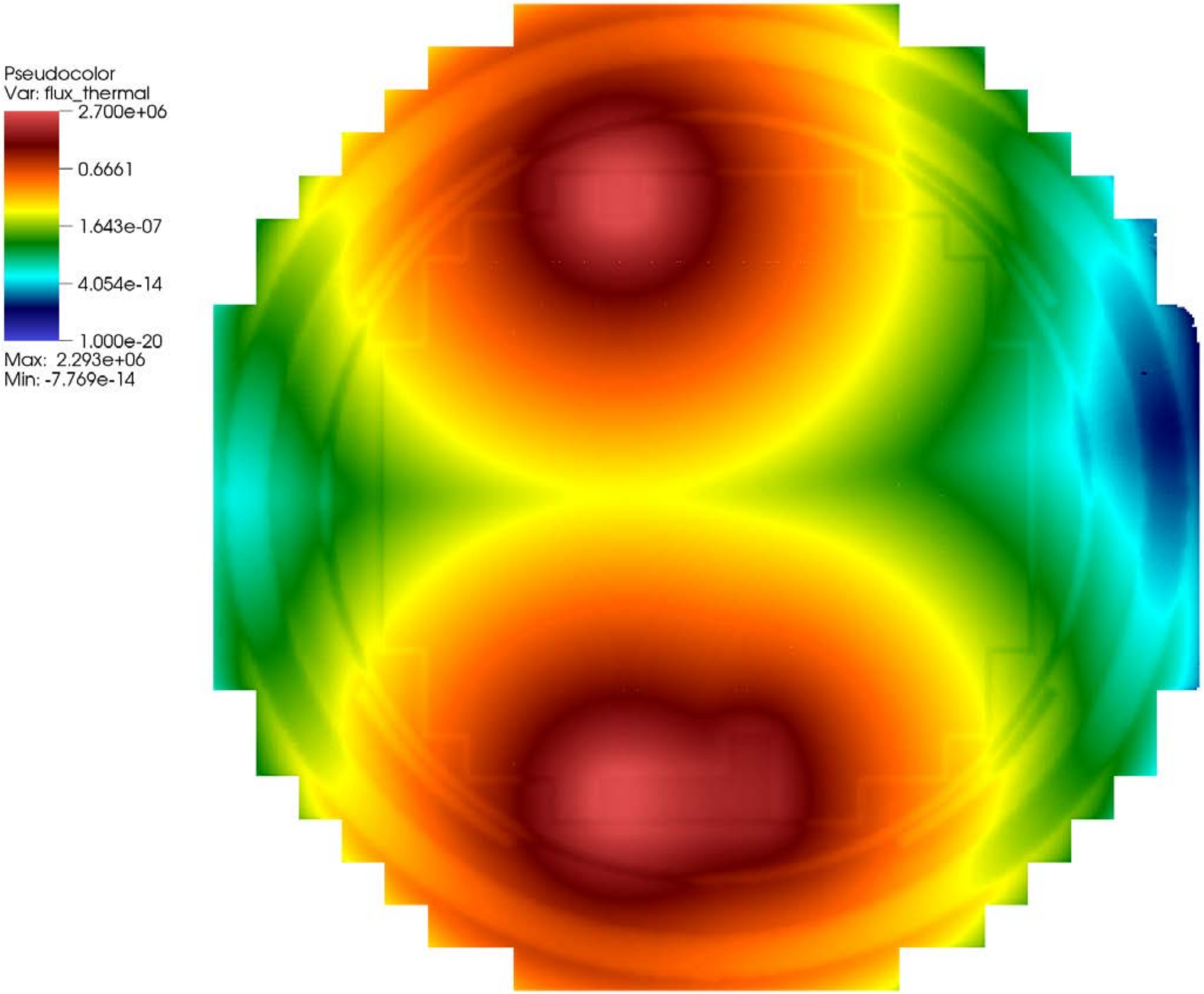
10B SS	8B	8A	

Step 4
Add burned fuel



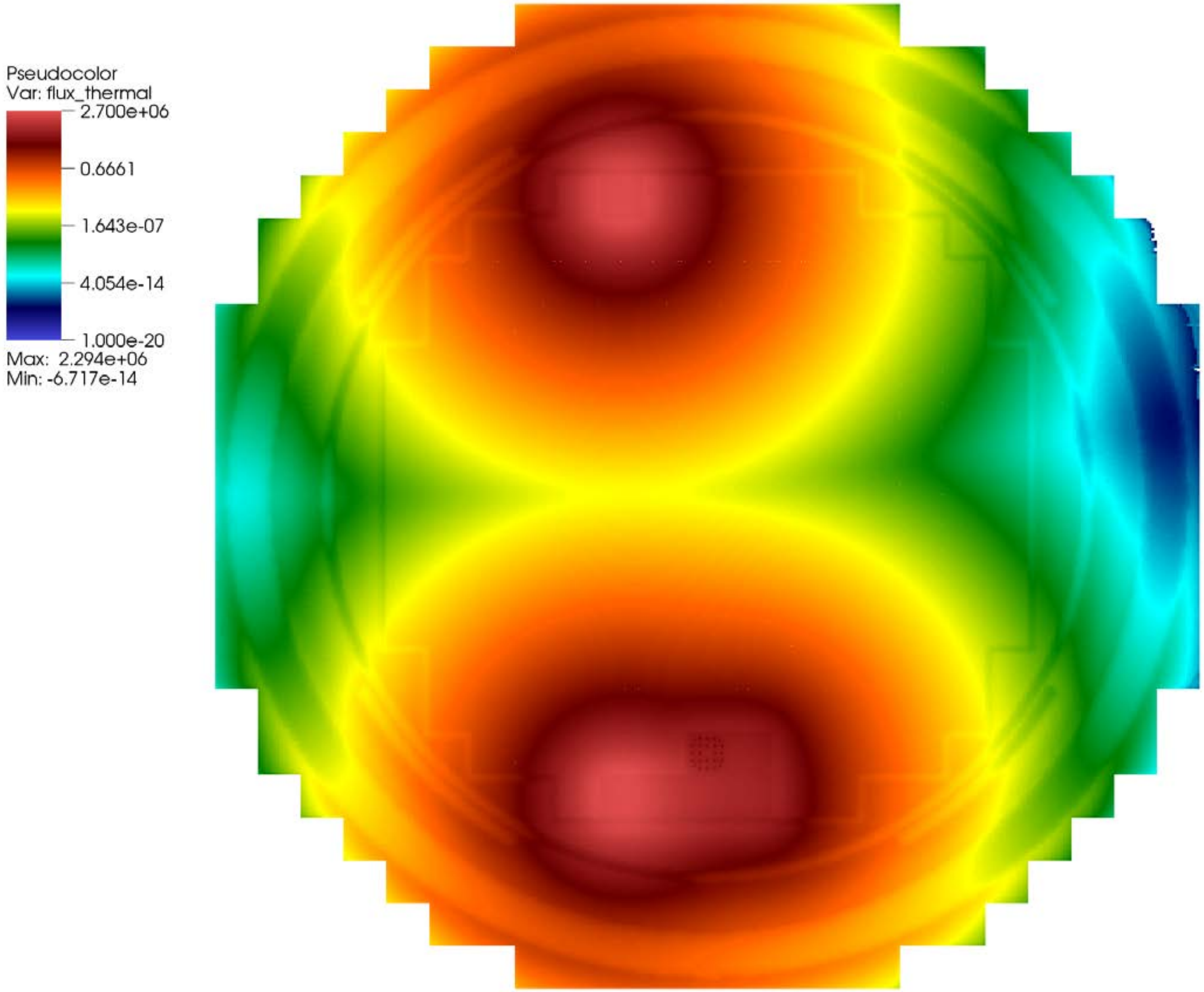
10B SS	8B	8A	8A

Step 5
Add fresh fuel with IFBA one row in



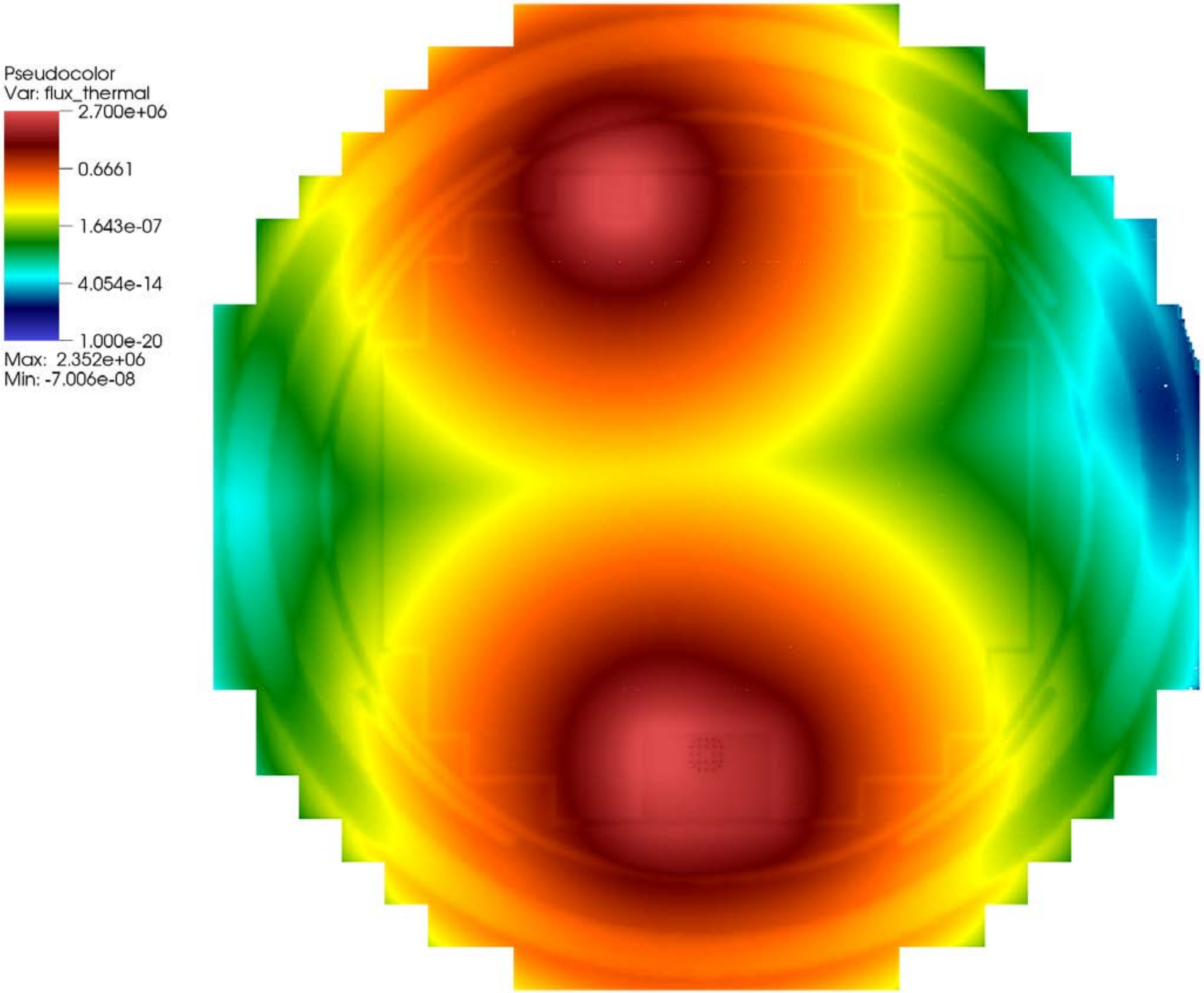
			10B
10B SS	8B	8A	8A

Step 6
Add burned fuel with RCCA one row in



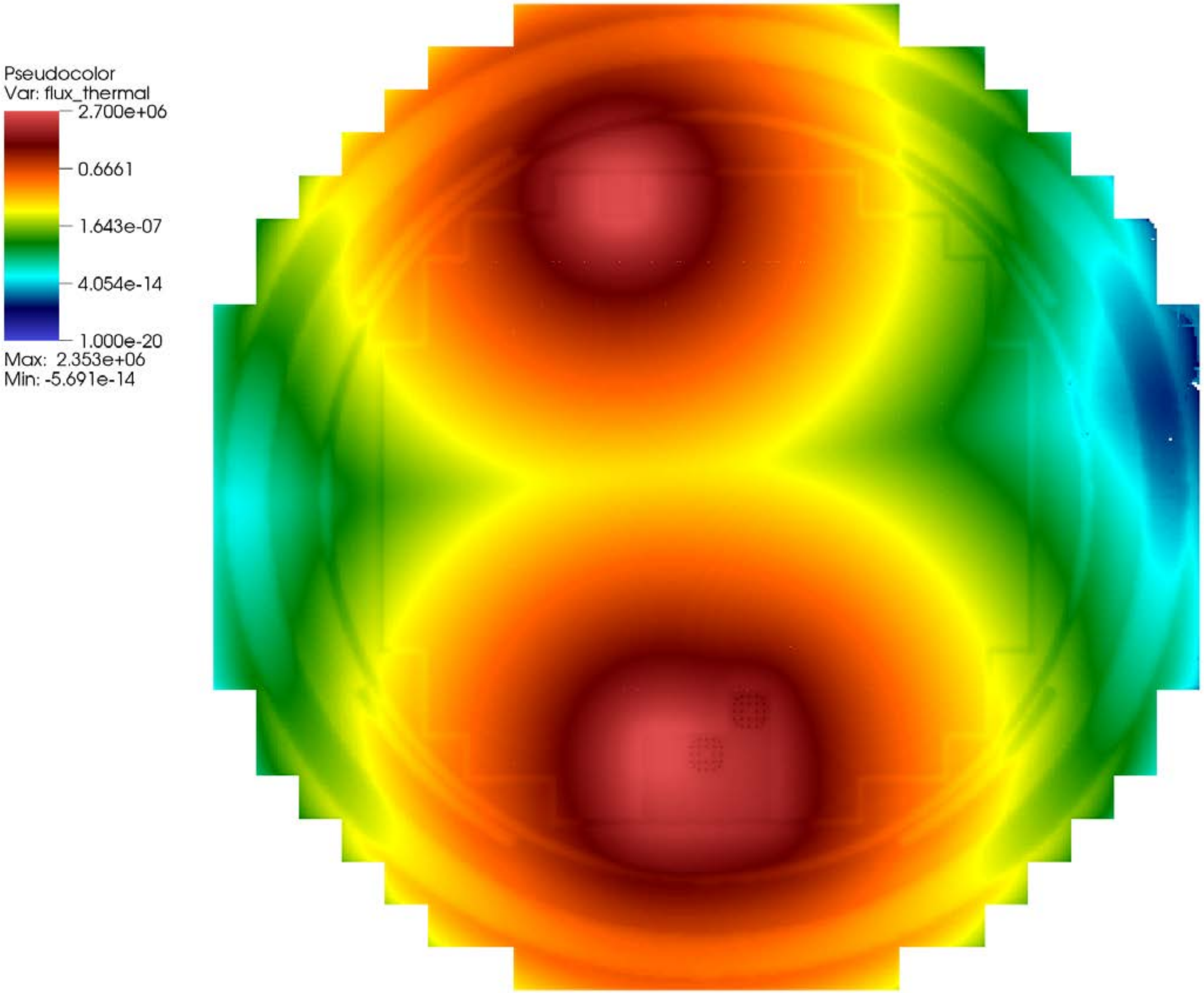
		9B RCCA	10B
10B SS	8B	8A	8A

Step 7
Relocate southern source-bearing assembly



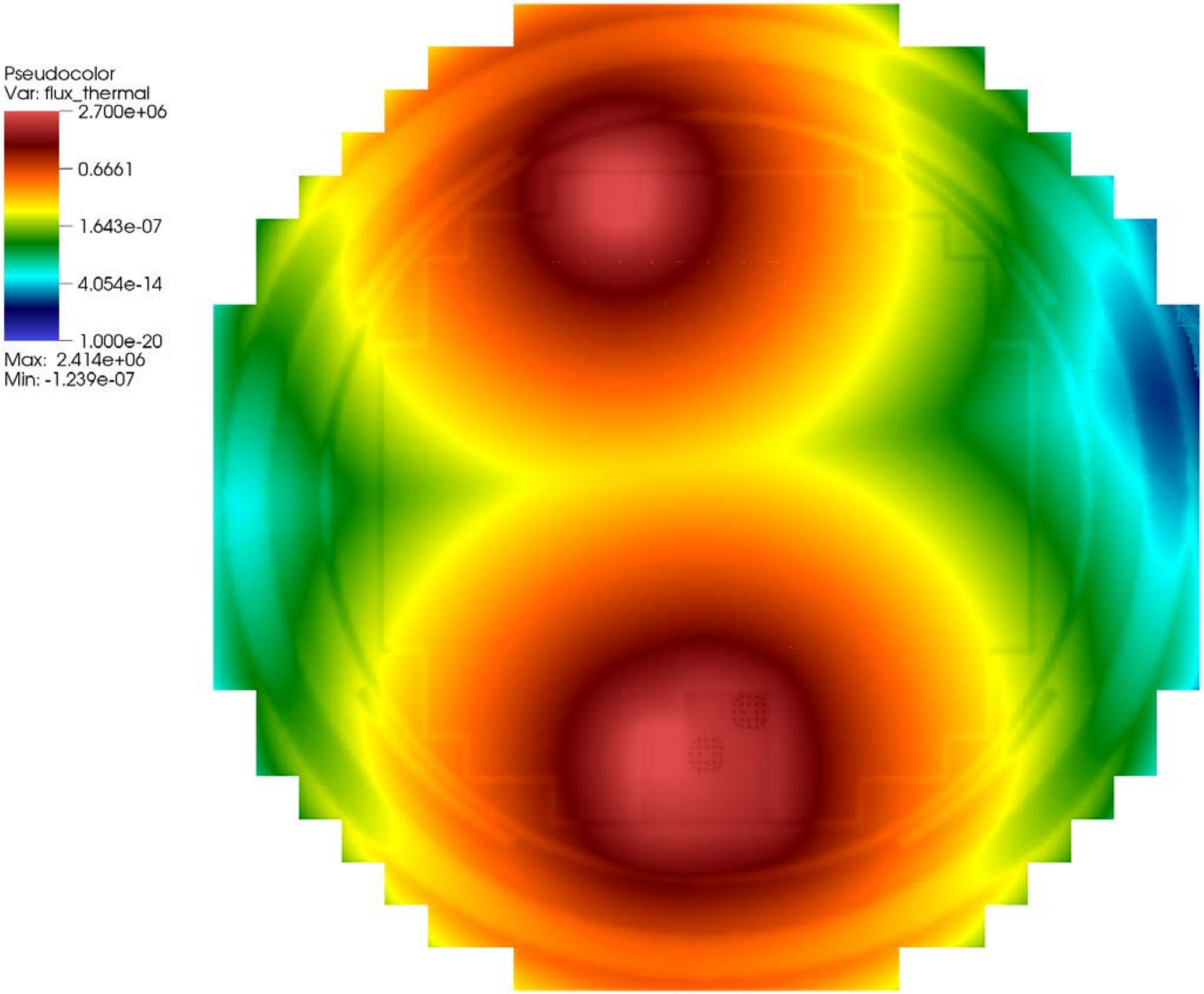
10B SS	9B RCCA	10B
8B	8A	8A

Step 8
Add burned fuel with RCCA



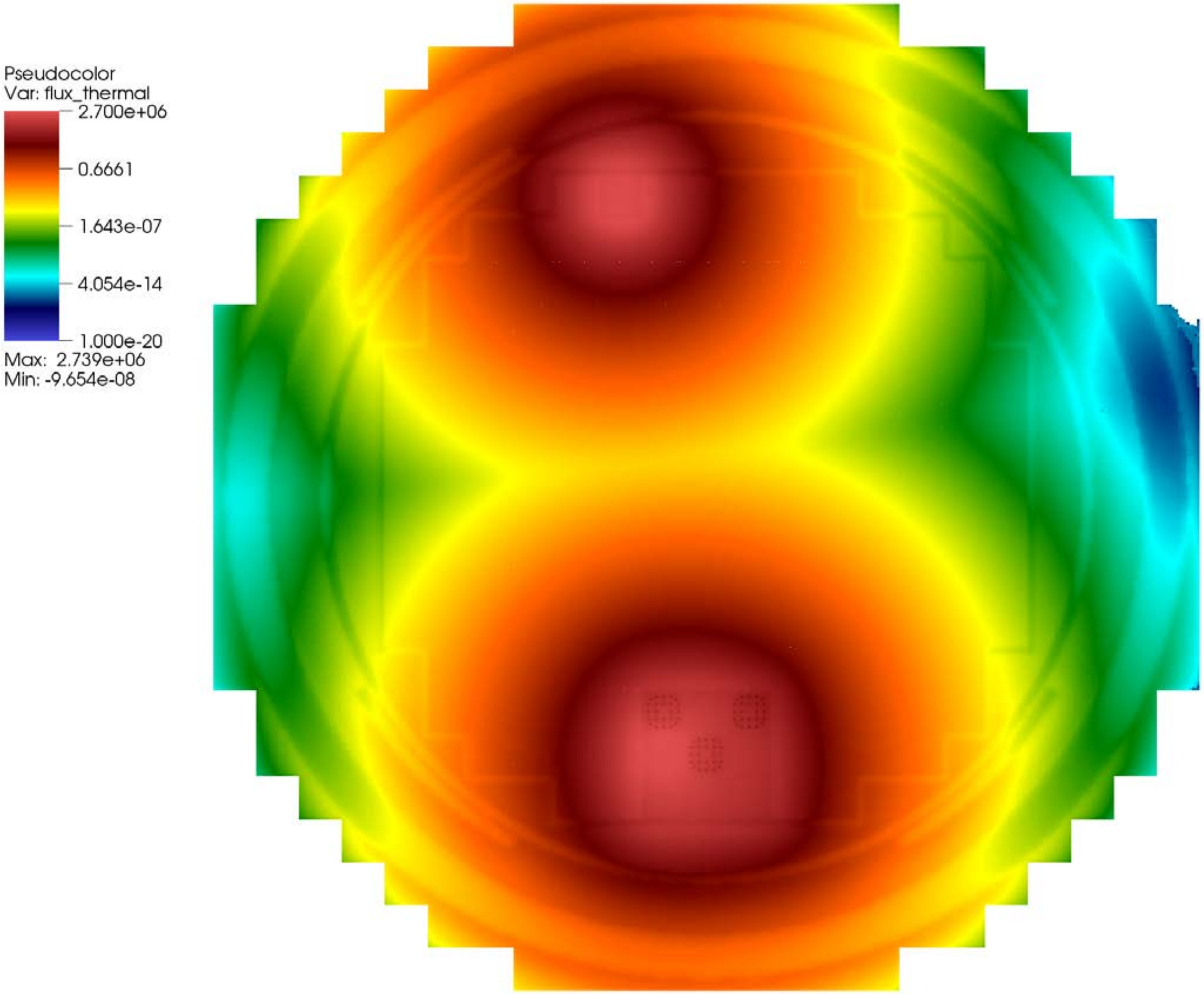
		9B RCCA
10B SS	9B RCCA	10B
8B	8A	8A

Step 9
Add fresh fuel with WABA



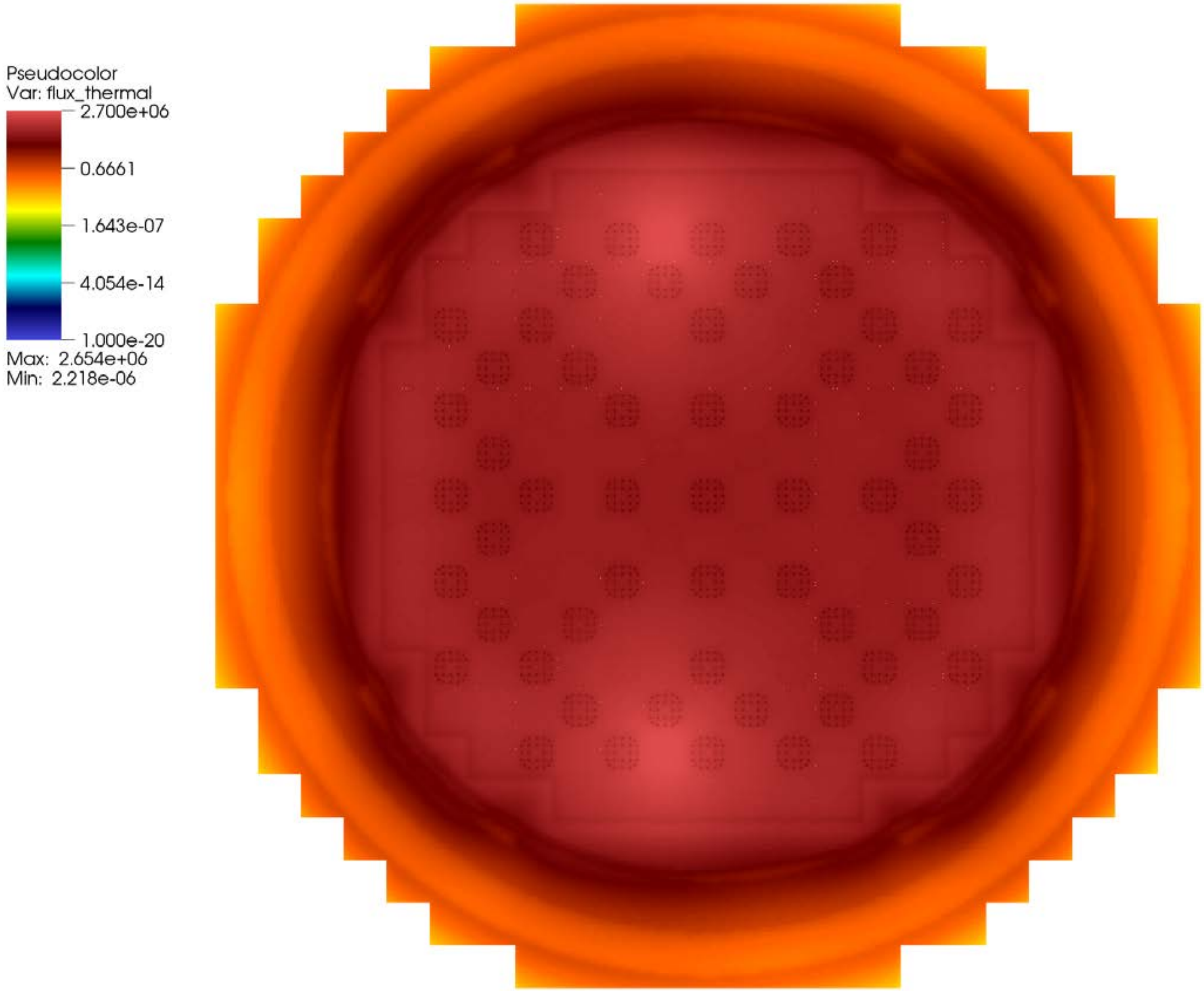
	10A 4W	9B RCCA
10B SS	9B RCCA	10B
8B	8A	8A

Step 10
Add burned fuel with RCCA

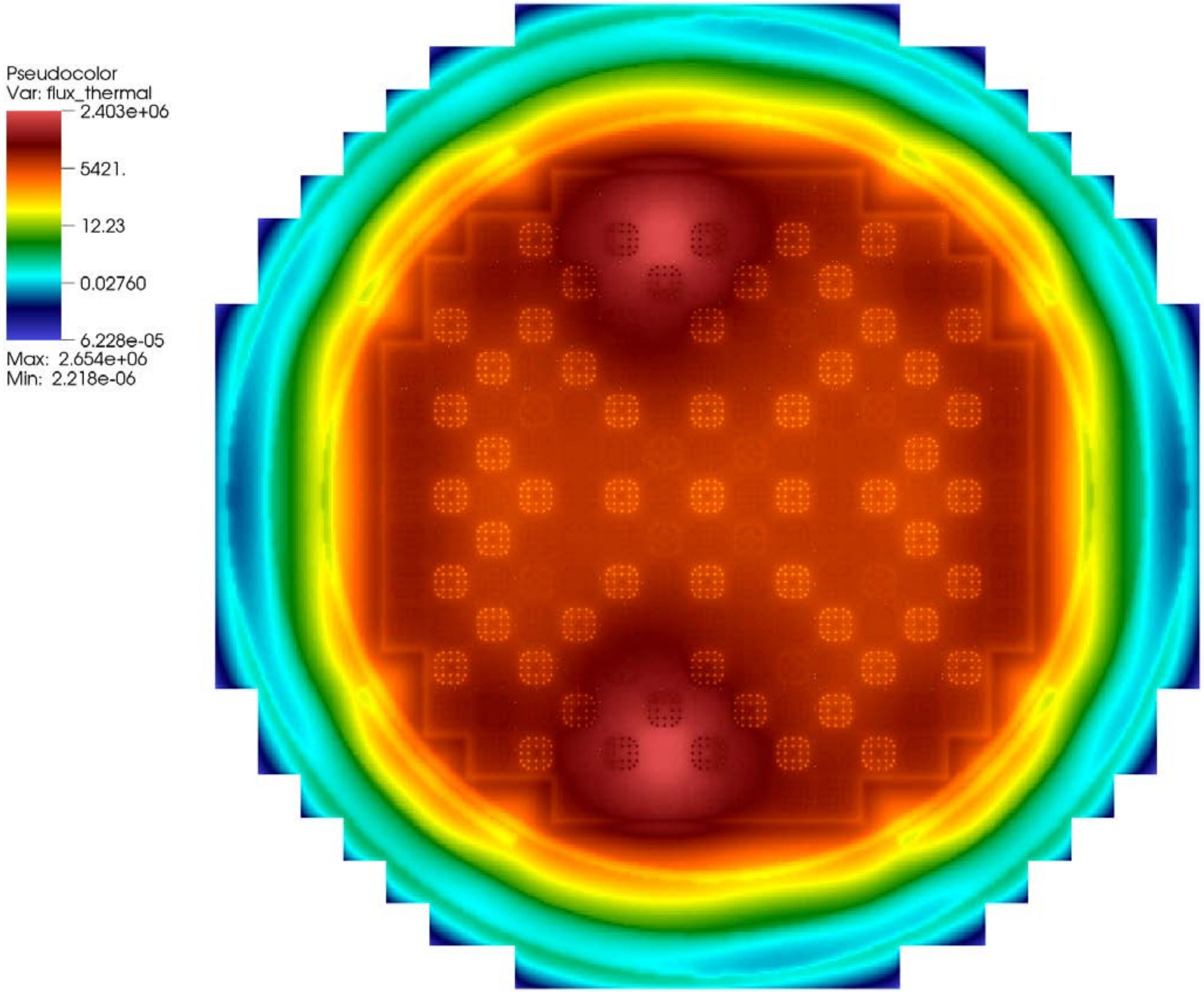


9B RCCA	10A 4W	9B RCCA
10B SS	9B RCCA	10B
8B	8A	8A

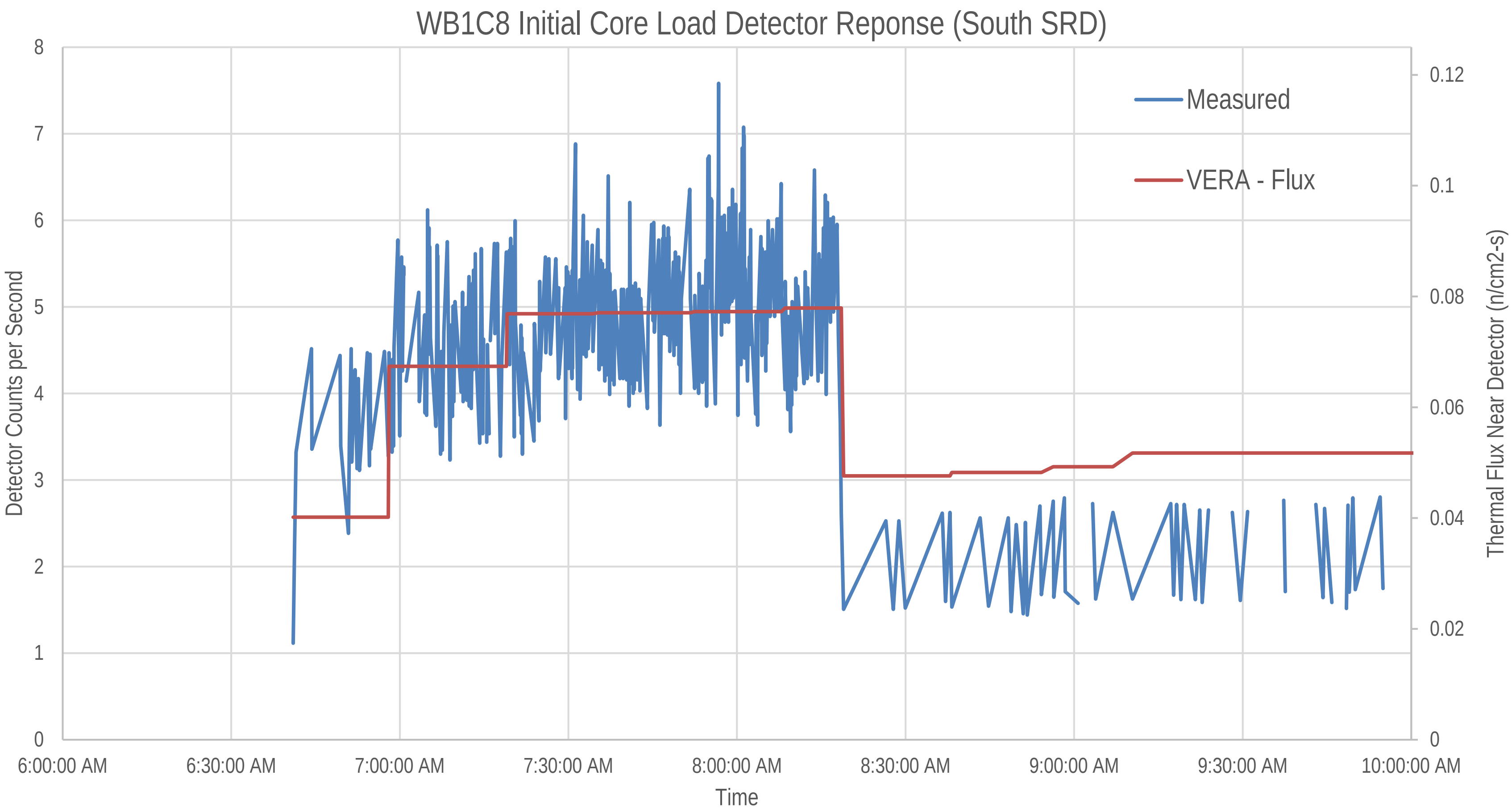
Additional Picture
Fully Loaded on Same Scale



Additional Picture
Fully Loaded on Different Scale



Preliminary Detector Comparison



- Single thermal flux response comparison at core-midplane

Next Steps

- Calculate source range detector response for the core loading and compare to measured data
- Validate against data where secondary sources are placed in burned fuel assemblies
- Support TVA in further analyses of previous cycles and future cycles using the CASL tools
- Apply and validate these methods in an ICRR approach to criticality

A DOE Energy Innovation Hub

www.casl.gov