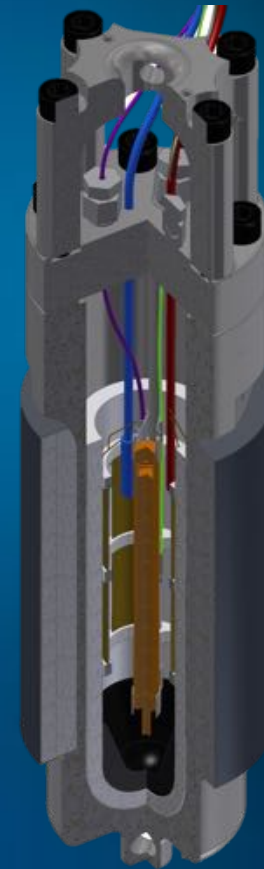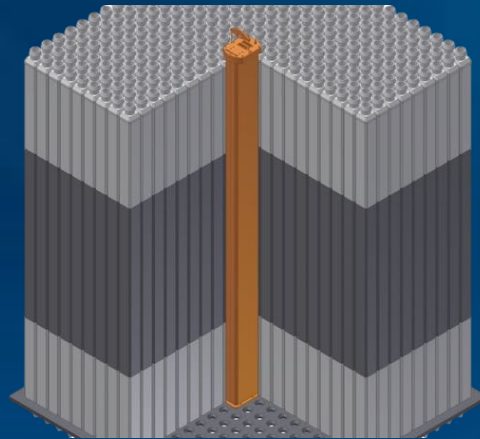# *The Use of Serpent 2 in Support of Modeling of the Transient Test Reactor at Idaho National Laboratory*

Sixth International Serpent User's Group Meeting
Politecnico di Milano, Milan, Italy
26-29 September, 2016

Mark D. DeHart, PhD
Deputy Director for Reactor Physics
Modeling and Simulation
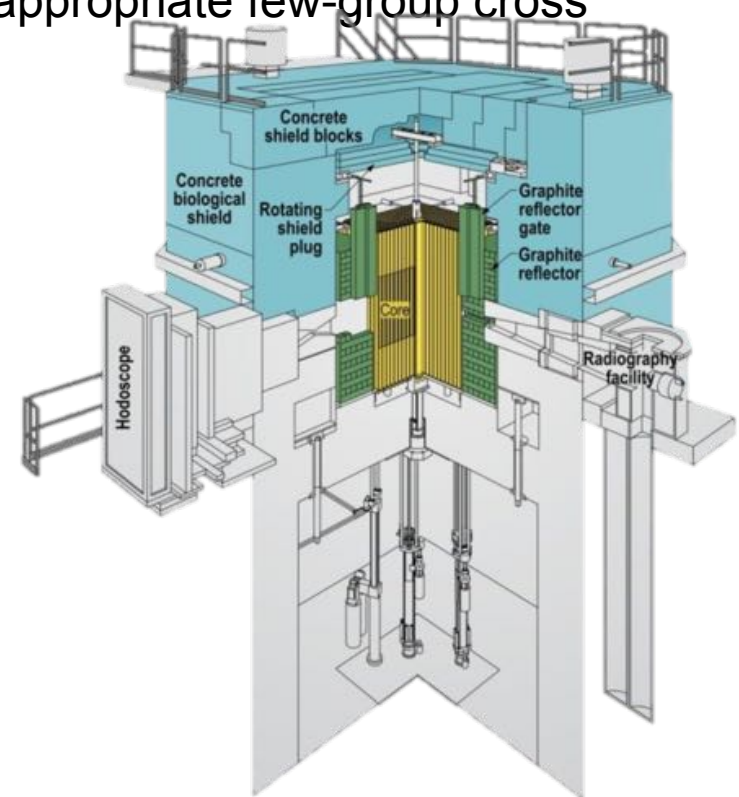**Idaho National Laboratory, USA**

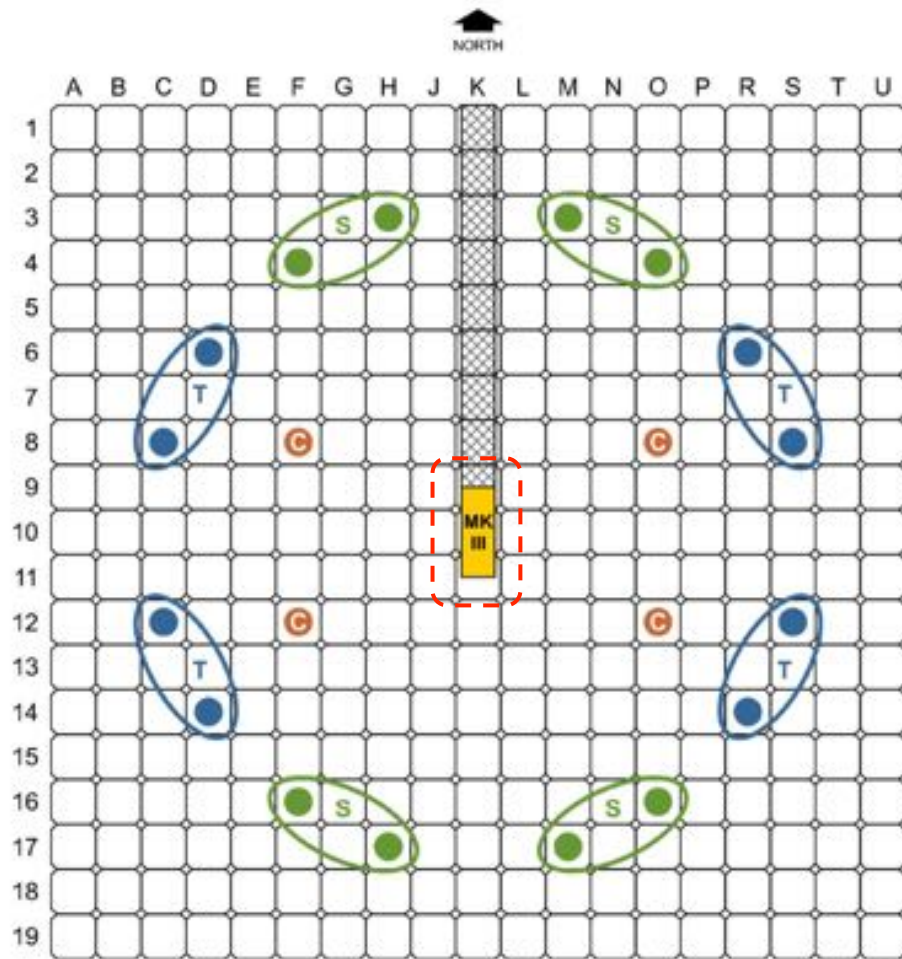www.inl.gov

INL
Idaho National
Laboratory

TREAT Modeling and Simulation

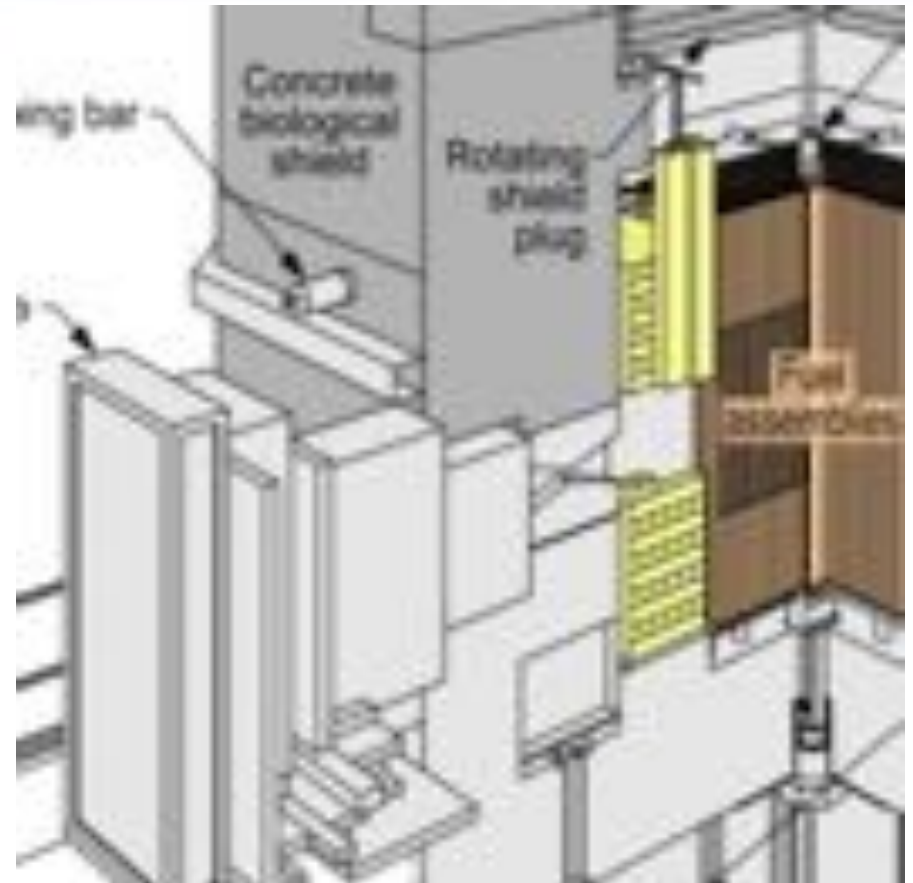- No (unclassified) method is readily available accurate 3D transient simulations for TREAT

- Streaming channels both horizontally and vertically are a challenge for ALL deterministic methods.

- The small size of the core (~193 x 193 x 122cm) and the long mean free path in graphite makes cross section generation three-dimensional

- Serpent has been instrumental in developing appropriate few-group cross sections
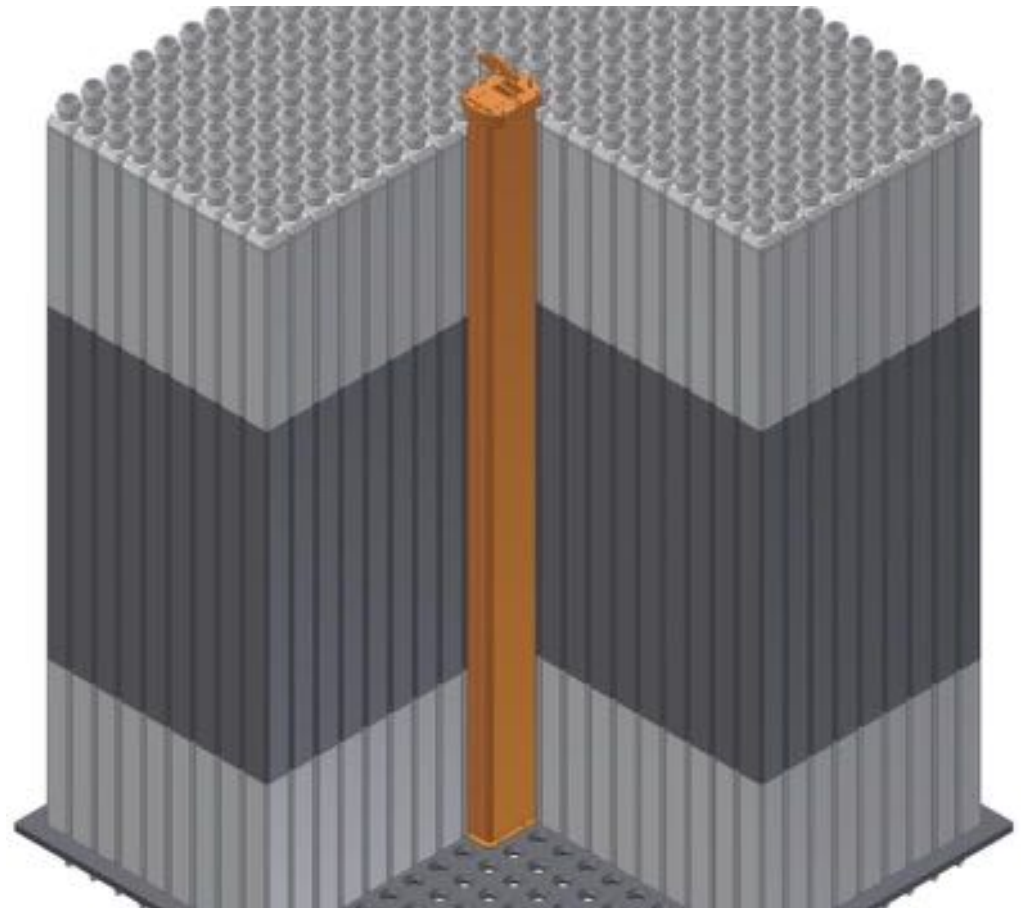
The INL Transient Test Reactor

Slotted hodoscope assembly
S Control/shutdown rod pair
C Compensation/shutdown rod assembly
T Transient rod pair
MK III Experiment locations (Note: other experiment locations and configurations possible)

First Experiments

Static Environment Rodlet
Transient Test Apparatus
(SERTTA)

- General purpose devices <u>without</u>
forced convection

- Pre-pressurized and electrically
heated
  - Liquid water up to PWR
    condition (320°C 16 MPa)
  - Inert gas or steam
  - Liquid sodium

- Two SERTTA's under
development
  - 4X capsule "Multi-SERTTA"
  - 1X capsule "Super-SERTTA"

- At present MAMMOTH is the only
means available to assess the
transient performance of these
capsules.

SERTTA shown in TREAT core ¾ section view
Secondary containment shroud ("can") visible

Multi-SERTTA

- Best for smaller scale specimens and four-for-one testing (concept screening)
- Planned to be the first new test to be used in restarted TREAT
- Even modeling with Serpent will be difficult (statistics)
- Modeling with an unstructured mesh deterministic method will be a challenge.
- However, that is our ultimate plan.
- This will be a challenge to generate cross sections for using any present method.

Leak Tight Enclosure

4X Vessels Within

Shield Block

Lower Reflector

Pressure Transducer (not visible)

Instrument Penetrations

Expansion Tank

Accelerometer

Valve

Rodlet

Crucible

Vessel

Flux Collar

Heater

Melt Catcher

How TREAT works

- Three sets of control rods
  - Safety – fully out for transient
  - Compensation – partially inserted to set critical state pre-transient
  - Transient – partially inserted for desired delta-k, then rapidly fully withdrawn
- Core is 100 ppm highly enriched uranium – very little resonance absorption
- As core heats, a shift in the thermal Maxwellian takes the core back to a new critical state; eventually rods are driven in to shut down

Modeling TREAT with MAMMOTH

- MAMMOTH has been built using the MOOSE framework (Multi-physics Object Oriented Simulation Environment)

- MOOSE allows implicit, strong, and loose coupling of MOOSE animal solutions

- MAMMOTH is the MOOSE-based multi-physics reactor analysis tool.

- At present, TREAT <u>core</u> simulation efforts rely on BISON (fuel performance), Rattlesnake (time-dependent neutron transport) and MAMMOTH. LWR-type pin experiments are being evaluated using RELAP-7 as well.

- Note that MAMMOTH is a single executable code with multiple personalities all co-existing.

- All codes are based on FEM – MOOSE routines perform all solutions.

- All data from all codes is available to the solver(s) used.

- Nothing like this exists elsewhere – MAMMOTH is <u>earth-shaking</u>.
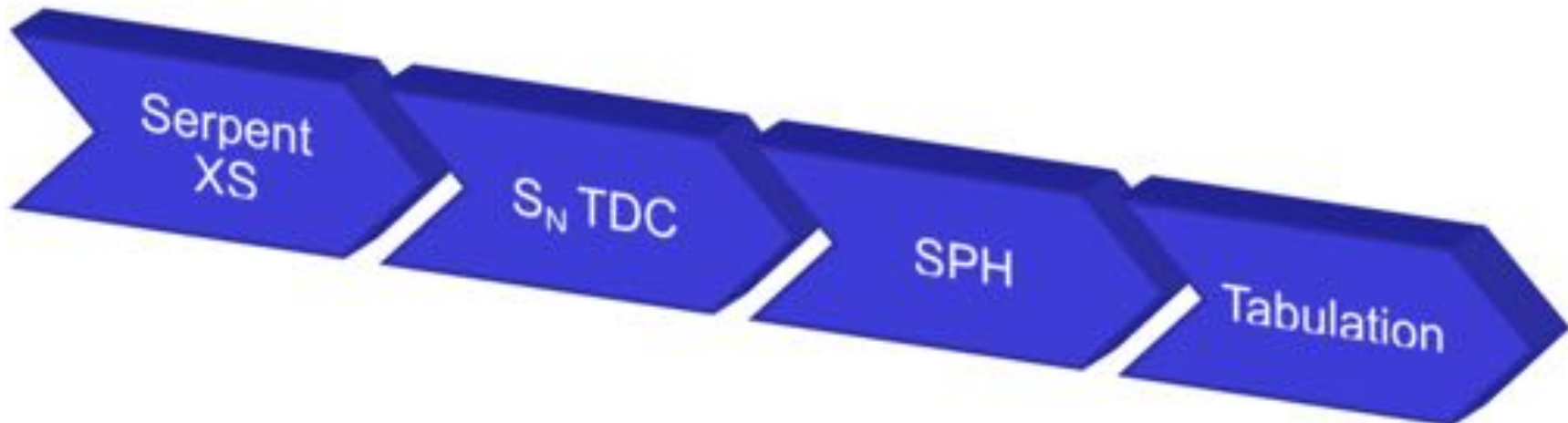
Application of Serpent

- The neutron transport solver within MAMMOTH is Rattlesnake.
  - Finite element unstructured-mesh solver
  - First and second order S_n, P_n, and diffusion solve capabilities
  - Solves time-dependent version of transport equation with delayed neutrons
  - Capable of solving three dimensional rapid transient analysis
  - Multi-group solver needs appropriately weighted cross sections
- Serpent was selected as the main cross section preparation tool for this project because it offers 3-D spatial homogenization and group constant generation for deterministic reactor simulator calculations.
- At the same time, Serpent 2 provides a detailed reference calculation without energy, angular, or spatial discretization error.
- The neutron cross sections used in Serpent 2 are based on ENDF/B-VII.1.
- Serpent has been in use at the Idaho National Laboratory since 2010 (used for LEU conversion analysis and fuel design for the Advanced Test Reactor and for HTGR and Advanced Test Reactor designs).

Challenges in TREAT Cross Sections

- Previous research indicated two deficiencies that adversely affect the power distribution in the
    - the axial streaming in the air channels that surround each element
    - the lack of an equivalence procedure to preserved reaction rates in controlled elements.
- The (current) M8 calibration configuration also includes
    - a half slotted core with large void channels (~ 10cm x 120 cm x 90cm) inside core
    - an experiment vehicle with significant void regions
- Angular fluxes are extremely anisotropic – a challenge to high order S_n methods as well. Diffusion coefficient calculations fail even in Serpent.
- Currently Serpent does not <u>currently</u> have the capability to generate anisotropic diffusion coefficients to allow better modeling of neutron streaming effects with a diffusion solver.
- We still rely heavily on Serpent for base cross sections – TREAT cross section processing is three dimensional.
- Serpent also provides our reference solution for steady state calculations.
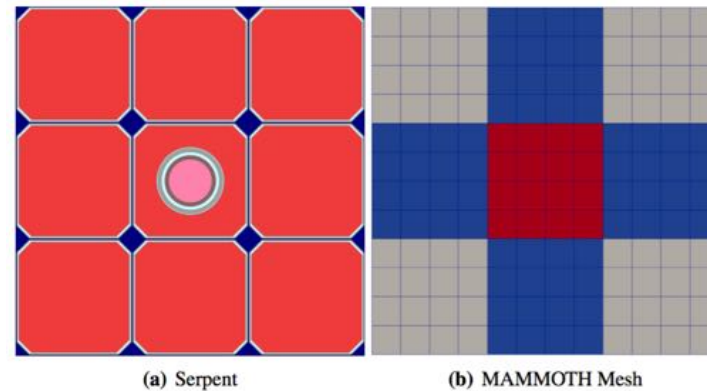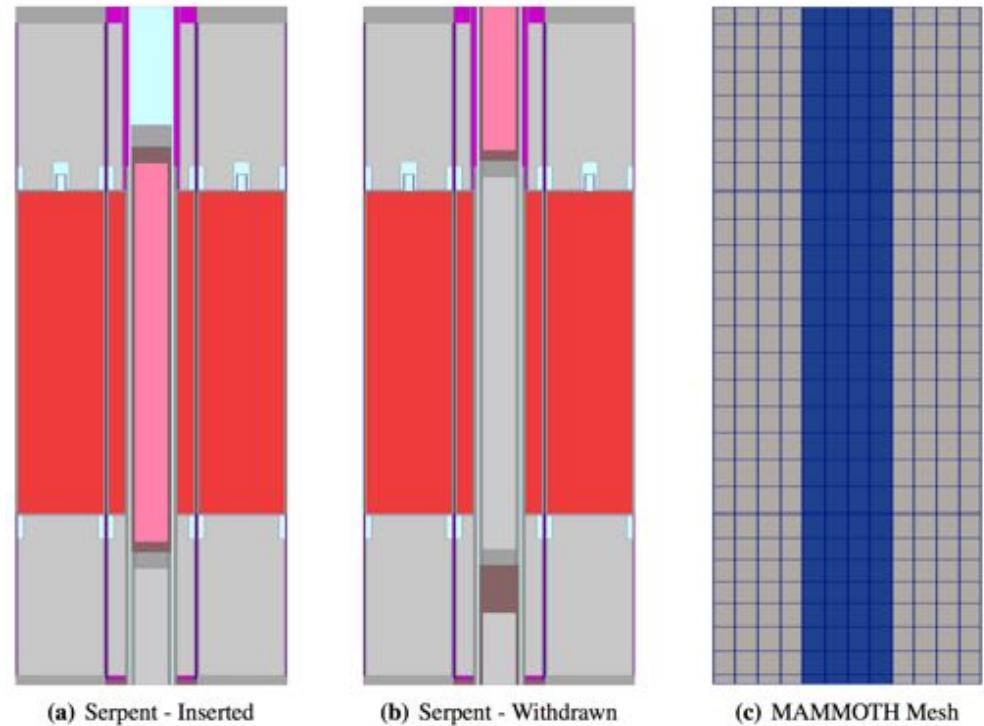
Correcting the "Incorrect"

- INL has developed the capability to calculate tensor (anisotropic) diffusion coefficients (TDCs) using the Larsen-Trahan approach (requires transport solution in Rattlesnake.

- Added Hébert's generalized Super Homogenization method to preserve the reaction rate between the macro and reference calculations to correct for streaming.

- Corrected cross sections are tabulated as a function of zones (multiple zones in single material to account for spatial effects from reflector and control rods)

- For transient calculations, also tabulated for temperature and control rod position.

Serpent Core Calculations

- Detailed core calculation using Serpent

- Few group (10-11 g) cross sections produced for axial and radial zones

- Cross sections are applied in a detailed a rectilinear finite element mesh for predetermined spatial regions.

- Given the reference Serpent calculation and a Rattlesnake calculation on the homogenized mesh, an SPH correction factor is calculated for each homogenized region and each energy group.

- Cross sections are modified to used in subsequent calculations.

- For TDC calculations a detailed Sn solution is required
  - No benefit for air gap
  - Needed for slot region

(a) Serpent - Inserted   (b) Serpent - Withdrawn   (c) MAMMOTH Mesh

(a) Serpent   (b) MAMMOTH Mesh

So Why Not Just Use Serpent???

1. Rattlesnake is coupled to BISON (fuels performance) within MAMMOTH.
   - Rattlesnake calculates fluxes to get power density for an assumed temperature
   - Bison uses power density to calculation temperature distribution
   - MAMMOTH updates cross sections for temperature distributions
   - Rattlesnake recalculates fluxes
   - MAMMOTH iterates to convergence
   - Not needed at critical but at power the core has a temperature distribution
   - Multi-physics solution is imperative for resolution of physics of experiments inside core

2. Rattlesnake directly solves the time-dependent form of the transport equation with delayed neutrons to simulate power excursions with control rod motion.

3. Rattlesnake's diffusion solution is much faster than a Serpent solution for the same domain.

4. Streaming to the hodoscope and interactions in the target have poor statistics

5. TREAT is the most thermal of thermal systems. Slow tracking in MC.

Moving Forward

- Dr. Leslie Kerby has already presented her work on BISON-Serpent coupling
- Within the next year we hope to have a converged solution for TREAT at power with BISON and Serpent.
- Serpent now has delayed neutron solutions that to Ville's work/Serpent 2.1.27
- Work is underway to allow Serpent is able to calculate a anisotropic diffusion coefficient in the future.
- Weighted delta tracking research under Dr. Kerby will perhaps accelerate Serpent solutions
    - However, it may be that all the air streaming channels in TREAT will defeat delta tracking
- Sedat Goluoglu at University of Florida has coupled Monte Carlo (KENO) with the Improved Quasi-Static (IQS) method in T-ReX (formerly TDKENO)
    - He is looking at doing the same with Serpent
    - IQS requires an adjoint solution for weighting kinetics parameters
    - Perhaps these can be calculated by Serpent without an adjoint?
- Variance reduction may help with experiment and hodoscope resolution
- Transient data is available from historical TREAT operations for benchmarking.
- We will be looking at TREAT simulations with Serpent in the very near future!

QUESTIONS?