TREAT Modeling & Simulation Using PROTEUS

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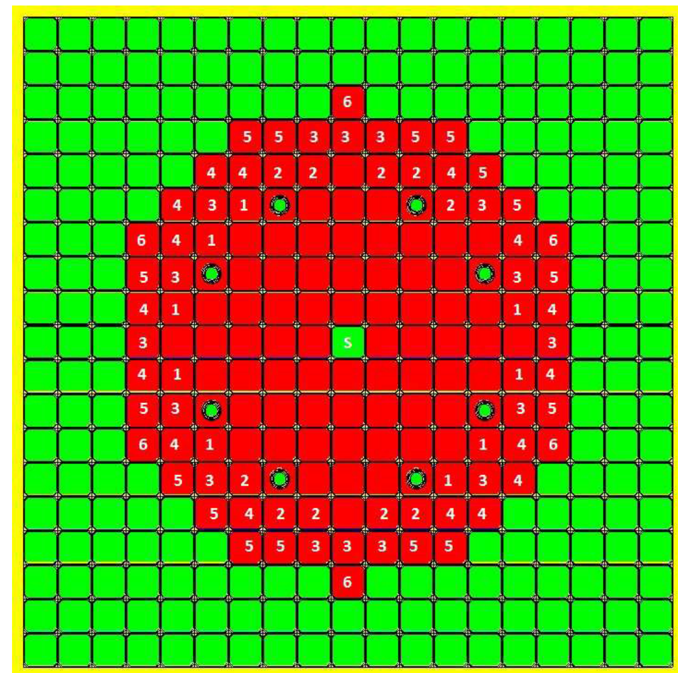
Historic TREAT Experiments: Minimum Critical Core

- Series of experiments performed in the first six months of TREAT operation
- Focused on detailed characterization of the reactor
- Data available for validation includes
  - Critical core loading
  - Approach to criticality experiment
  - Temperature coefficient of reactivity
  - Neutron flux distribution
  - Temperature distribution
- UM SERPENT model of TREAT Minimum Critical Core demonstrates good agreement in eigenvalue with MCNP model developed by ANL TREAT conversion team

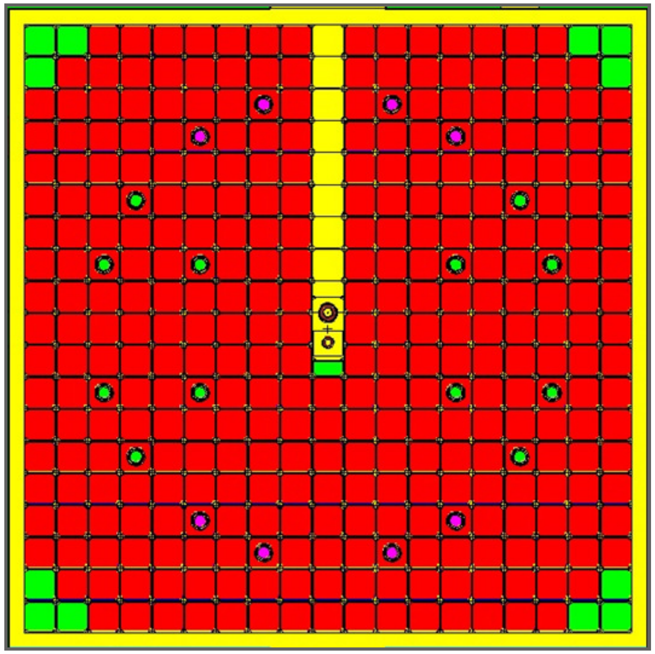


MCNP Model Indicating Loading Sequence of the Final 73 Elements in the Historic Approach to Criticality Experiment

*Figure from ANL/GTRI/TM-14/13, “Neutronics Analysis of the Minimum Original HEU TREAT Core”, D. Kontogeorgakos, et al., 2014.

Historic TREAT Experiments: M8 Power Calibration Experiment (M8CAL)

- Latest, best-documented historic TREAT experiment series
- Represents the current core loading in TREAT
- Focus of experiment series was evaluation of relationship between test sample behavior and core behavior
  - Power Coupling Factor, PCF
  - Transient Correction Factor, TCF
- Steady-state and transient power-time history data available for validation
- Irradiated samples (a) two fuel pins (U-Zr and U-Pu-Zr) and (b) flux monitor wires

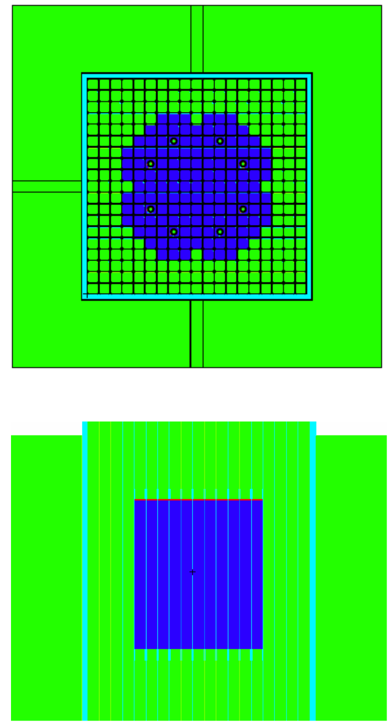


MCNP Model of Half-slotted Core Loading with Experiment Vehicle for the M8CAL Experiment Series

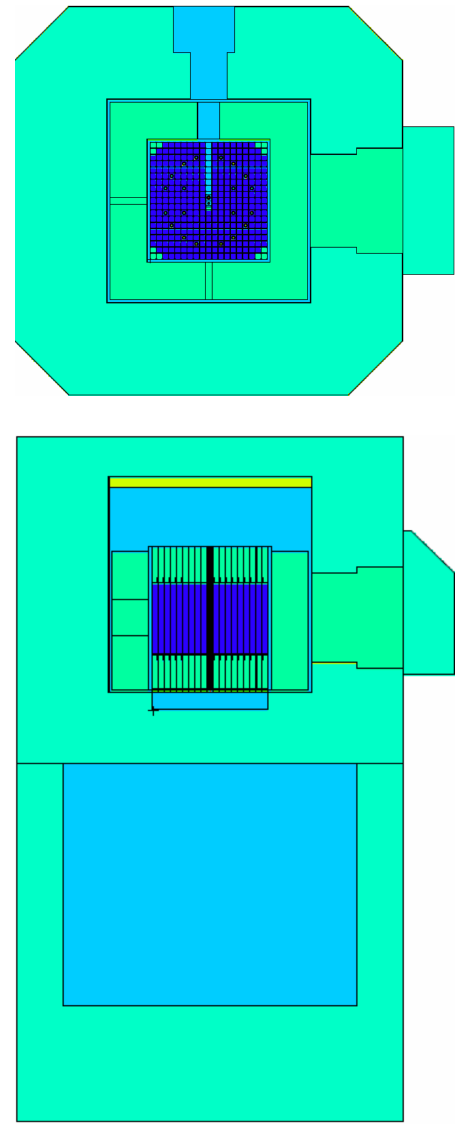
*Figure from ANL/GTRI/TM-14/11, "TREAT Transient Analysis Benchmarking for the HEU Core", D. Kontogeorgakos, et al., 2014.

PROTEUS Heterogeneous Core Models for TREAT

- Due to the geometry complexity of TREAT, we tried to convert the MCNP models using the MCNP2CAD code and then to mesh it using CUBIT
  - However, it was found to require significant effort to correct and debug misinterpreted geometries from MCNP2CAD
- As an initial effort, we decided to create 2D and 3D benchmark problems for MinCC and M8CAL, which are as close to actual geometries as possible, including the core and permanent graphite reflector only



MinCC

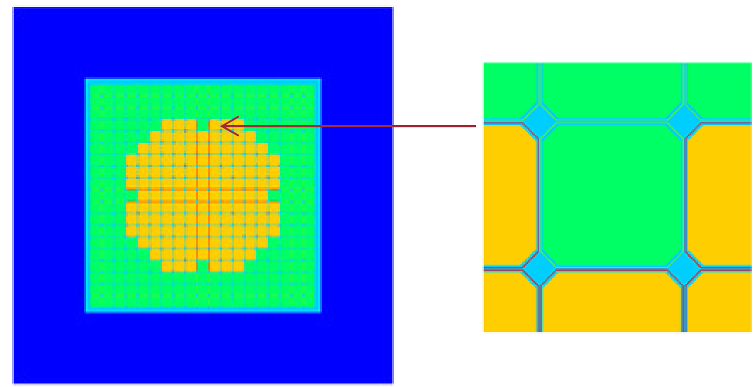


M8CAL

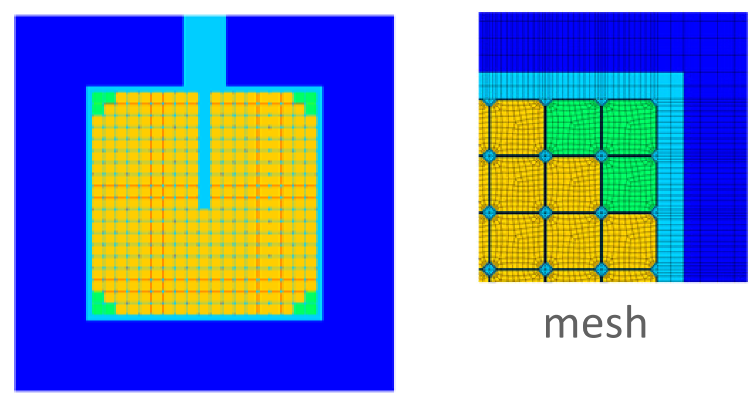
Benchmark Problems for MinCC and M8CAL

- Geometry and mesh
  - Use CUBIT to create base components (fuel, control rod blocks)
  - Use UFmesh (meshing tool of PROTEUS) to create simple geometry components (air gap, permanent graphite reflector) and merge them all for 2D or 3D problems

- PROTEUS simulation
  - To accurately treat the air channels and hodoscope in M8CAL, we use the MOCex solver (2D MOC coupled with discontinuous Galerkin finite element method axially)
  - MOCex is based on <u>an extruded geometry</u>, requiring the 2D mesh and building the 3D mesh in the code
  - MOCfe (3D MOC based on the finite element method) can be used for 2D problems, which should produce the same solutions with MOCex



MinCC

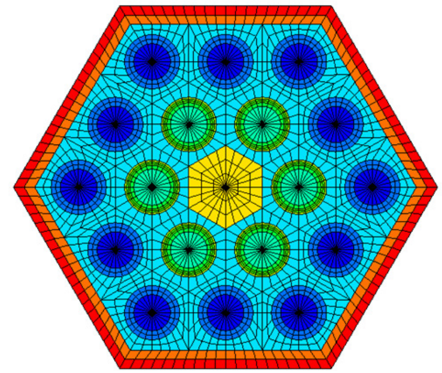


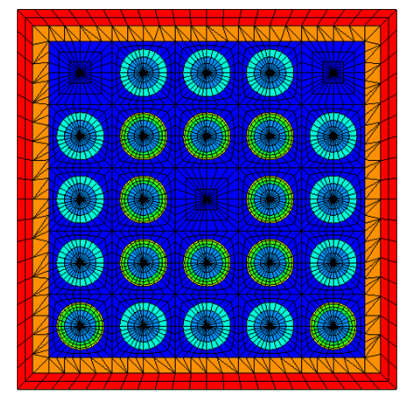
M8CAL

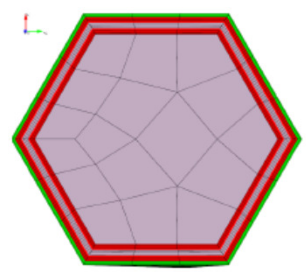
Mesh Generation (UFmesh) and Conversion Tools in PROTEUS System

- Simple pin/assembly/core meshing capability with no use of CUBIT
  - Part of PROTEUS input set
  - Reduces time for new users to start using the code
  - Easily add boundary layer meshing
  - Easily control meshing within each pin-cell and assembly for standard Cartesian and hexagonal type based cores

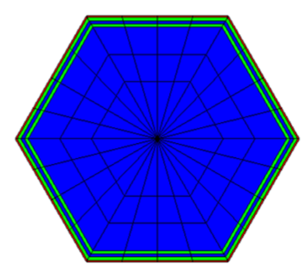
- Various mesh conversion tools
  - Easily merge meshes
  - Easily alter basis function expansions
  - Axially extrude 2D meshes into 3D meshes
  - Perform volume and surface checks on the mesh
  - Generate visualizations for debugging purposes





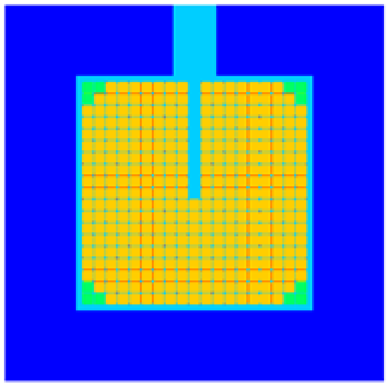


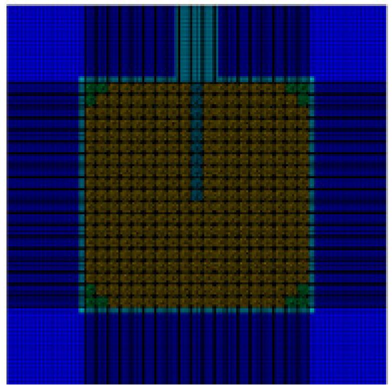
CUBIT mesh

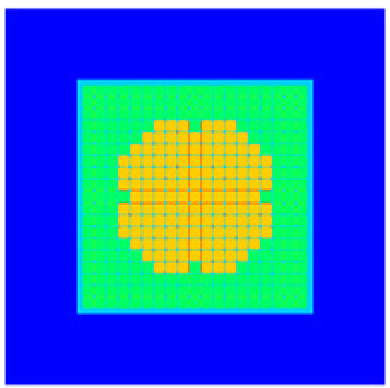


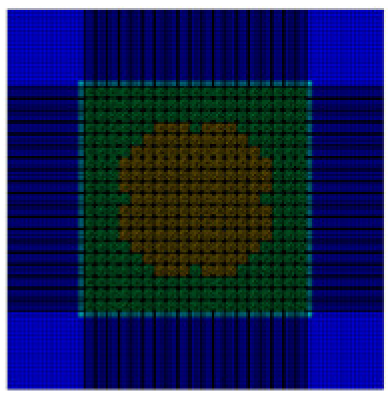
UFmesh

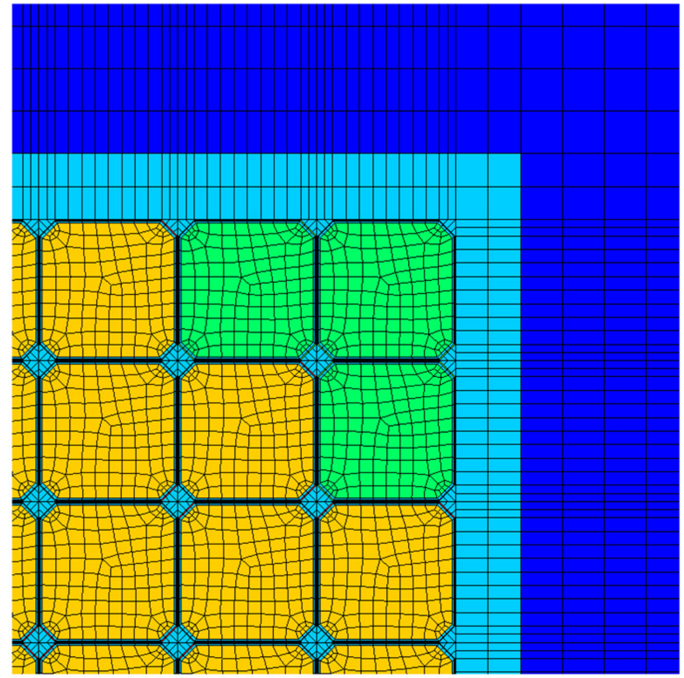
Meshes for MinCC and M8cal

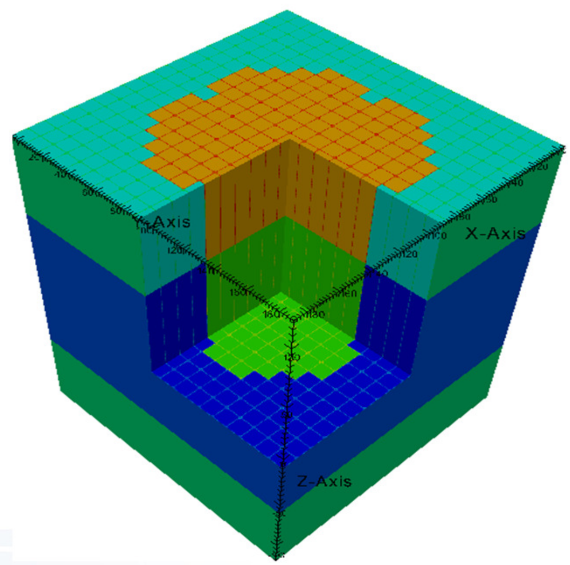












PROTEUS-MOCex

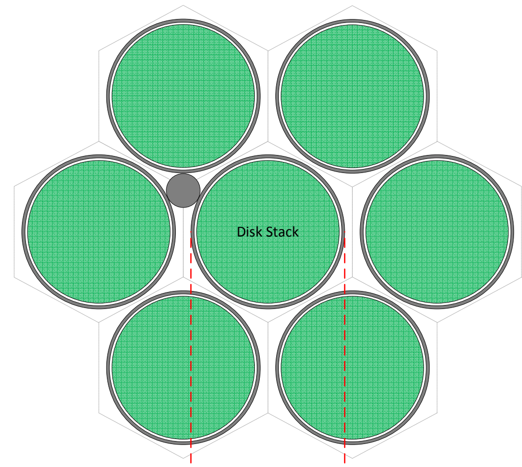
- 3-dimensional Method of Characteristics : 2-D MOC combined with the discontinuous Galerkin FE method for the treatment of the axial variable
  - Eliminate the synthesis approach adapted in the 2-D/1-D method (DeCART, MPACT, …)
  - Use the extruded geometry
- 3-D Transport equation with axial basis functions

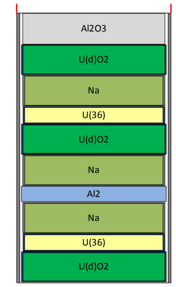
$$\left(\mu_m \frac{\partial}{\partial x} + \eta_m \frac{\partial}{\partial y} + \xi_m \frac{\partial}{\partial z}\right)\varphi_i^m(x,y,z) + \Sigma_i \varphi_i^m(x,y,z) = Q^m(x,y,z)$$

$$\varphi_i^m(x,y,z) \simeq \sum_j \varphi_{i,j}^m(x,y)\,\mathrm{u}_i^j(\mathrm{z}), \quad Q_i^m(x,y,z) \simeq \sum_j Q_{i,j}^m\,\mathrm{u}_i^j(\mathrm{z})$$

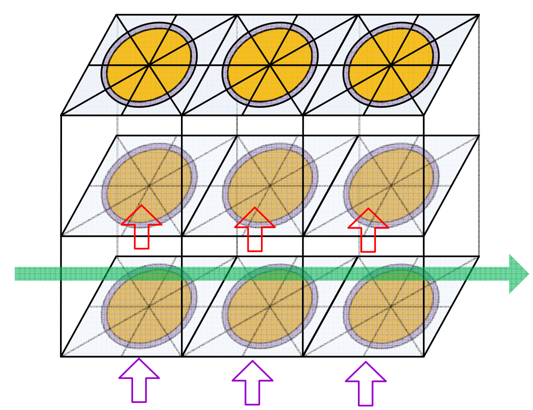
$$\sum_j \left(\mu_m \frac{\partial \varphi_{i,j}^m(x,y)}{\partial x} + \eta_m \frac{\partial \varphi_{i,j}^m(x,y)}{\partial y}\right) u_i^j(z)$$

$$+\sum_j \xi_m \varphi_{i,j}^m(x,y)\frac{\partial u_i^j(z)}{\partial z} + \sum_j \Sigma_i \varphi_{i,j}^m(x,y) u_i^j(z) = \sum_j Q_{i,j}^m u_i^j(z)$$





BFS Fuel



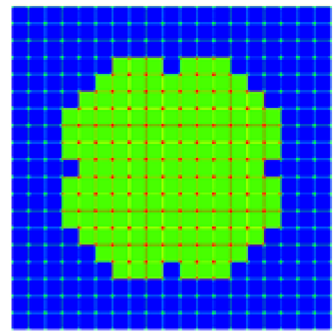
Preliminary Results

- Cross sections
  - Serpent / GenISOTXS : 9-group cross sections
  - The cross section API of PROTEUS with the cross section library (online cross section generation)
- 2D problems
  - No control rods were modelled for these tests
  - The MOCfe solver of PROTEUS with Serpent 9-group cross sections was used
  - Good agreement in eigenvalue with Serpent

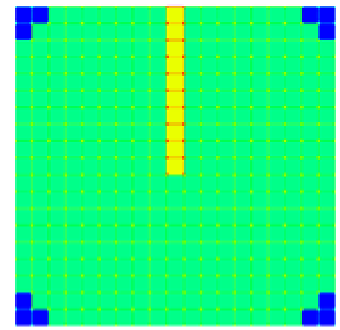
Case	Serpent	PROTEUS	Δk, pcm
Fuel Block	1.68269	1.68286	17
MinCC	1.36104	1.36043	-61
M8CAL	1.67182	1.67164	-18

* Serpent standard deviation: < 15 pcm

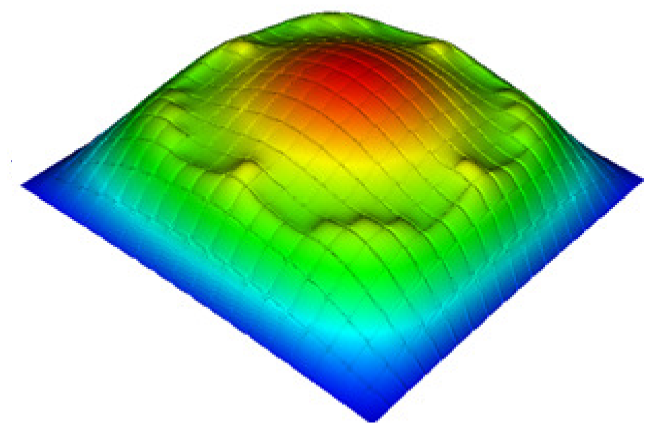
- 3D problems
  - Ongoing work using the MOCex solver of PROTEUS



MinCC



M8CAL



Group Fluxes from PROTEUS for MinCC Benchmark