INL/MIS-18-51511-Revision-0

Performance Prediction of Irradiated TREAT Fuel

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Performance Prediction of Irradiated TREAT Fuel

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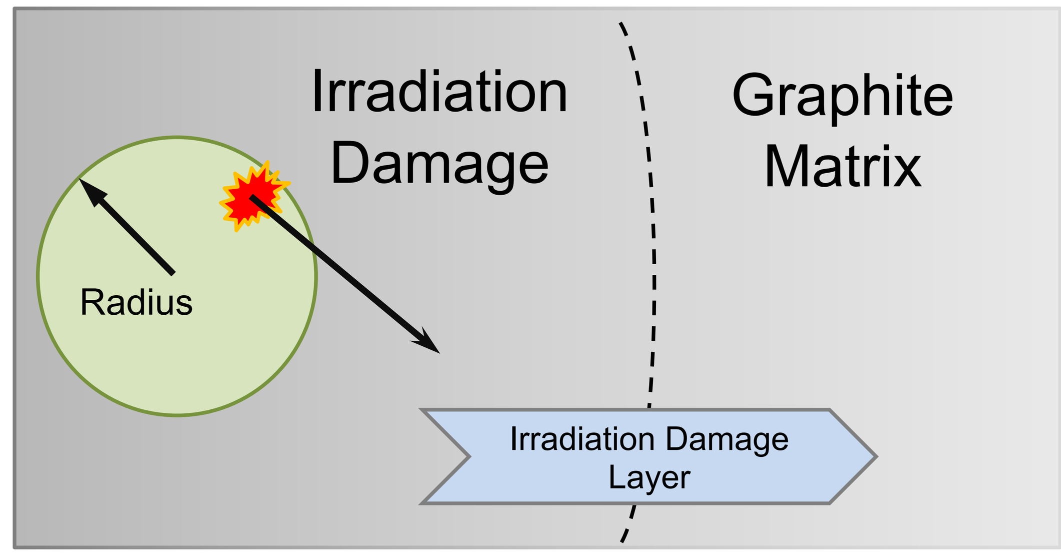
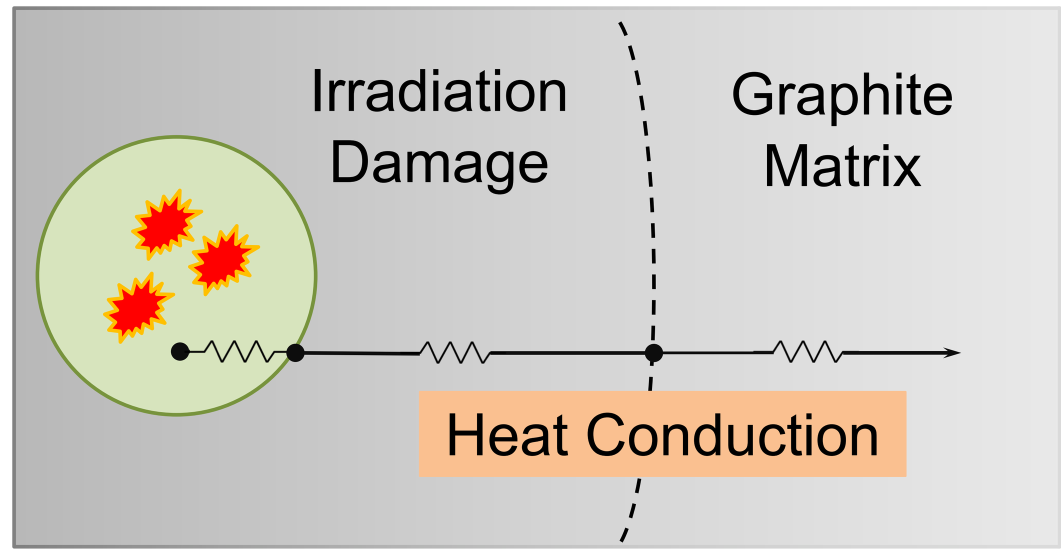
How Irradiation Affects TREAT Pulses

- TREAT microscopic fuel consists of UO_2 particles surrounded by a graphite matrix
- Fission fragments produced in the periphery of the particle travel into the graphite causing irradiation damage
- Fission fragment irradiation layer develops around particle over time

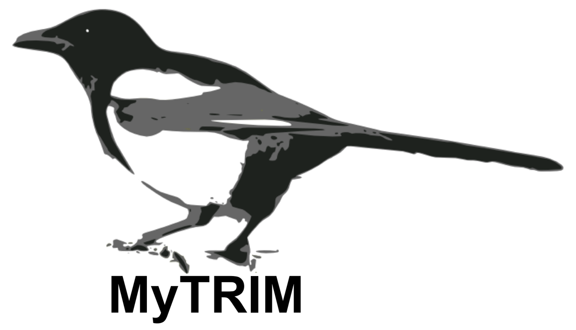


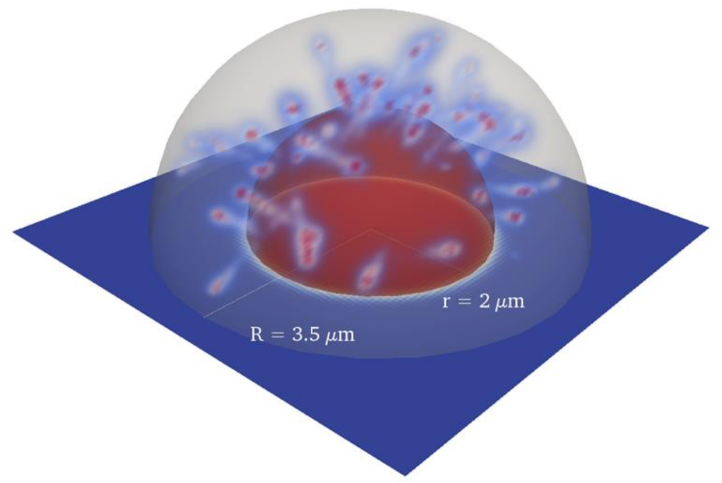
- Irradiation damaged graphite has reduced thermal properties: 41.8 W/mK saturates at 1.046 W/mK (1)
- Acts as serial thermal resistor increasing the temperature of the particle during pulses
- Some fission energy ballistically transported by fission fragments leaving the particle
- Particle size influences irradiation damage layer



Calculating Displacements per Atom (dpa)

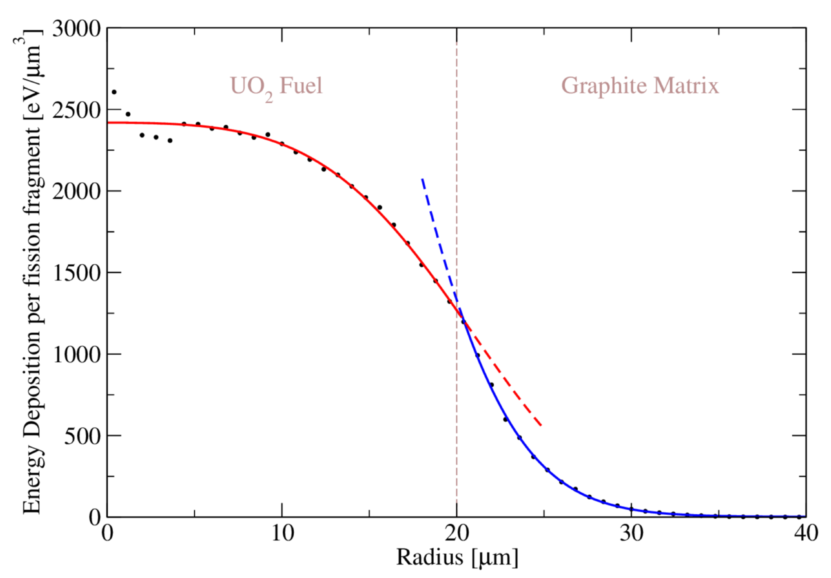
Mesoscale Atomistic Glue Program for Integrated Execution (Magpie)



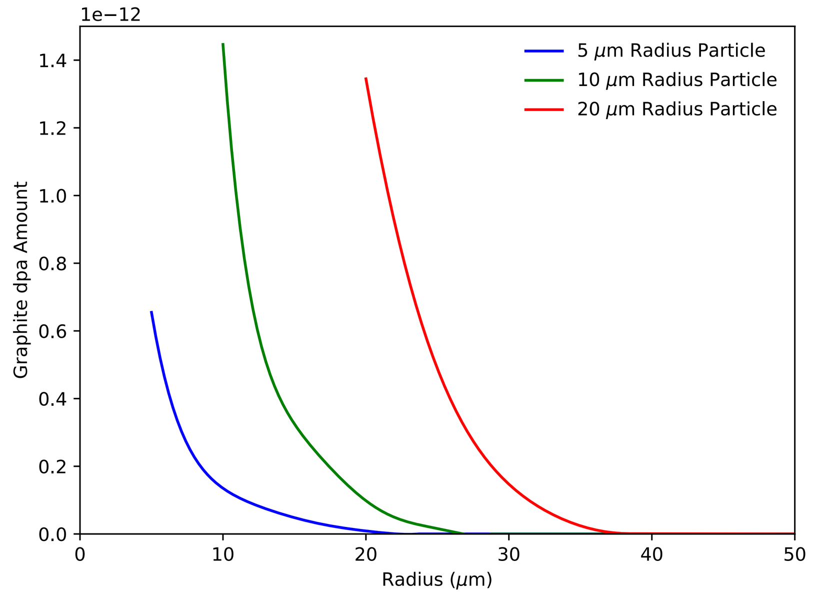


- Magpie polynomial fits provide:
  - Ballistic transport fission energy deposition distribution
  - Graphite dpa distribution away from particle for single EOS pulse(1)
- Magpie tracking of oxygen interstitials
- Reducing particle radius increases number of particles in TREAT fuel reducing local particle fission events

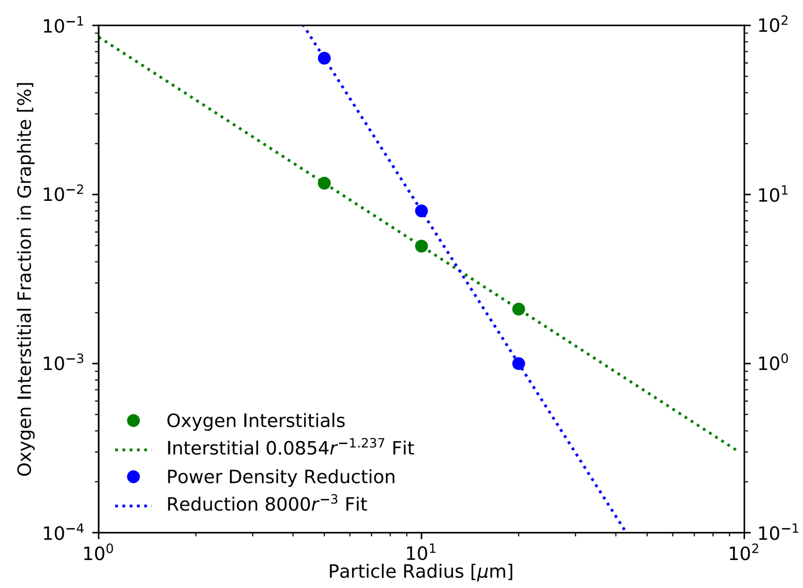
Energy Deposition from Ballistic Transport



Graphite dpa Produced in Single EOS Pulse



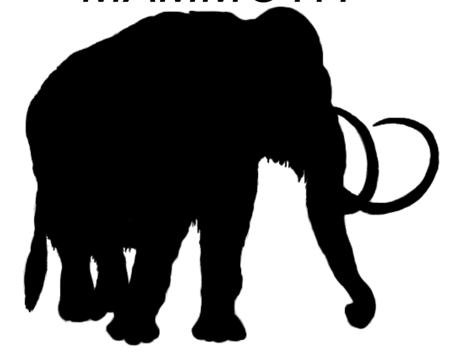
Irradiation Damage Increase Versus Particle Fission Decrease



Simulating Pulses with Varying Damage

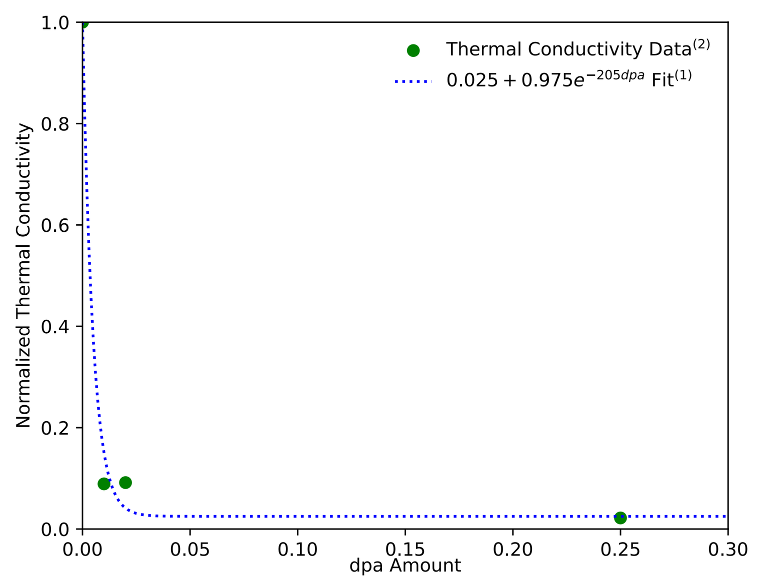
- MAMMOTH couples heat conduction solution with results from Magpie
- Compare temperature difference of particle to graphite (a.k.a. time lag)
- Requires graphite dpa reduction of thermal conductivity correlation from <200 °C experiments(3)
  - Normalized for TREAT graphite data(1)

MAMMOTH

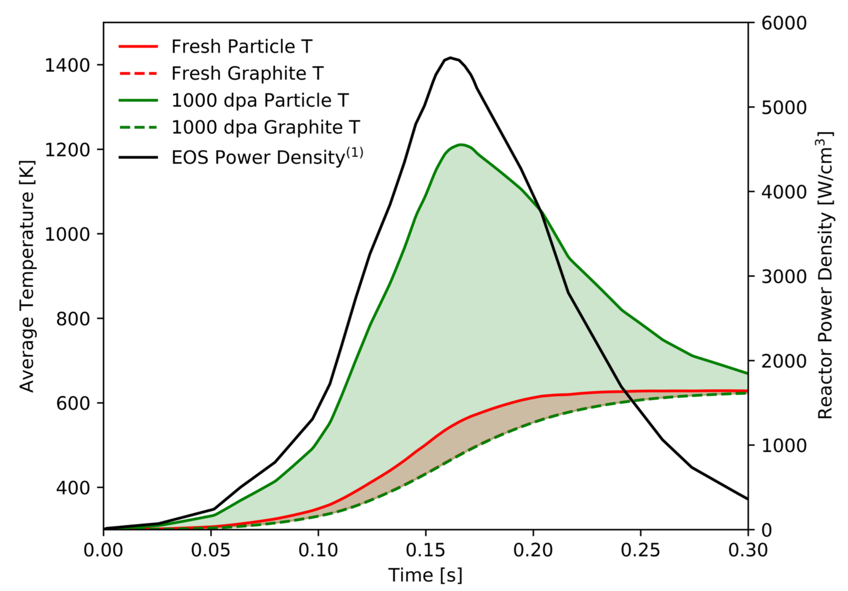


- Single EOS pulse produces 2.6 GJ(3)
- TREAT operated 35 years before shutdown producing 2,600 GJ(3)
- Assume every pulse is a 2.6 GJ TREAT EOS pulse
- Assume all particles are a single size
- TREAT operates with reduced thermal properties from irradiation damage

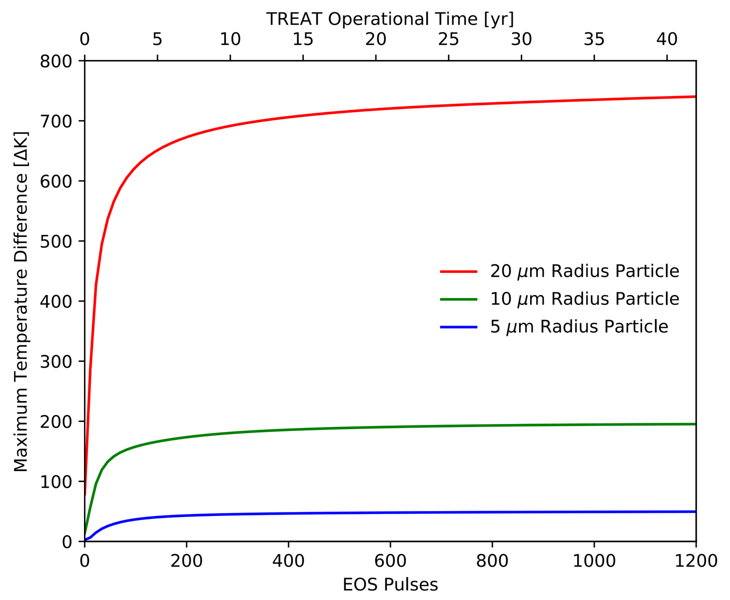
Correlation of dpa to Thermal Conductivity Degradation



Two 20 μm Radius MAMMOTH Results



Temperature Difference with Irradiation



Conclusions

- ➢ Larger particles receive more irradiation damage than smaller particles
  - ➢ Fissions per particle increase by r^3 as particle size increases
  - ➢ Graphite damage increases by $r^{-1.237}$ as particle size decreases
- ➢ Temperature difference is larger in larger particles
- ➢ Temperature differences increases with irradiation damage over time
- ➢ Larger particles experience larger increases in peak particle temperatures

Future Work

- ❑ Take into account graphite annealing during pulse
- ❑ Include effect on feedback through multi-physics coupling
- ❑ Improve correlation between fission fragment damage and degraded thermal properties of graphite

(1) K. Mo, et al., "Heat transfer simulations of the UO_2 particle-graphite system in TREAT fuel," *Nucl. Eng. Des.*, ***293***, *Supplement C*, 313 (2015)

(2) T. Maruyama and M. Harayama, "Neutron irradiation effect on the thermal conductivity and dimensional change of graphite materials," *J. Nucl. Mater.*, ***195***, 44 (1992)

(3) J. Carmack, "Future Transient Testing of Advance Fuels," INL/EXT-09-16392, Idaho National Laboratory, Idaho Falls, ID 83415 (2009)