Effects of Boron and Graphite Uncertainty in Fuel for TREAT Simulations

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Introduction

- Due to the accident at Fukushima there is renewed interest in accident tolerant fuel (ATF).
- 2012 - Congress laid out a schedule for development of ATF to be tested in a commercial reactor by 2022.
- Idaho National Lab's (INL) Transient Reactor Test Facility (TREAT) will be performing ATF testing and is scheduled for restart in 2018
- Pre-test calibrations are required before evaluation of fuel can begin
- Full core TREAT simulations to understand the pre-test core and minimize required calibrations
- To simulate TREAT with a high degree of precision the reactor materials must also be modeled with a high degree of precision

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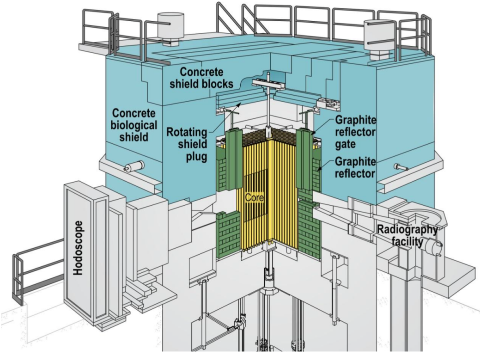
Transient Reactor Test Facility (TREAT) Overview

- Air-cooled, graphite moderated
- Simulate accident conditions
- No resultant core damage
- UO_2 fuel particles in graphite matrix
- 93.1% HEU

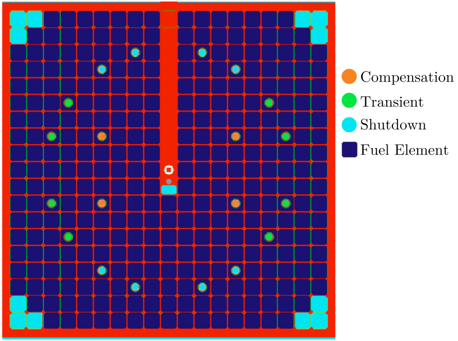


Graphite Uncertainty

- Graphite matrix isn't just graphite
- Only 59% of carbon in fuel is graphite.
- Crystal structure is a complex mixture of graphite particles in non-graphitized elemental carbon matrix
- **How is this important?**
    - Graphite/carbon matrix acts as moderator
    - Graphitized and non-graphitized carbon have different scattering cross sections
    - Effects moderation

Graphite Uncertainty

- Found to be 59% $\pm$ 1% graphite to total carbon ratio (GCR)
- Most of TREAT core is graphite/carbon matrix fuel elements
- Is this material uncertainty a concern for simulation?



Boron Uncertainty

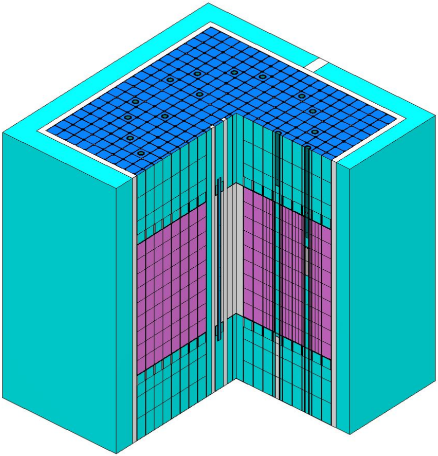
- Material blocks used to construct the fuel only had a boron content very close to 1 ppm
- Fuel contains boron impurity of 5.90 ± 0.35 ppm
- **How did this happen?**
  - Diffusion of boron from borated steel divider plates in baking crucibles used in manufacturing fuel
- **Why does this matter?**
  - Boron is a strong neutron absorber
  - Small differences in boron can affect criticality

Our Problem

Does this uncertainty in materials effect our ability to simulate TREAT?

KENO-VI TREAT Models

- Model created with KENO-VI
- Model based on the M8CAL configuration.
- ENDF/B-VII.1 238 M.G. cross section library



KENO-VI TREAT Models

- 9 Models with same geometry, but different material compositions
- 3 Boron groups each with 3 graphite to carbon ratio (GCR) values
- Evaluated at given value, upper bound, and lower bound

	Boron Concentration (ppm)		
GCR	5.55	5.90	6.25
0.58	Model 1	Model 2	Model 3
0.59	Model 4	Model 5	Model 6
0.60	Model 7	Model 8	Model 9

Results - Pre-transient Core k_{eff}

- Each model evaluated with KENO-VI from SCALE 6.2.1
- 5000 generations, 500 skipped generations, and 20000 particles per generation

Boron (ppm)	GCR	k_{eff}
5.55	0.58	0.998748±0.000086
5.55	0.59	0.998389±0.000089
5.55	0.60	0.998168±0.000086
5.90	0.58	0.9958145±0.000085
5.90	0.59	0.995317±0.000085
5.90	0.60	0.995224±0.000084
6.25	0.58	0.992791±0.000089
6.25	0.59	0.992341±0.000094
6.25	0.60	0.992209±0.000087

Results - Pre-transient Core k_{eff}

- Increased GCR yields decrease in k_{eff}
- Max difference in k_{eff} due to GCR $\approx 6 \times 10^{-4}$

Boron (ppm)	**GCR**	k_{eff}
5.55	0.58	0.998**748**±0.000086
5.55	0.59	0.998**389**±0.000089
5.55	0.60	0.998**168**±0.000086
5.90	0.58	0.995**8145**±0.000085
5.90	0.59	0.995**317**±0.000085
5.90	0.60	0.995**224**±0.000084
6.25	0.58	0.992**791**±0.000089
6.25	0.59	0.992**341**±0.000094
6.25	0.60	0.992**209**±0.000087

Results - Pre-transient Core k_{eff}

TREAT
Graphite
Boron
Problem
Models
K
2855
Conclusion

- Increased boron impurity yields decrease in k_{eff}
- Max differences in k_{eff} due to boron impurity $\approx 6 \times 10^{-3}$

Boron (ppm)	GCR	k_{eff}
5.55	0.58	0.998748$\pm$0.000086
5.55	0.59	0.99**8389**$\pm$0.000089
5.55	0.60	0.998168$\pm$0.000086
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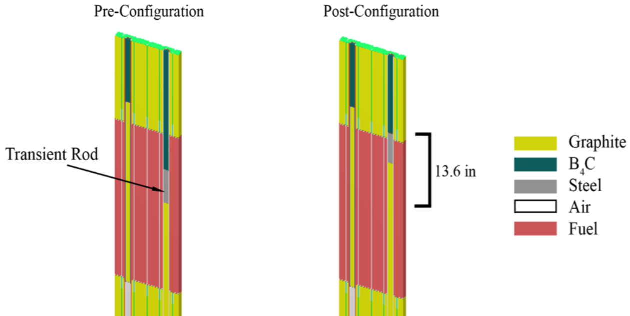
Simulation of Transient #2855

- Simulation of temperature-limited transient #2855 from M8CAL.
- Experiment designed to aid in calibration of TREAT core.
- Initial power of 10W
- 60 second transient time
- Transient rods removed at t=0, completely removed by 0.13 seconds, and remain so for the duration of the experiment.

Simulation of Transient #2855

- Evaluated with T-ReX (formerly TDKENO), time-dependent neutron transport code
- Run on University of Florida's HiperGator computer on 64 cores
- 5000 generations, 500 skipped generations, and 20000 particles per generation
- ENDF/B-VII.1 238 M.G. cross section library



Results - Boron - Peak Power

- Higher peak power with lower boron concentration
- Difference in peak power between 5.55 ppm and 6.25 ppm was 108 MW

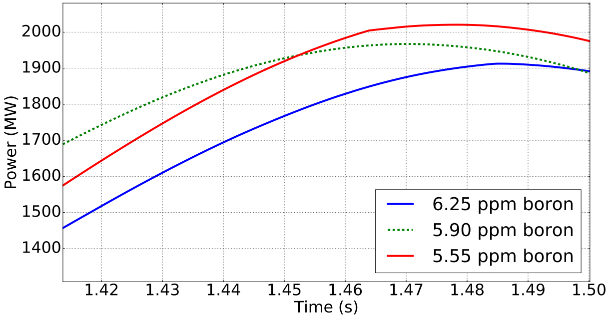


Figure: Power vs Time - 59% Graphite

Results - Boron - Yield

- Higher yield with lower boron concentration
- Difference in final yield between 5.90 ppm and 6.25 ppm was 12.18 MJ

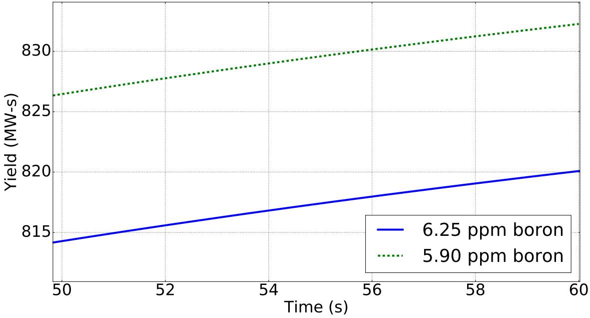


Figure: Yield vs Time - 59% Graphite

Results - Graphite - Yield

- Clear trend in k_{eff} vs GCR of pre-transient core
- But not for final yield

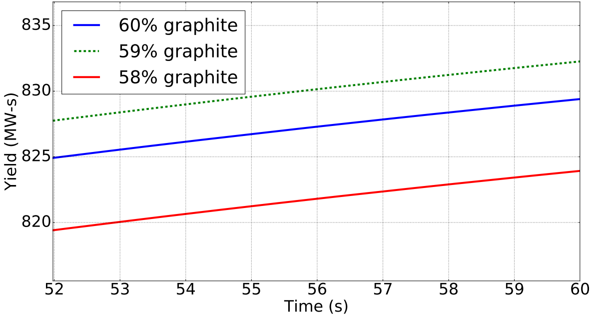


Figure: Yield vs Time - 5.90 ppm Boron

Results - Graphite - Peak Power

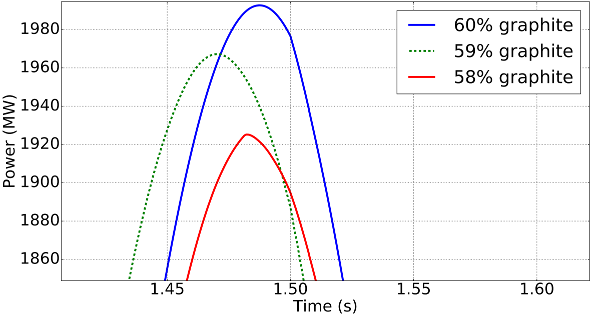


Figure: Power vs Time - 5.90 ppm Boron

Results - Graphite - Peak Power

- Need further work to verify graphitization effects

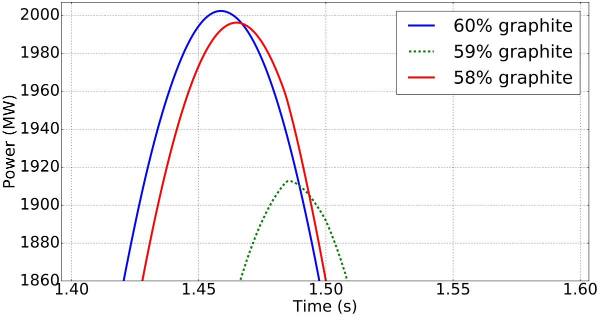


Figure: Power vs Time - 6.25 ppm Boron

Conclusion

- Uncertainty in boron content effects ability to simulate TREAT
- $\pm$ 0.35 ppm boron corresponds to $\pm$ 50 MW peak power and $\pm$ 12 MJ final yield
- $\pm$ 2.5% peak power, $\pm$ 1.5% final yield
- Need further work to verify effect of graphitization

Questions?