Preliminary Design of Temperature Dependent Critical Experiments at Atmospheric Pressure with Low Enriched UO_2 Fuel

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Outline

- Introduction
- Thermal expansion / compression and equilibrium
- Evolution of k_{eff} with temperature and moderator density for existing room temperature benchmark configurations
- Potential temperature dependent critical configurations
- Conclusions and future work

Introduction

- Motivation
  - Provide more integral data to validate on-the-fly Doppler energy broadening
  - Temperature dependence at atmospheric pressure with low enriched UO_2 applicable to spent nuclear fuel (pools, storage casks, etc.)
- Concept
  - Start with existing SNL critical experiments (7uPCX and BUCCX)
  - Modify these to be critical at different temperatures
  - Preliminary design shows that temperature dependent critical experiments are viable using these existing experiments
    - Note: LCT-079 benchmark uncertainty ~100 pcm

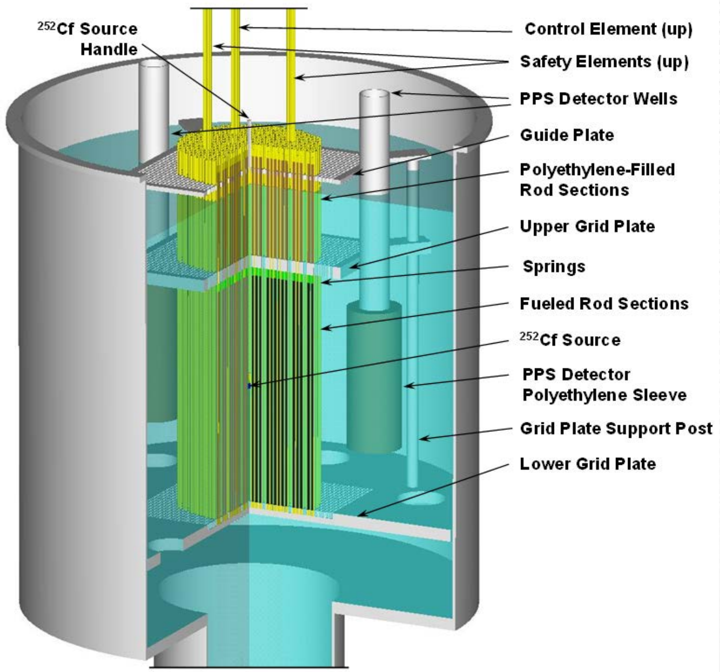

Figure 1. Critical assembly concept of the 7uPCX (thanks Gary).

Thermal Expansion / Compression and Equilibrium

- Concerns when modeling a temperature dependent experiment
  - What is the temperature and is the system temperature homogenous?
  - When the system temperature changes, how does the volume / density change?
- Strategy
  - Find linear expansion coefficients in the open literature and calculate volume expansions
  - Model materials at different temperatures
- At the temperatures and pressures of interest the change in volume and density is insignificant, <u>except for the water moderator / reflector</u>

Case	keff	Sigma (pcm)	k_{eff} difference (pcm)
LCT078 Case 1 at 25 °C	0.99820	21	0
95 °C without thermal expansion	0.98782	21	19
95 °C with thermal expansion	0.98801	21	
All materials at 95°C	0.98782	21	182
Only water at 95°C	0.98964	21	
For all simulations, the water density was correct for the given temperature			

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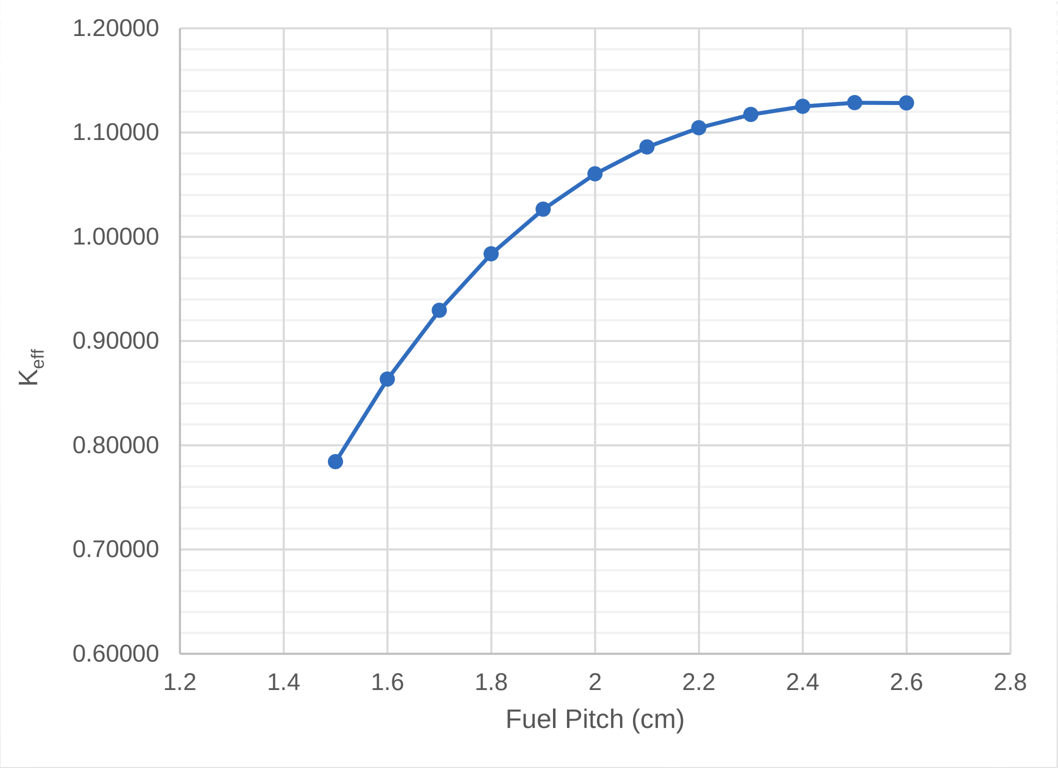
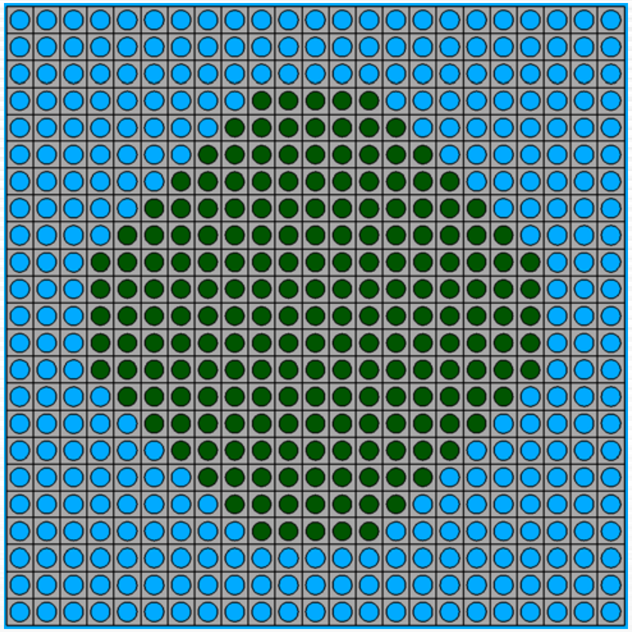
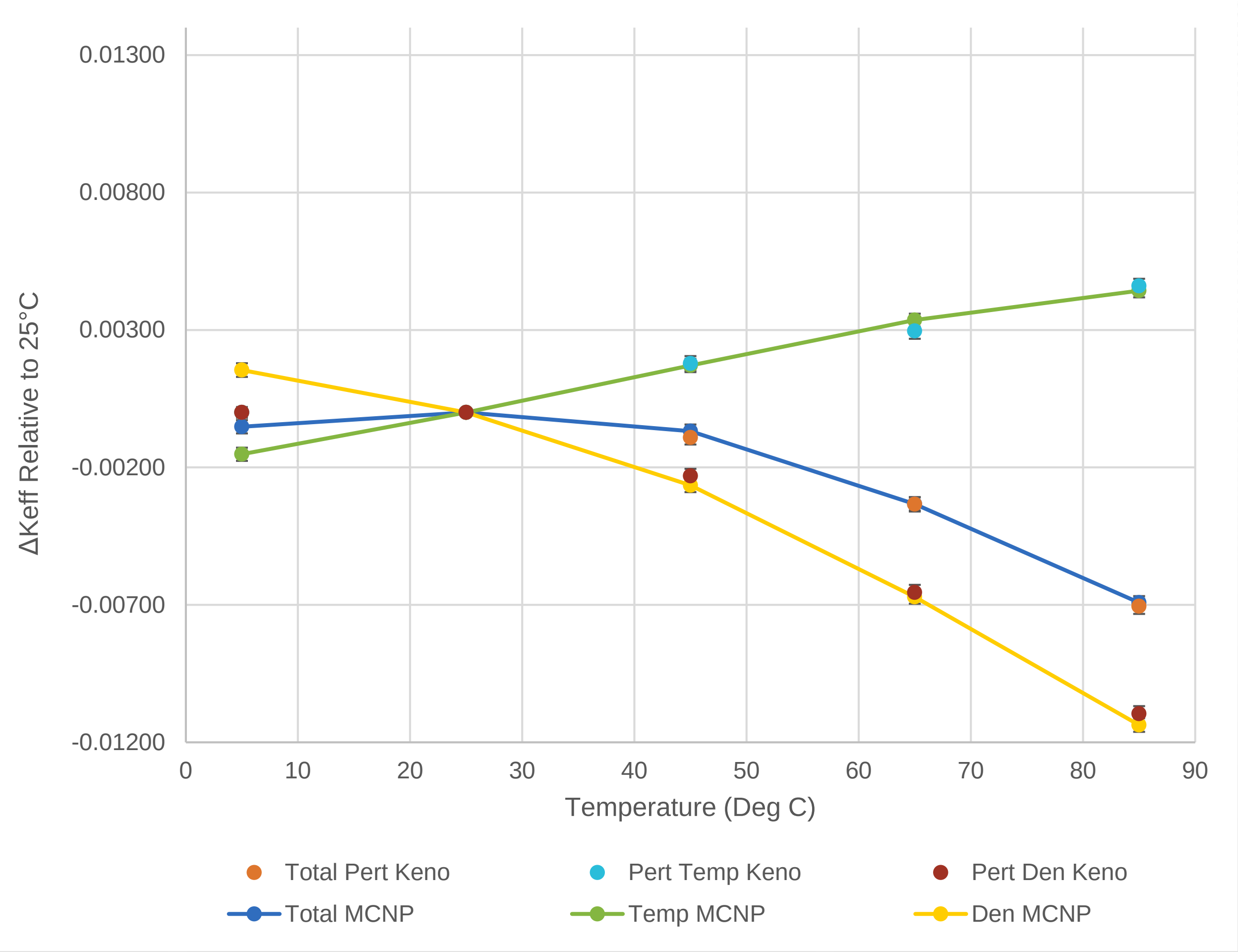
Decision to use BUCCX fuel rods

- After the preliminary design it was decided to focus on the BUCCX fuel rods
  - Enrichment, diameter, and cladding are close to typical commercial fuel today
- Current BUCCX grid plates use triangular pitch
- Designs moving forward based on square pitched BUCCX grid plates with a 2.0 cm pitch
  - Square pitch is similar to commercial reactors, but the pitch is larger than commercial reactors



Under Moderated Configuration Evolution of k_{eff} with Temperature (BUCCX Fuel – 205 Rods – k=0.99955 ±0.00019 @25°C)





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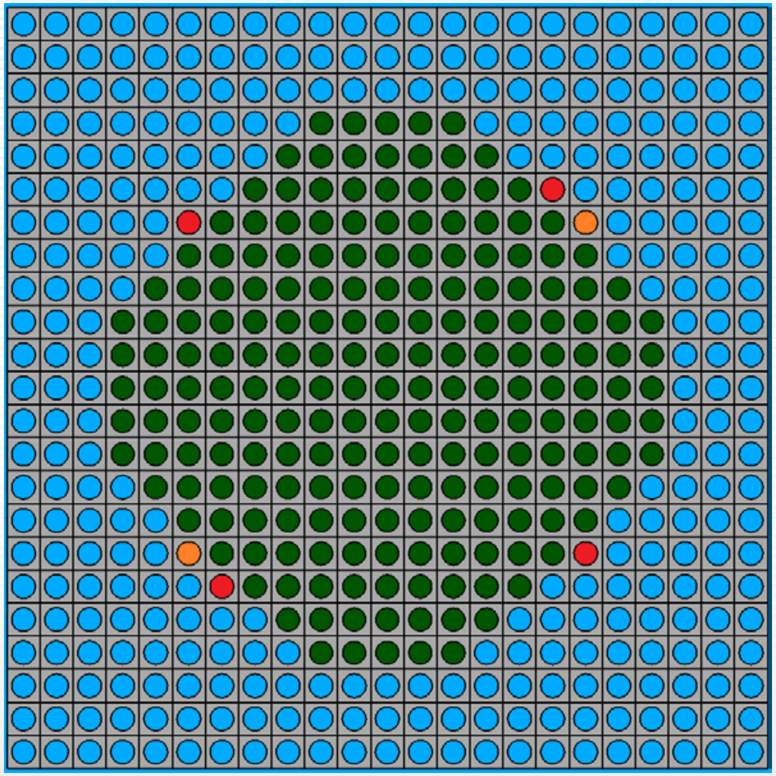
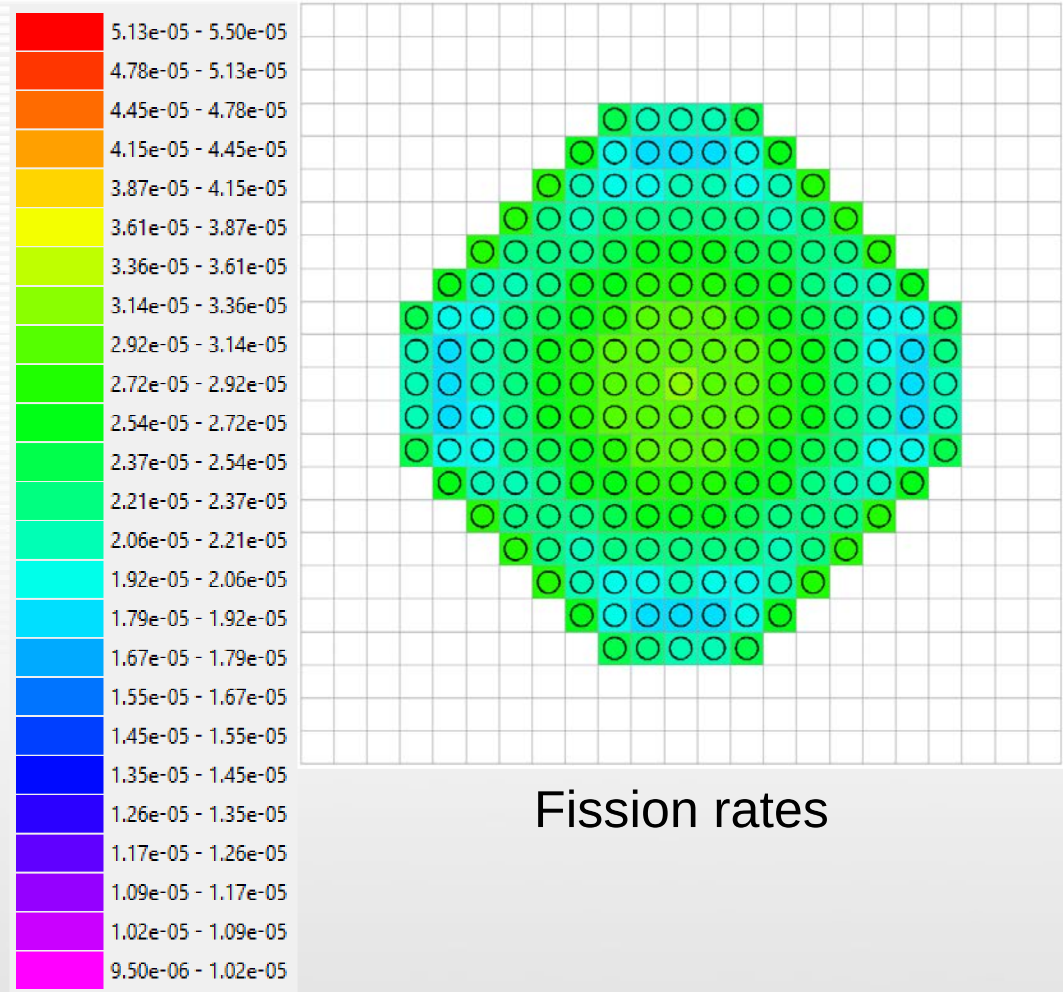
Under Moderated Critical Configurations (Compared to 25°C)



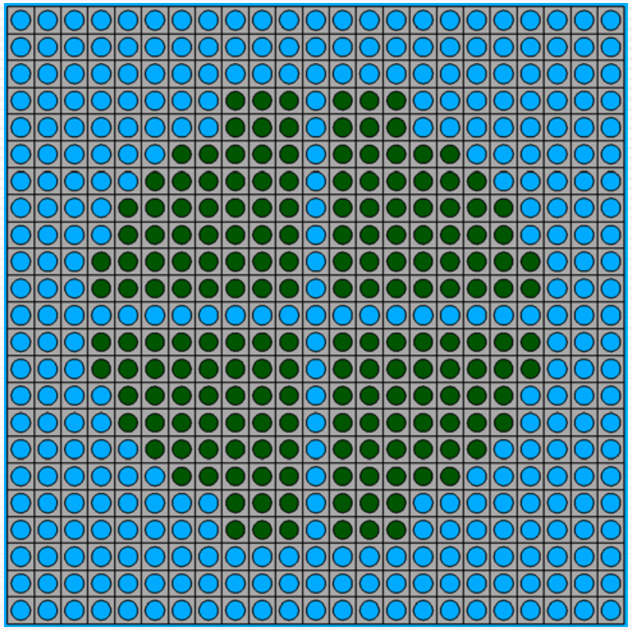
Add at 65°C

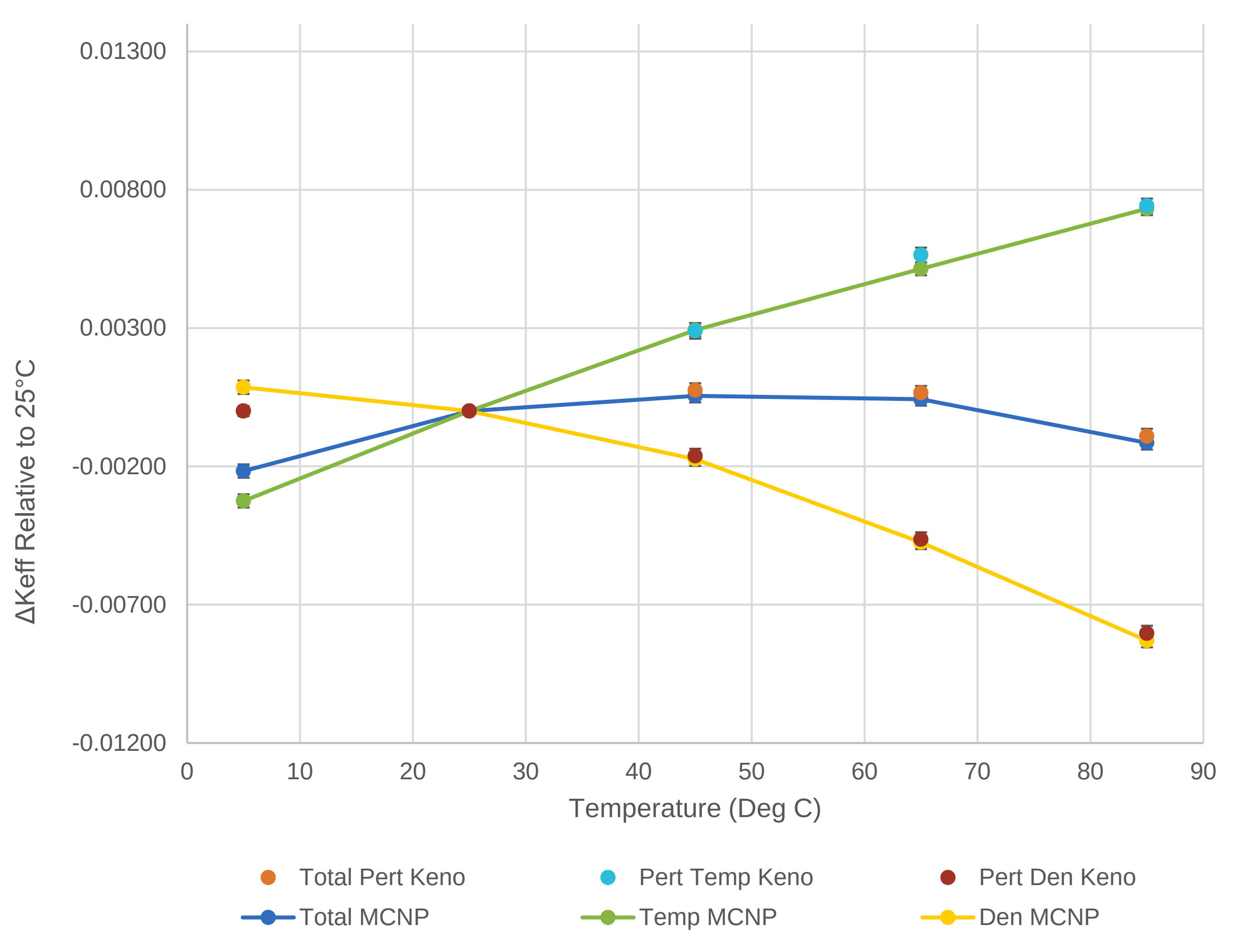
Add at 85°C



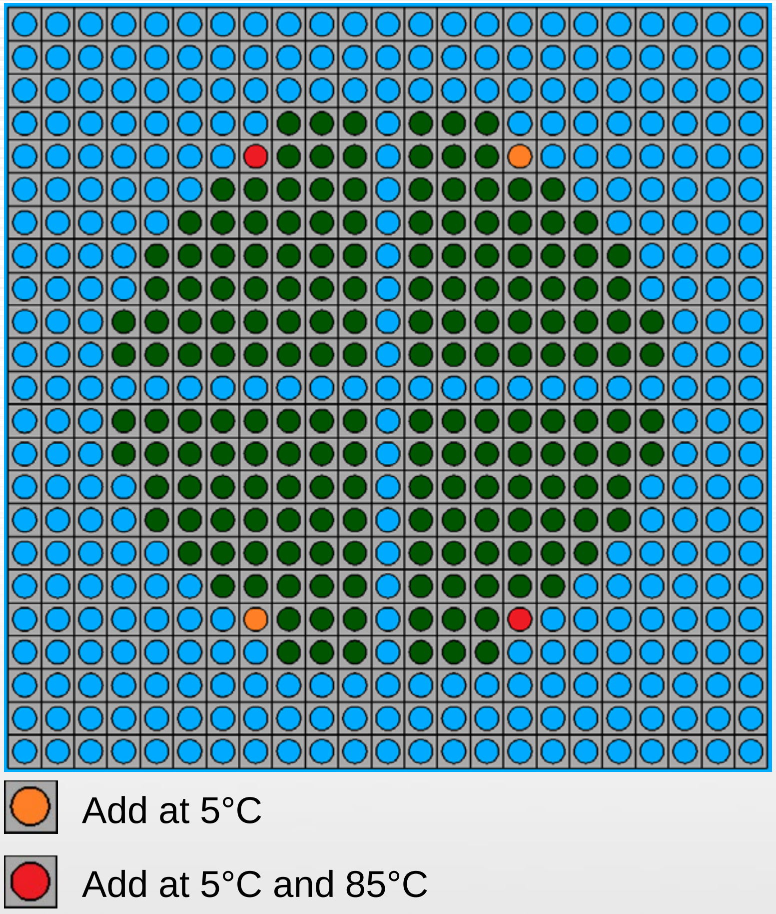
Fission rates

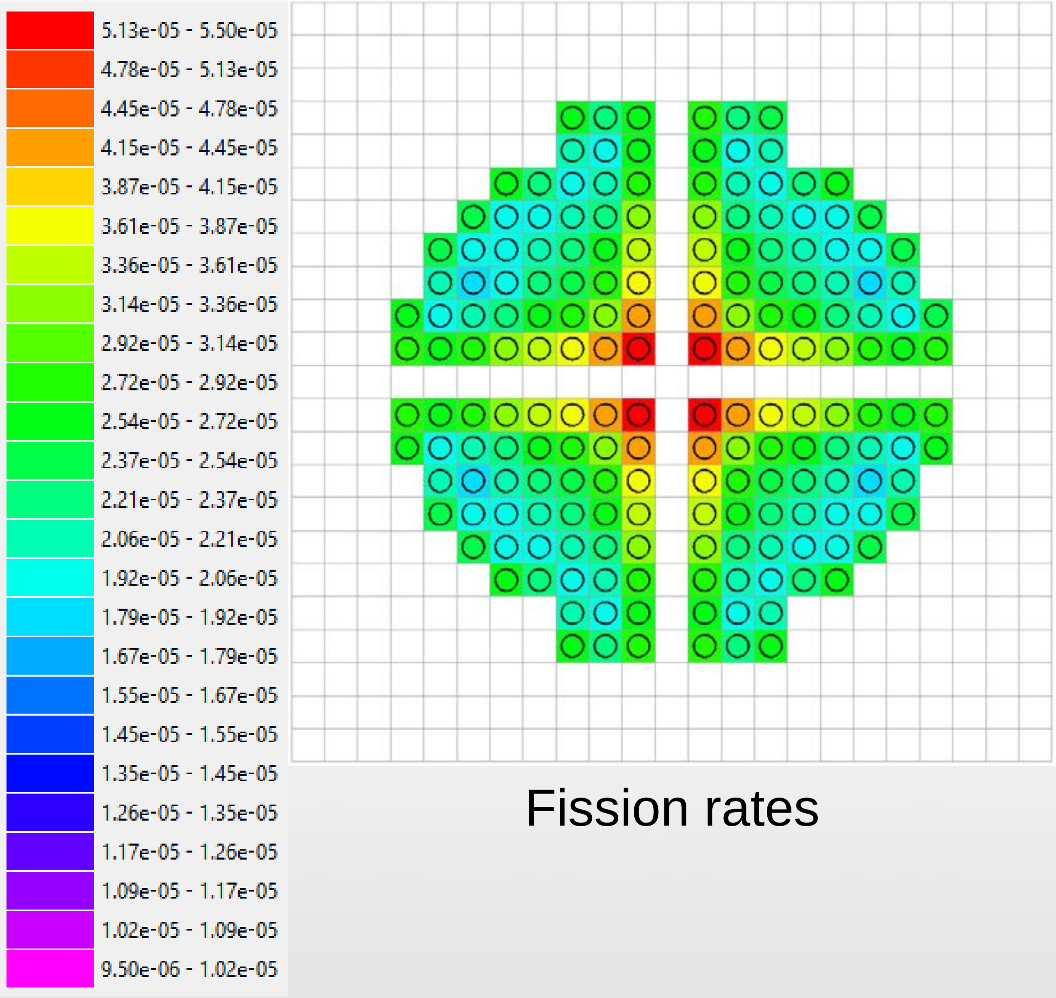
Optimum Moderation Configuration Evolution of k_{eff} with Temperature (BUCCX Fuel – 188 Rods – k=0.99757 ±0.00018 @25°C)





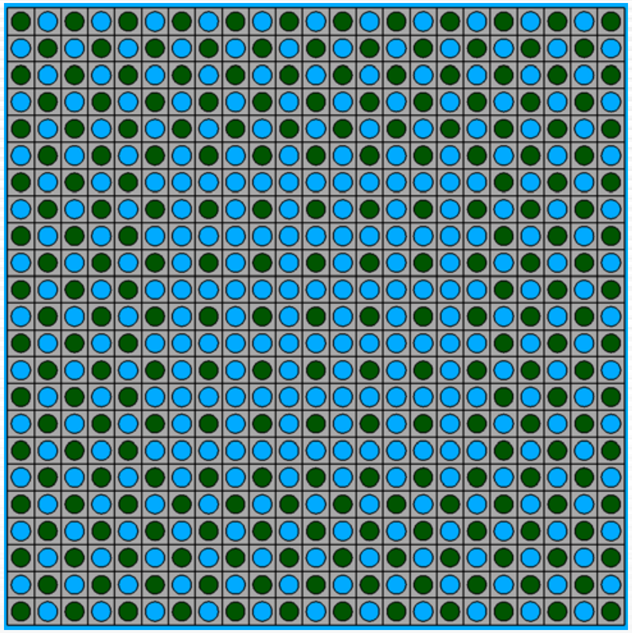
Optimum Moderation Critical Configurations (Compared to 25°C)

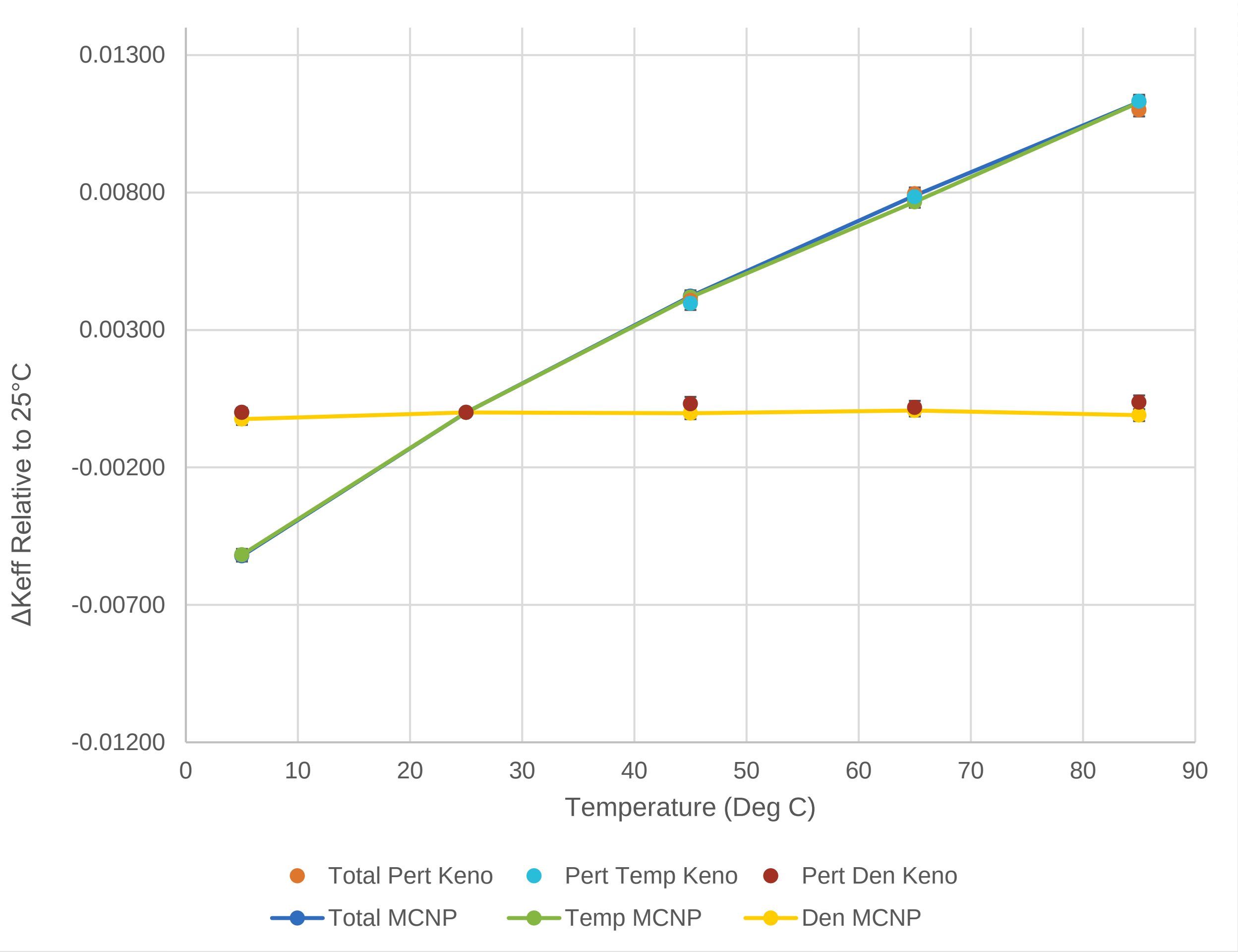




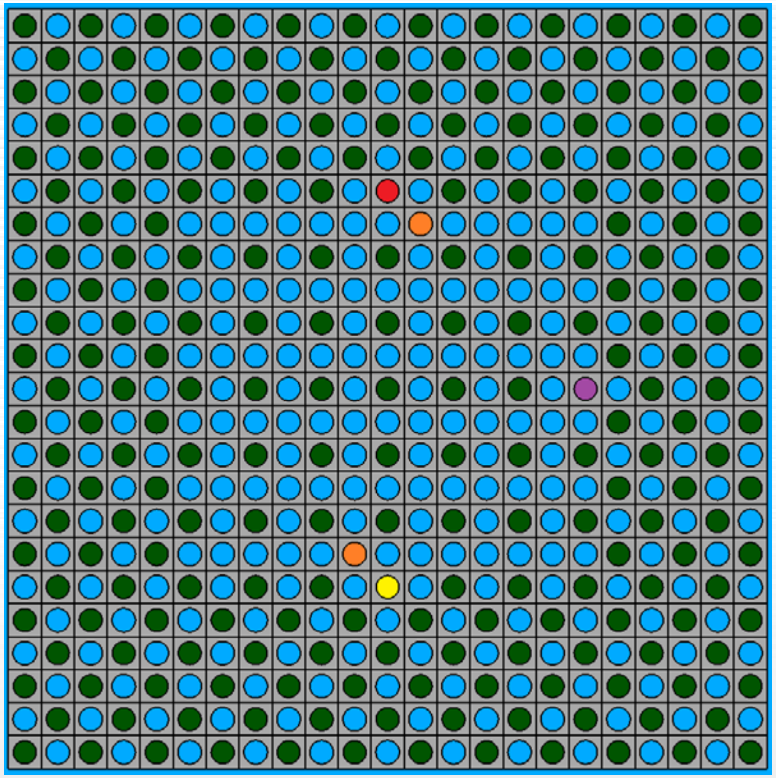
Fission rates

Over Moderated Configuration Evolution of k_{eff} with Temperature (BUCCX Fuel – 229 Rods – k=0.99834 ±0.00017 @25°C)

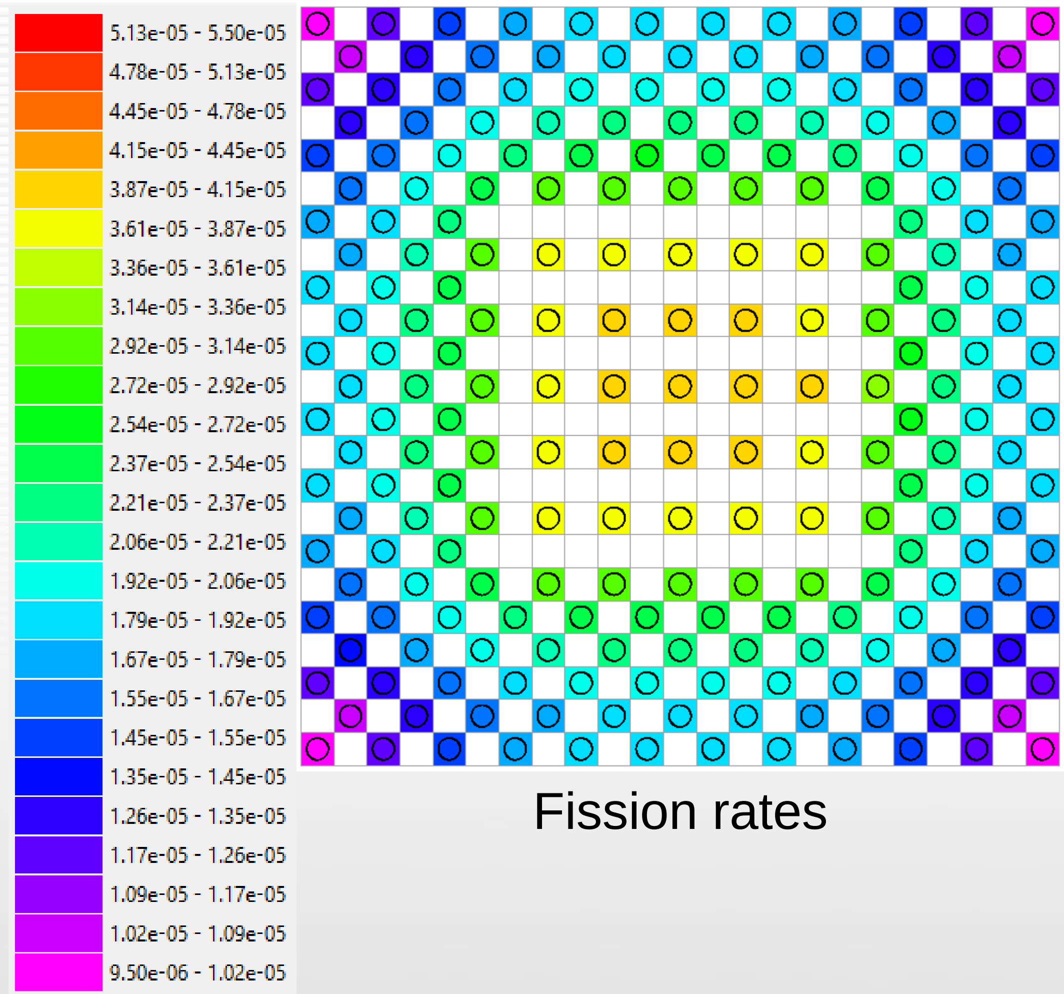




Over Moderated Critical Configurations (Compared to 25°C)



- Add at 5°C
- Remove at 45°C
- Remove at 65°C
- Remove at 85°C



Fission rates

Temperature Uncertainty Analysis is Underway

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- For these 3 configurations, temperature perturbations (±2°C & ±5°C) have been made to the fuel and everything else (bulk) to determine sensitivity
- Uncertainty for all simulations ~10 pcm
- Fuel
  - For all 3 configurations the ±5°C perturbations produced results that were statistically equivalent within 2 sigma – small sensitivity
- Bulk
  - Larger sensitives for all 3 configurations, but not necessarily all temperatures
  - Small sensitivity: optimum moderation configuration at 45°C and 65°C
  - Large sensitivity: $(^{\Delta k}/_{\Delta T})$ ~ 0.0002 for over moderated configurations
- Uncertainty in k_{eff} $\sigma_k = (^{\Delta k}/_{\Delta T})\sigma_T$
  - LCT-079 Rev. 1, 2.0 cm pitch BUCCX fuel: σ_k^{Temp} 3 pcm, σ_k^{Total} 102 pcm
  - If one desires a similar σ_k^{Temp}, σ_T must be 0.15°C or less
  - If σ_T were 1°C, σ_k^{Temp} would be 20 pcm, which would make σ_k^{Total} 103 pcm
  - Obviously, this all assumes the other LCT-079 sensitivities and uncertainties do not change

Conclusions and Future Work

- Conclusions
  - For configurations investigated, changes in temperature at atmospheric pressure without boiling produced experimentally interesting changes in k_{eff}
  - Uncertainties at this time are expected to be very similar to LCT-078 & 79 (7uPCX & BUCXX) – assuming temperature is homogenous and temperature measurement error 1°C or less
- Future work
  - Final design due at the end of FY18 Q4
    - An extension will be requested
  - Continue S/U analysis of new configurations to remove assumption that uncertainties will be similar to LCT-078 & 79
  - Perform simulations to determine time to reach thermal equilibrium
  - Perform KENO calculations with temperature gradients in the experiments to estimate uncertainties if temperatures are no homogenous
  - Design options to heat, cool, and insulate Sandia critical assembly

Questions?

- This work was funded by the US DOE Nuclear Criticality Safety Program
- Acknowledgments
  - Skip Kahler generated the temperature dependent H in H_2O thermal scattering data for MCNP
  - Charles Daily generated all the other temperature dependent cross section data for MCNP