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A Study of Temperature Feedback in the DARWIN Core Concept with Comparison of Monte Carlo and Deterministic Approaches

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Outline

- Motivation and introduction
- Computational model and procedure
- Criticality analysis
- Burnup analysis
- Conclusions

Motivation

- Climate changes & severe weather events
- Electrification → increase demand for electricity
- Intermittent renewable energy sources

Flexible needs

But today's reactors (mostly) for base-load electricity production ONLY

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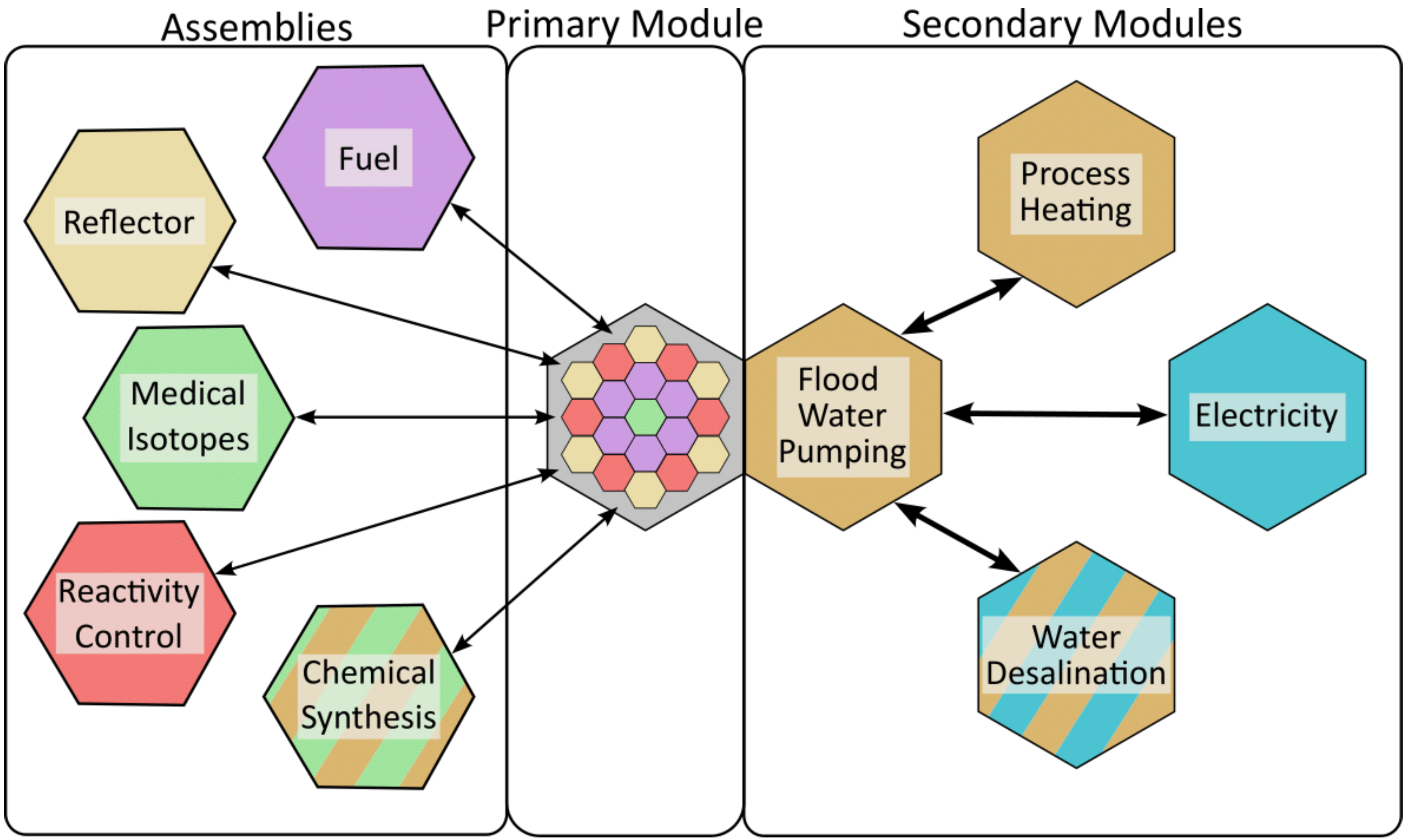
Motivation

- Adaptive design for flexible needs
- Dispatchable Adaptive Reactor With Interchangeable compoNents



Introduction

- First step to DARWIN design

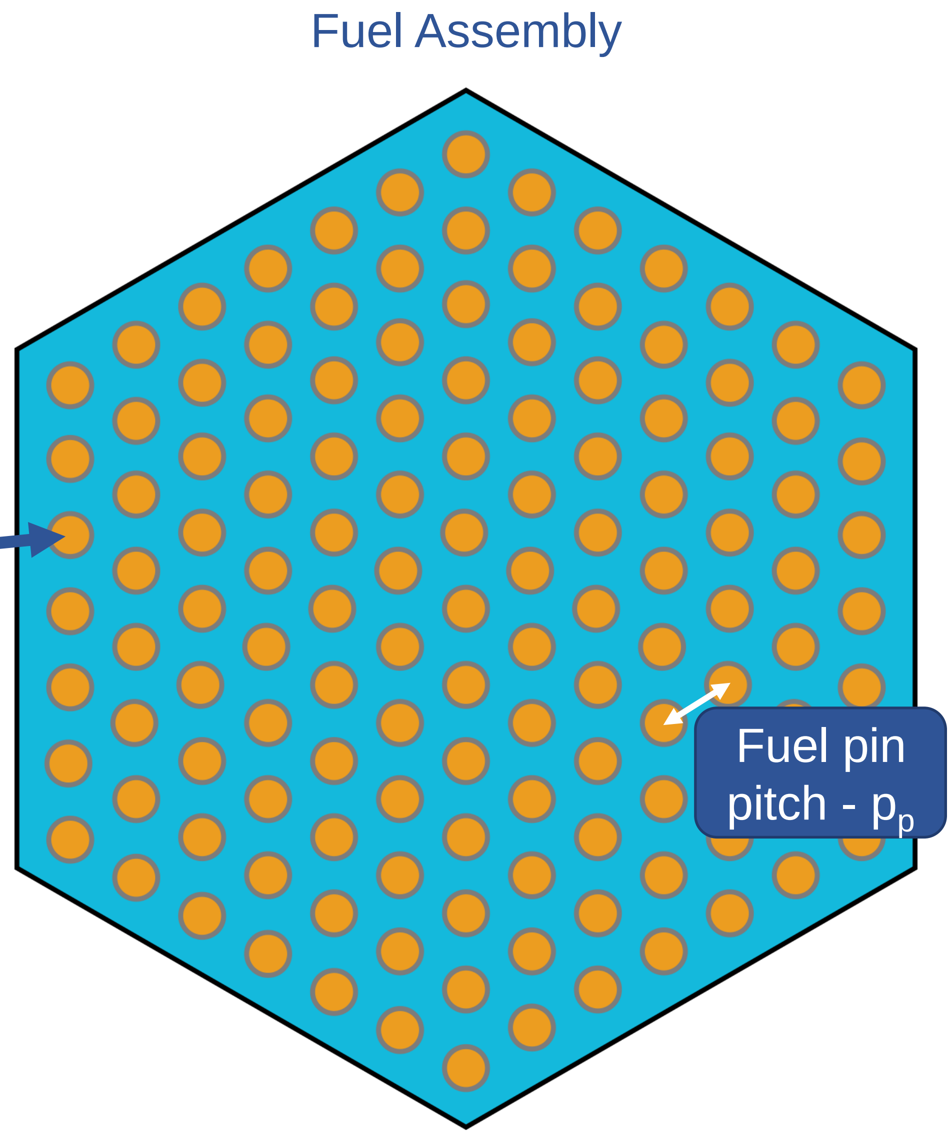
- Phase space research:
  - Fuel pin pitch
  - Fuels
  - Reactivity control
  - …

- Boundary conditions:
  - $k > 1$
  - $\alpha < 0$
  - Φ
  - Peaking factors
  - …

- Why Ants?
  - Deterministic code → high calculation speed
  - Hexagonal geometry is enabled

Computational model

- 2D:
  - Parametric analysis
  - Computational speed
- Hexagonal geometry:
  - Efficient space utilization
  - Uniform power distribution
- Fuel pin:
  - 3 % enriched UO_2
  - Gap with He
  - Zircaloy-4 cladding



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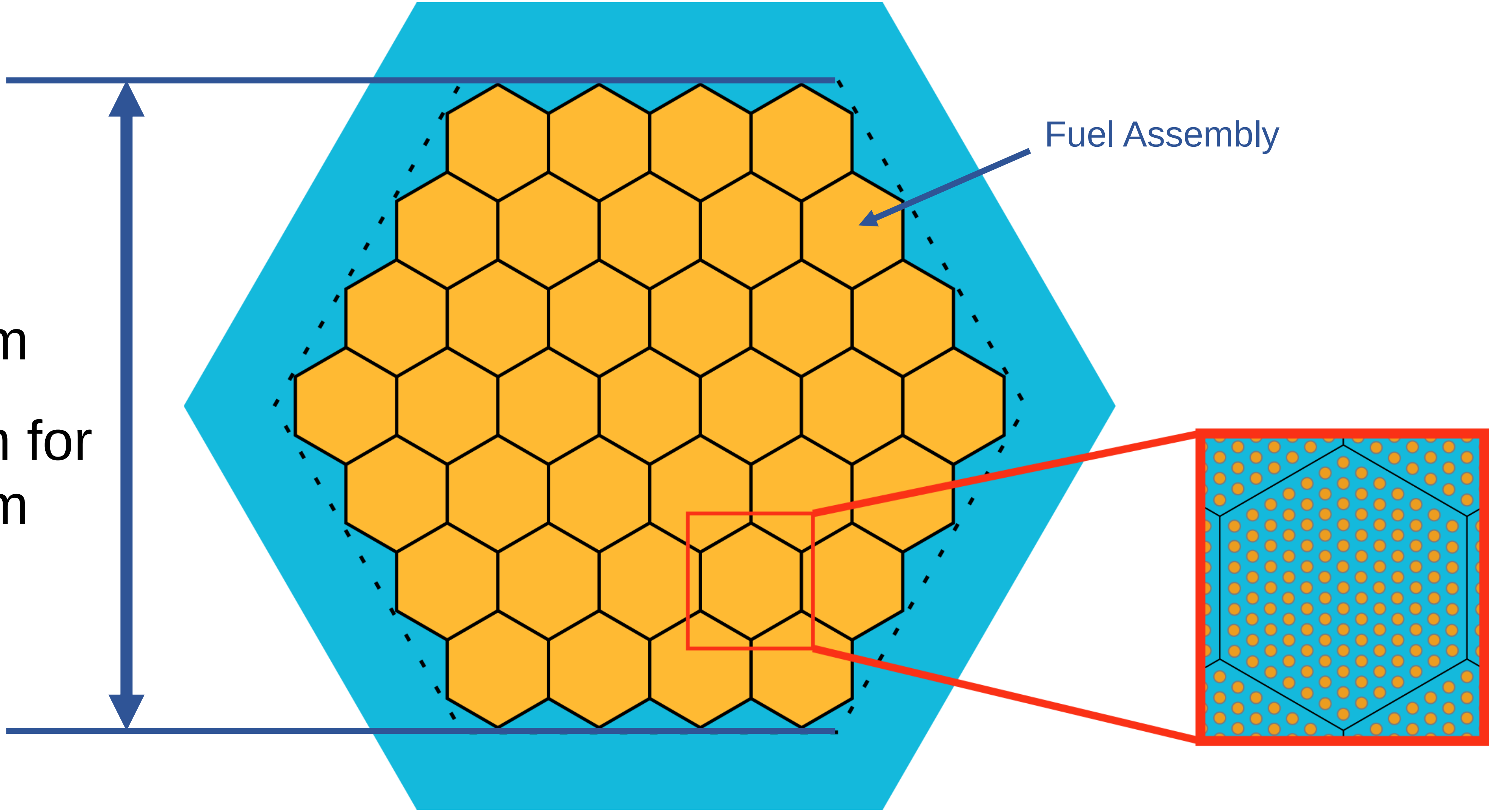
Computational model

- 113 cm for $p_p = 1.00$ cm
- $d_c = 260$ cm for $p_p = 3.00$ cm



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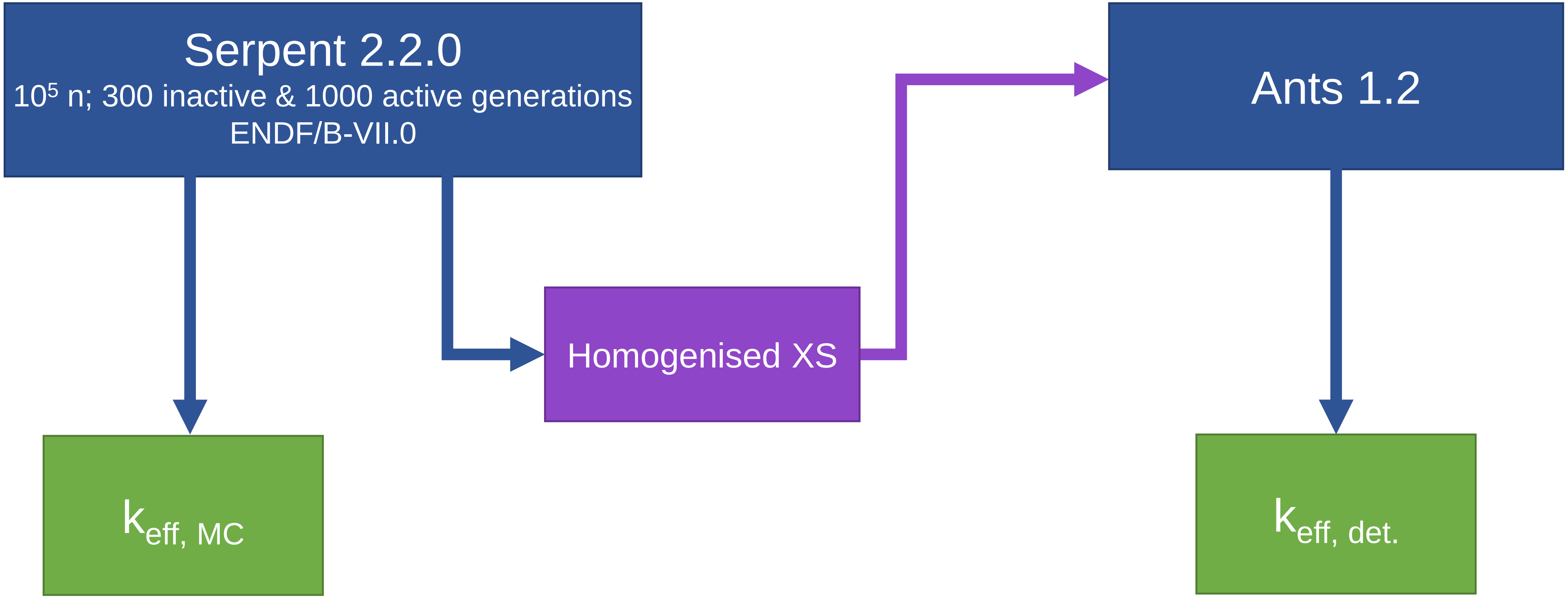
Computational procedure



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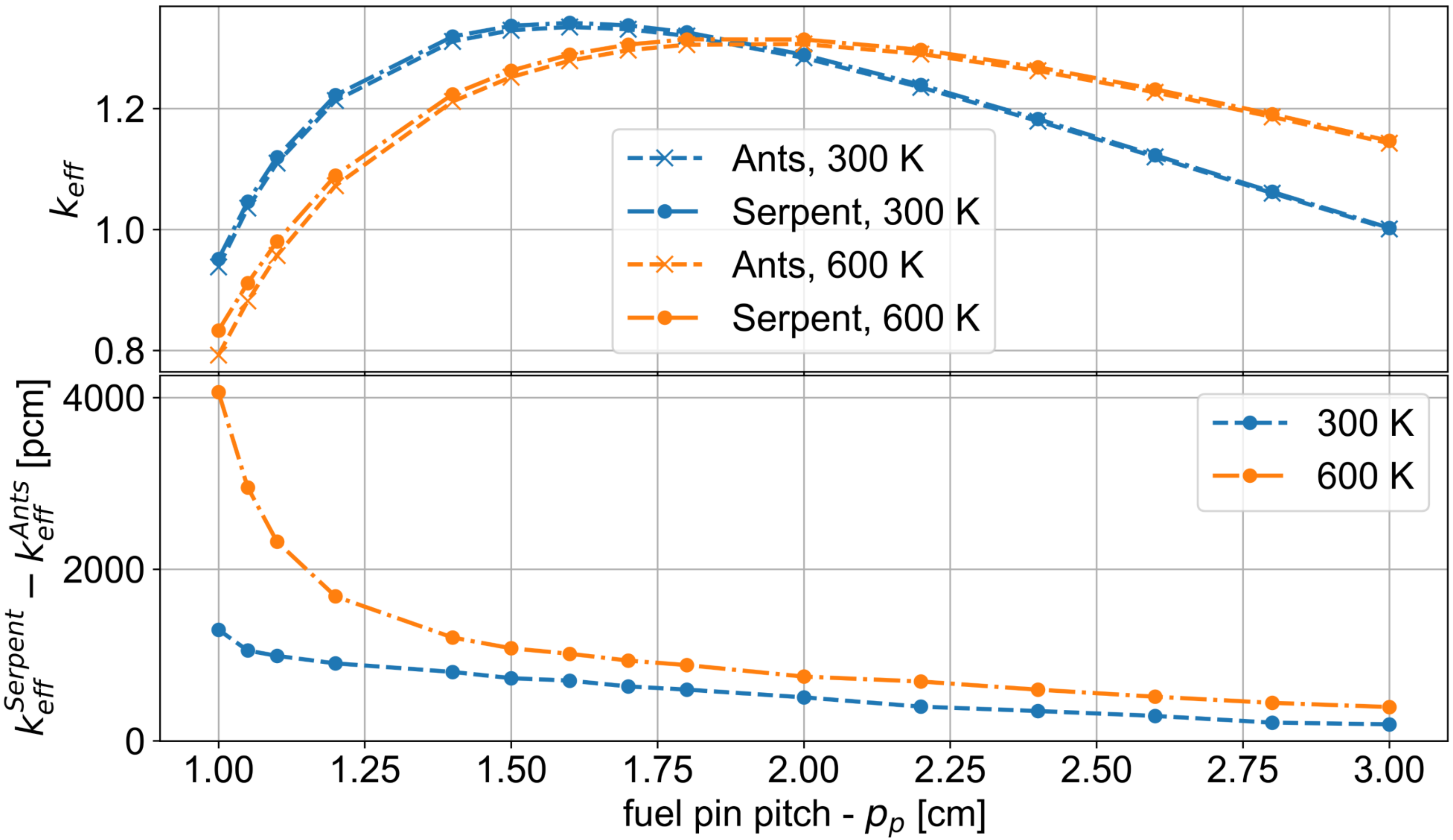
Criticality analysis



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Temperature effects

- Temperature feedback coefficients:

$$\alpha_j = \frac{\partial \rho}{\partial T_j}$$

- $T_{moderator} \in [560\ \text{K}, 600\ \text{K}]$
- $T_{fuel} \in [560\ \text{K}, 1080\ \text{K}]$
- $c_B \in [0\ \text{ppm}, 2500\ \text{ppm}]$

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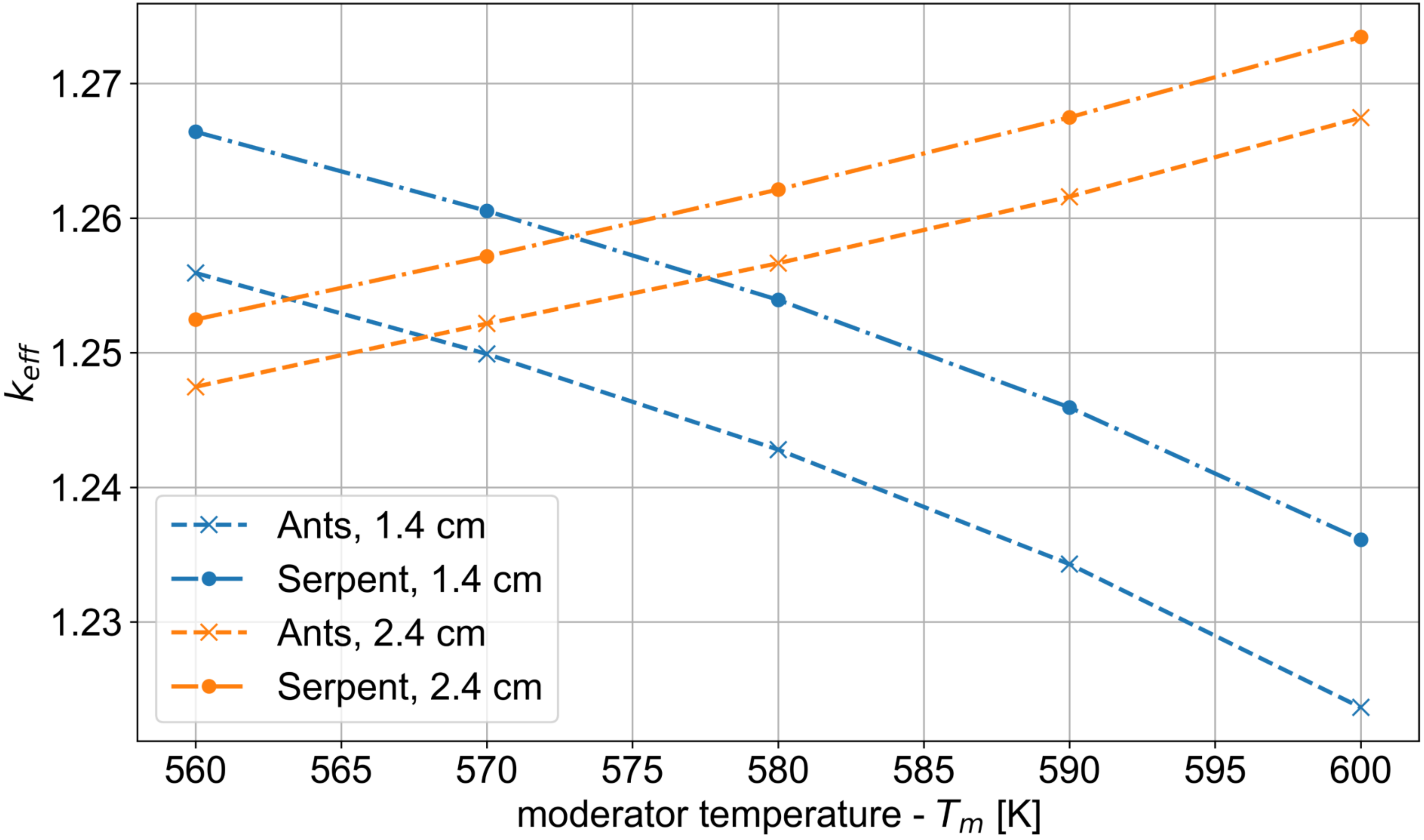
Moderator temperature



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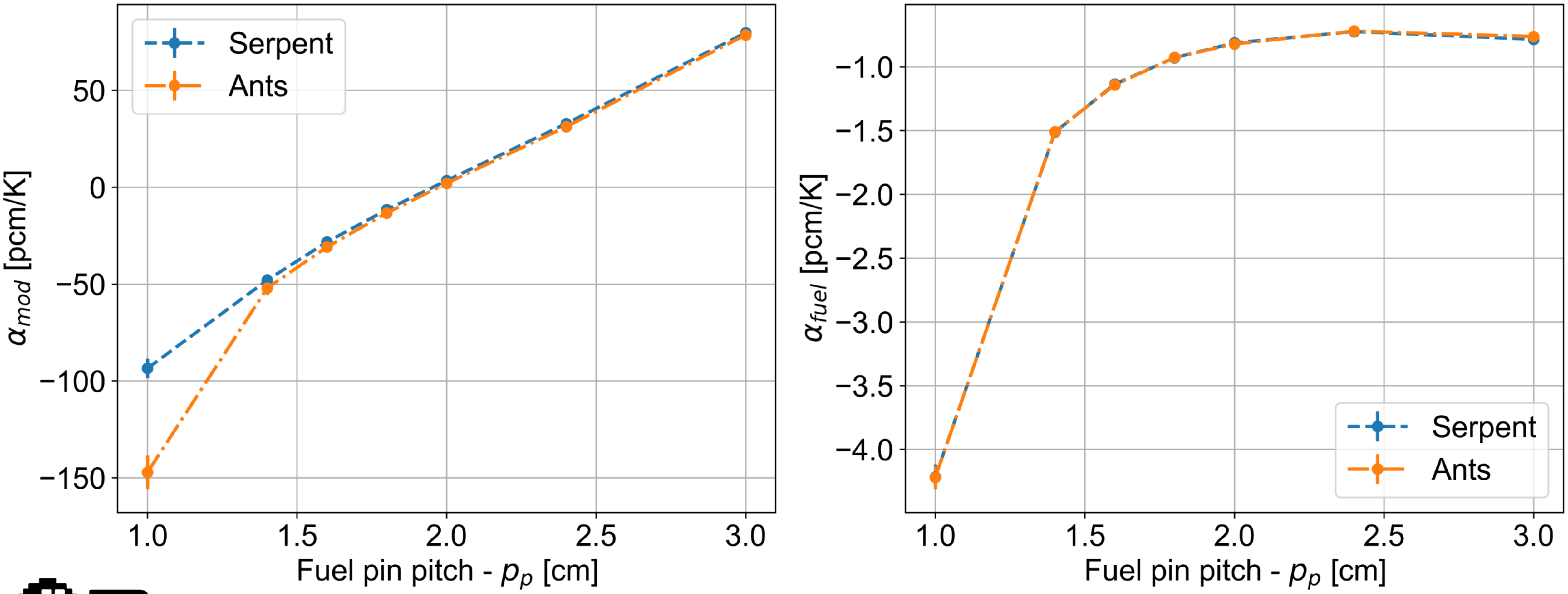
Temperature feedback coefficients (w/o boron)



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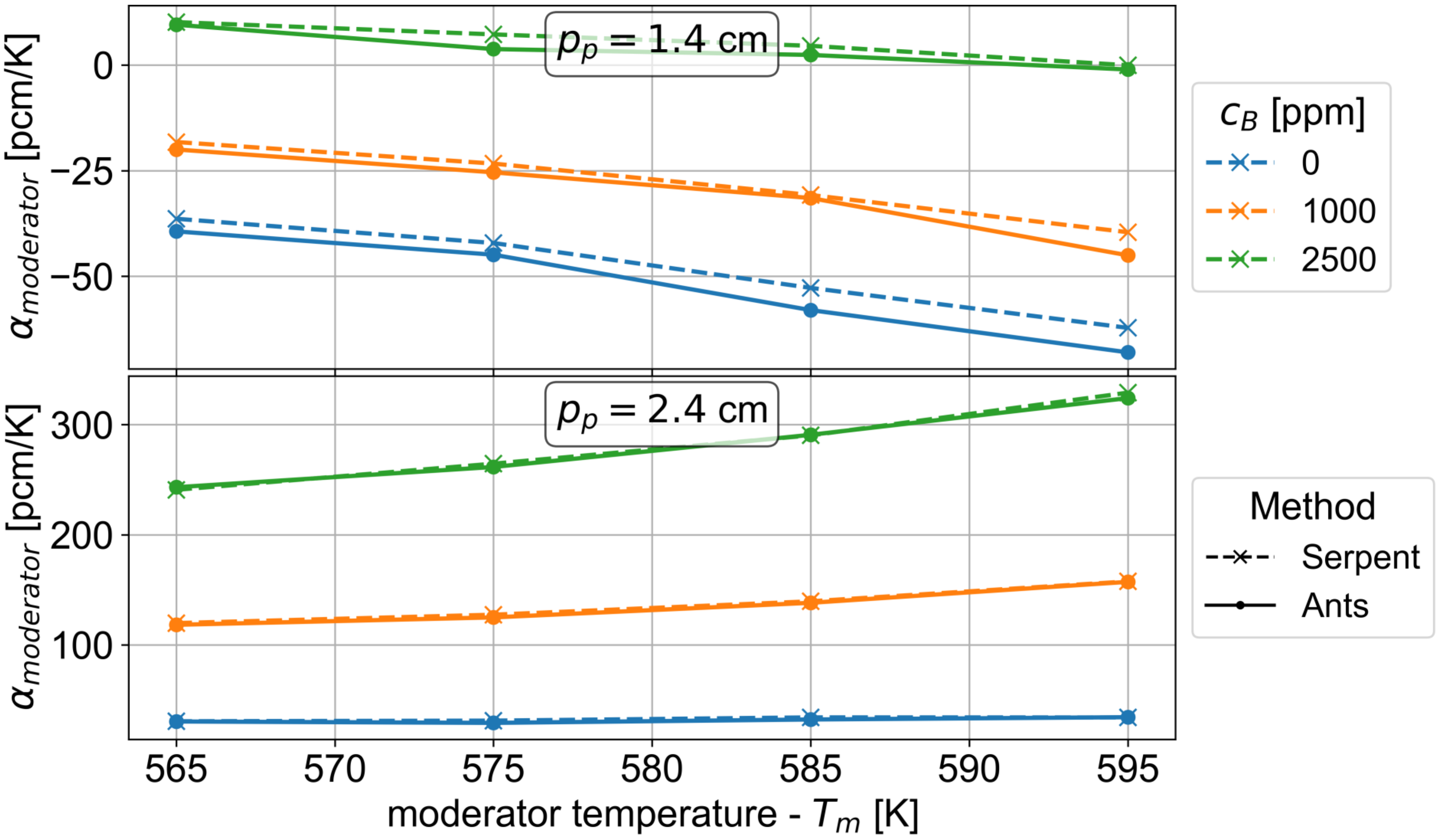
Boron

- $\alpha_{moderator}(T_i) = \frac{\rho\left(T_{i+\frac{1}{2}}\right) - \rho\left(T_{i-\frac{1}{2}}\right)}{T_{i+\frac{1}{2}} - T_{i-\frac{1}{2}}}$



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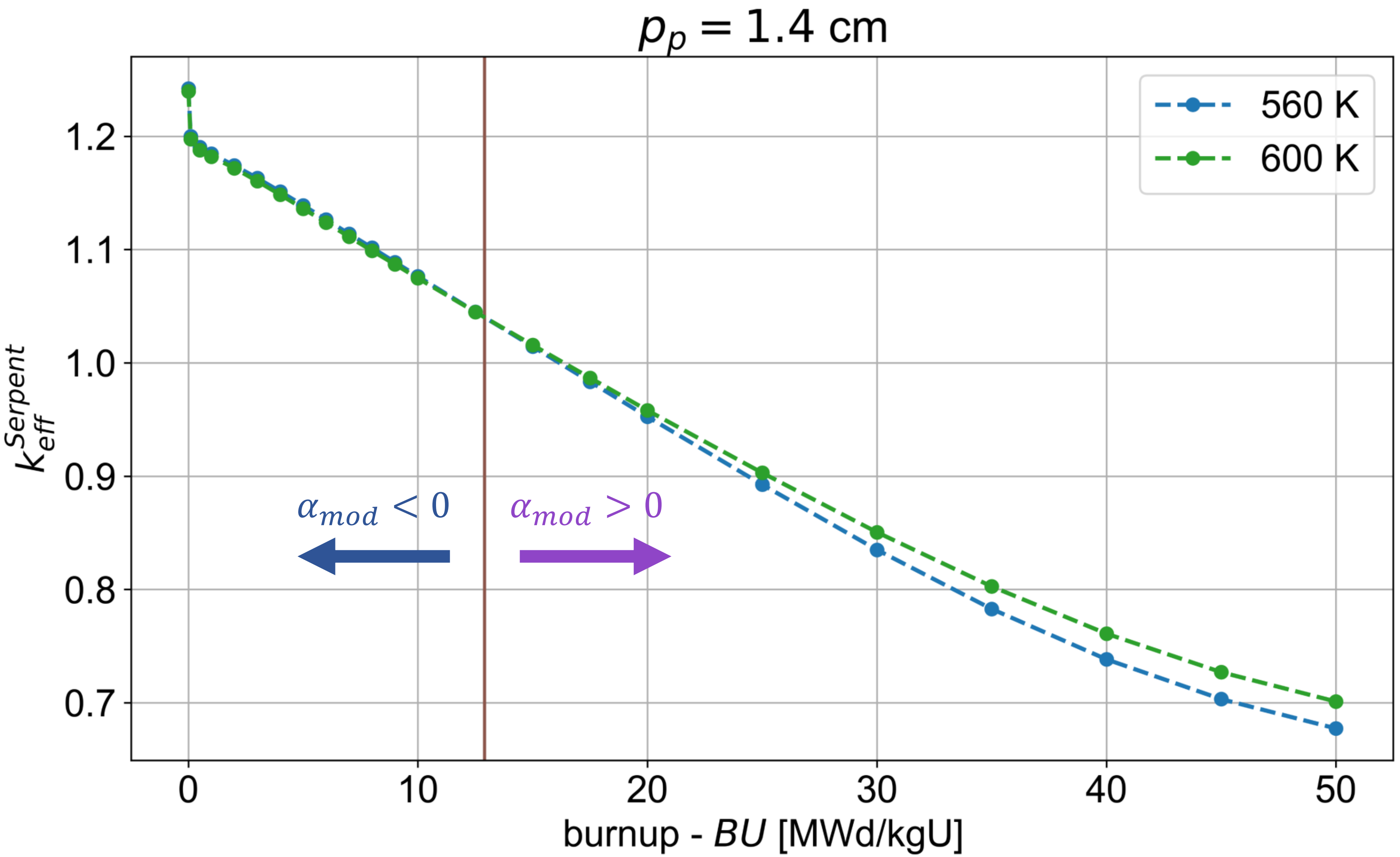
Burnup

- $\frac{P}{m} = 40$ W/g
- BU up to 50 MWd/kgU
- $T_{moderator}$ at 560 K & 600 K with $c_B = 1000$ ppm
- $T_{fuel} \in$ [560 K, 1080 K]
- c_B = const.

Moderator temperature



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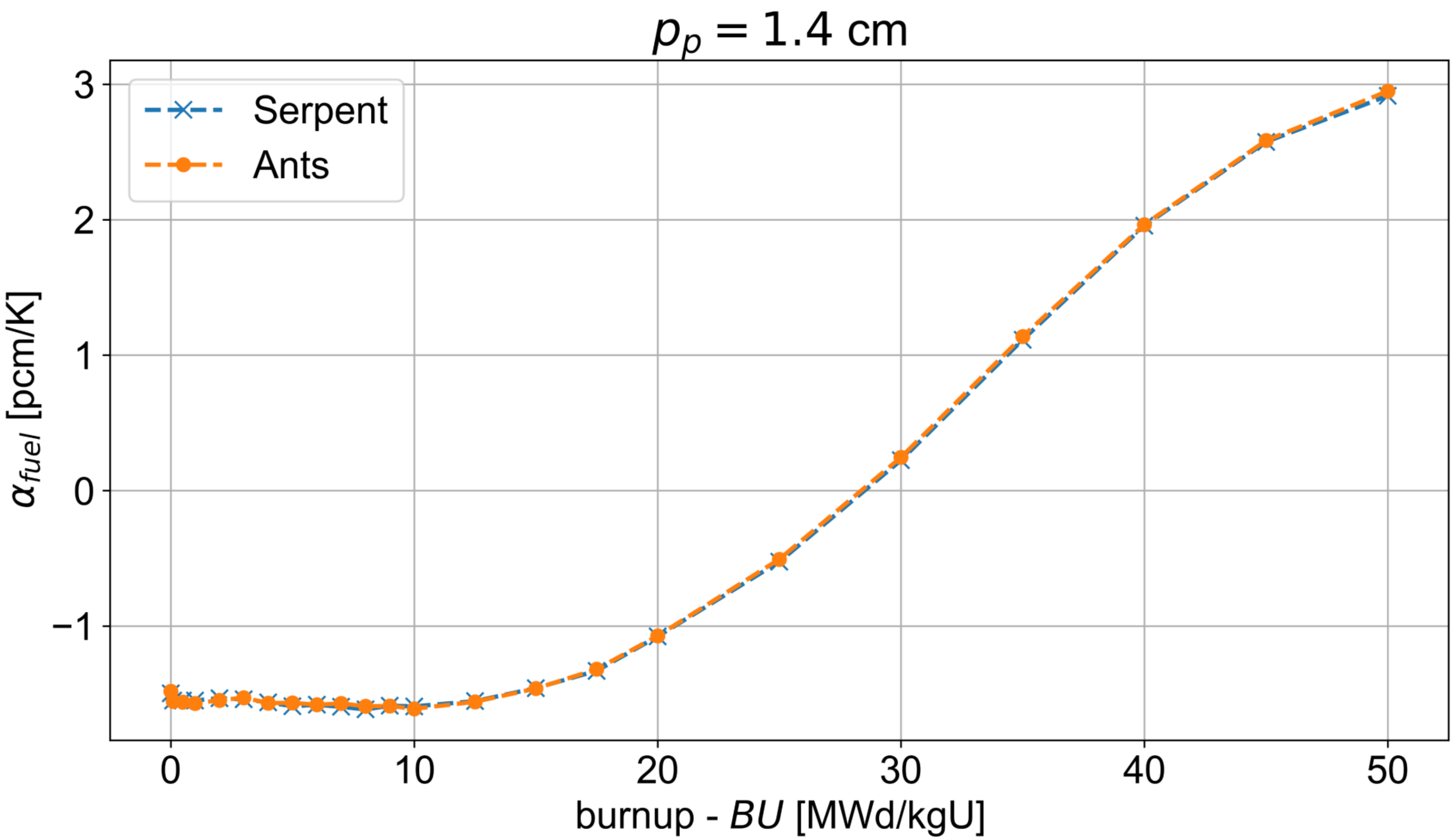
Fuel temperature feedback coefficient



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Conclusions

- Boundary conditions (changes with burnup):
  - $k_{eff} \geq 1$:
    - **1.1 cm ≤ p_p** ≤ 3.0 cm
    - **p_p < 1.5 cm under-moderated region**
  - $\alpha_{moderator} < 0$:
    - **c_B** $<$ **2000 ppm**
    - w/o boron: $p_p \leq 1.8$ cm
    - Depends on T_{mod}
  - $\alpha_{fuel} < 0$:
    - Negative for all p_p
- Significant difference between Serpent and Ants
- Diffusion approximation is not good enough

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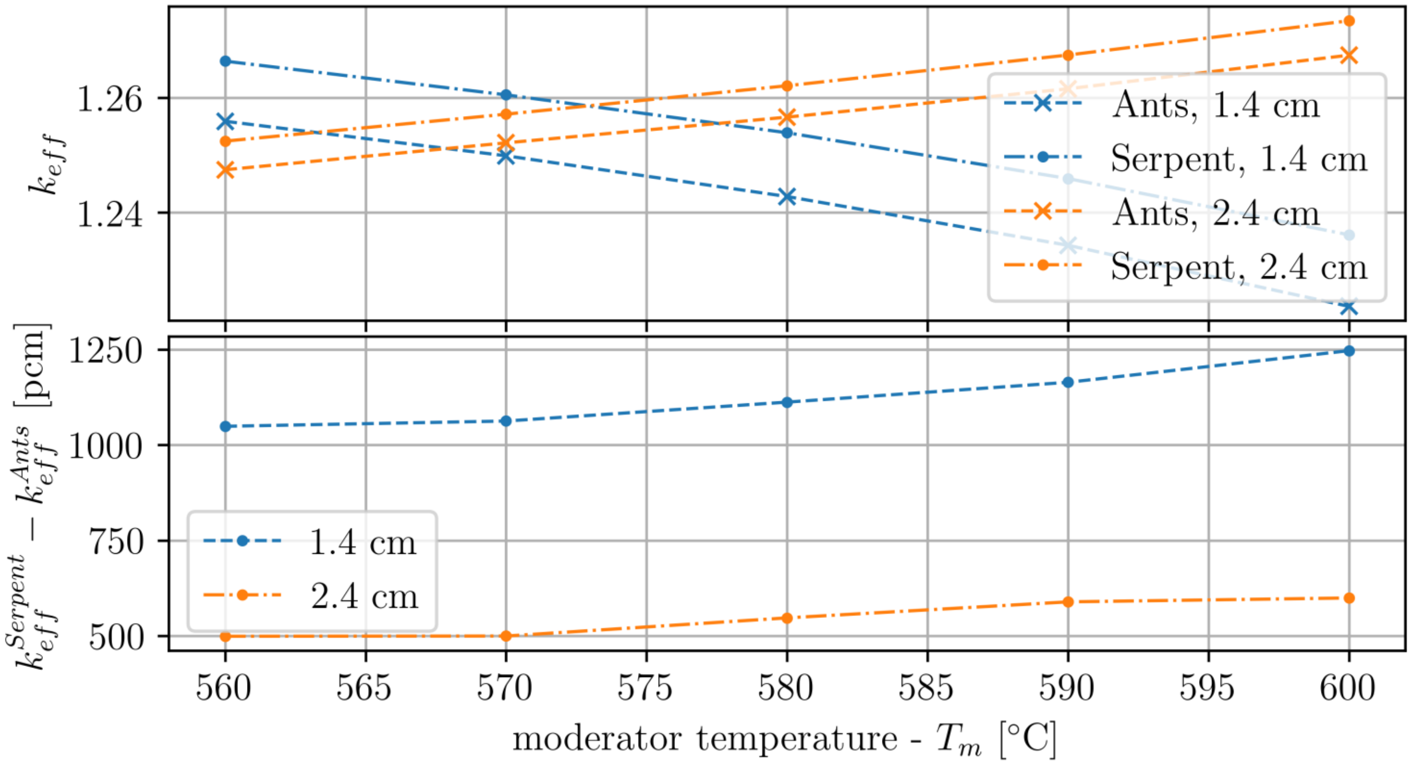
Moderator temperature



	$\alpha_{moderator}$ [pcm/K]	
p_p [cm]	Serpent	Ants
1.0	-93.5 ± 5.0	-147.2 ± 8.8
1.4	-48.0 ± 3.1	-52.1 ± 3.6
1.6	-28.3 ± 2.0	-30.9 ± 2.2
1.8	-11.6 ± 1.3	-13.3 ± 1.4
2.0	3.4 ± 0.5	2.0 ± 0.4
2.4	32.8 ± 0.8	31.2 ± 0.9
3.0	79.7 ± 2.7	78.6 ± 2.4

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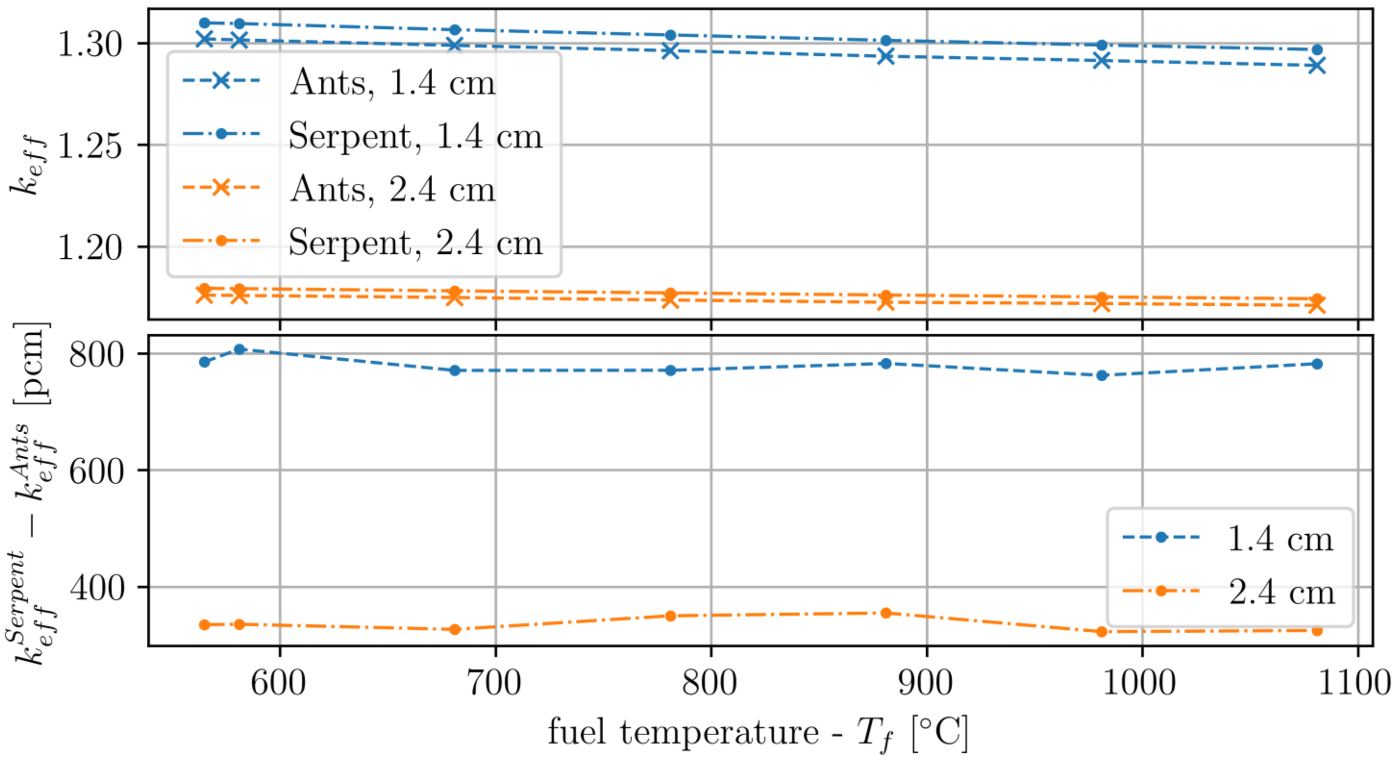
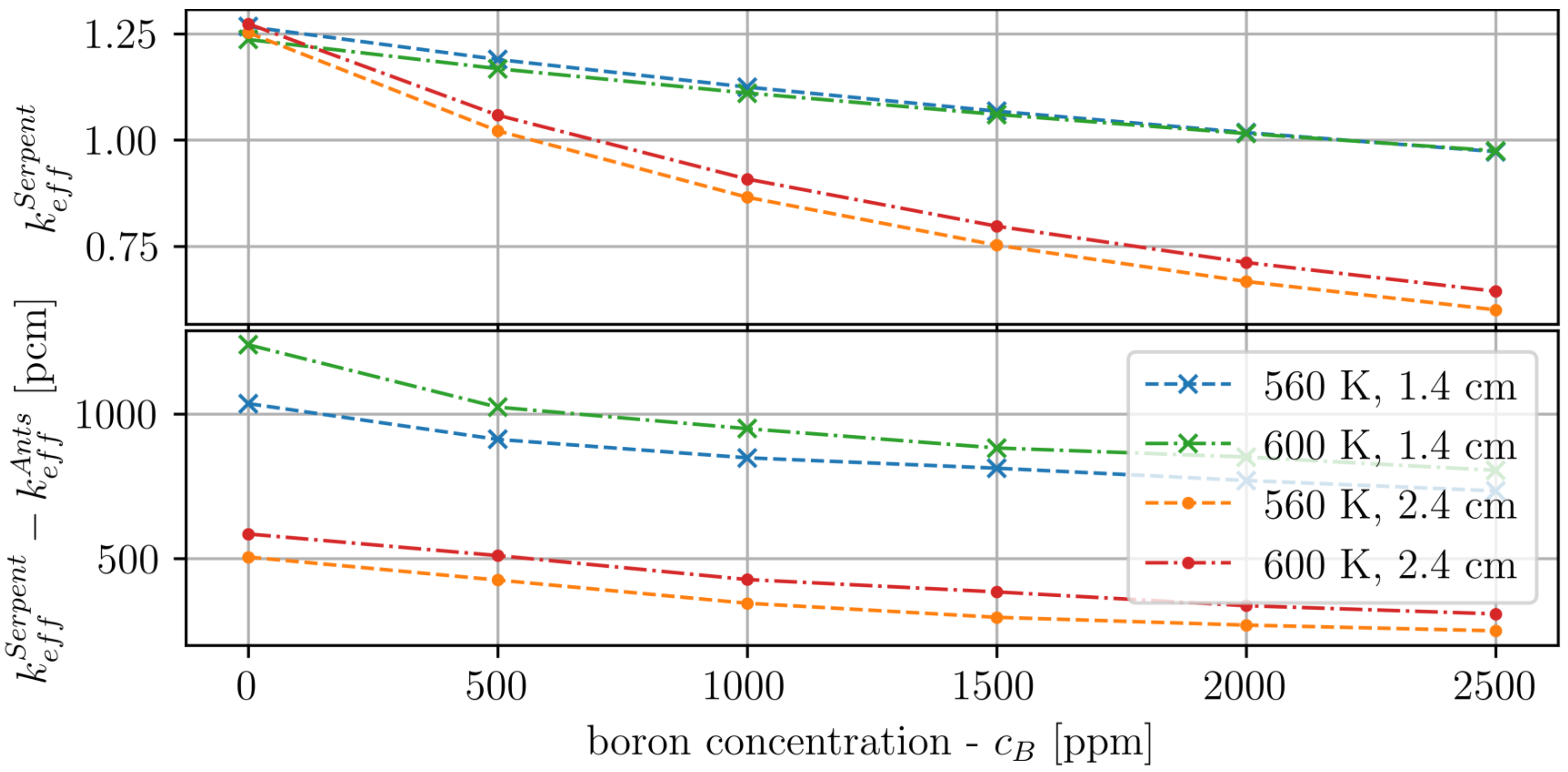
Fuel temperature



	α_{fuel} [pcm/K]	
p_p [cm]	Serpent	Ants
1.0	-4.215 ± 0.098	-4.218 ± 0.088
1.4	-1.512 ± 0.032	-1.509 ± 0.025
1.6	-1.136 ± 0.019	-1.142 ± 0.022
1.8	-0.929 ± 0.013	-0.927 ± 0.022
2.0	-0.813 ± 0.013	-0.822 ± 0.017
2.4	-0.724 ± 0.010	-0.720 ± 0.027
3.0	-0.785 ± 0.011	-0.763 ± 0.018

Boron



- $\alpha_{moderator}(T)$ at each c_B?

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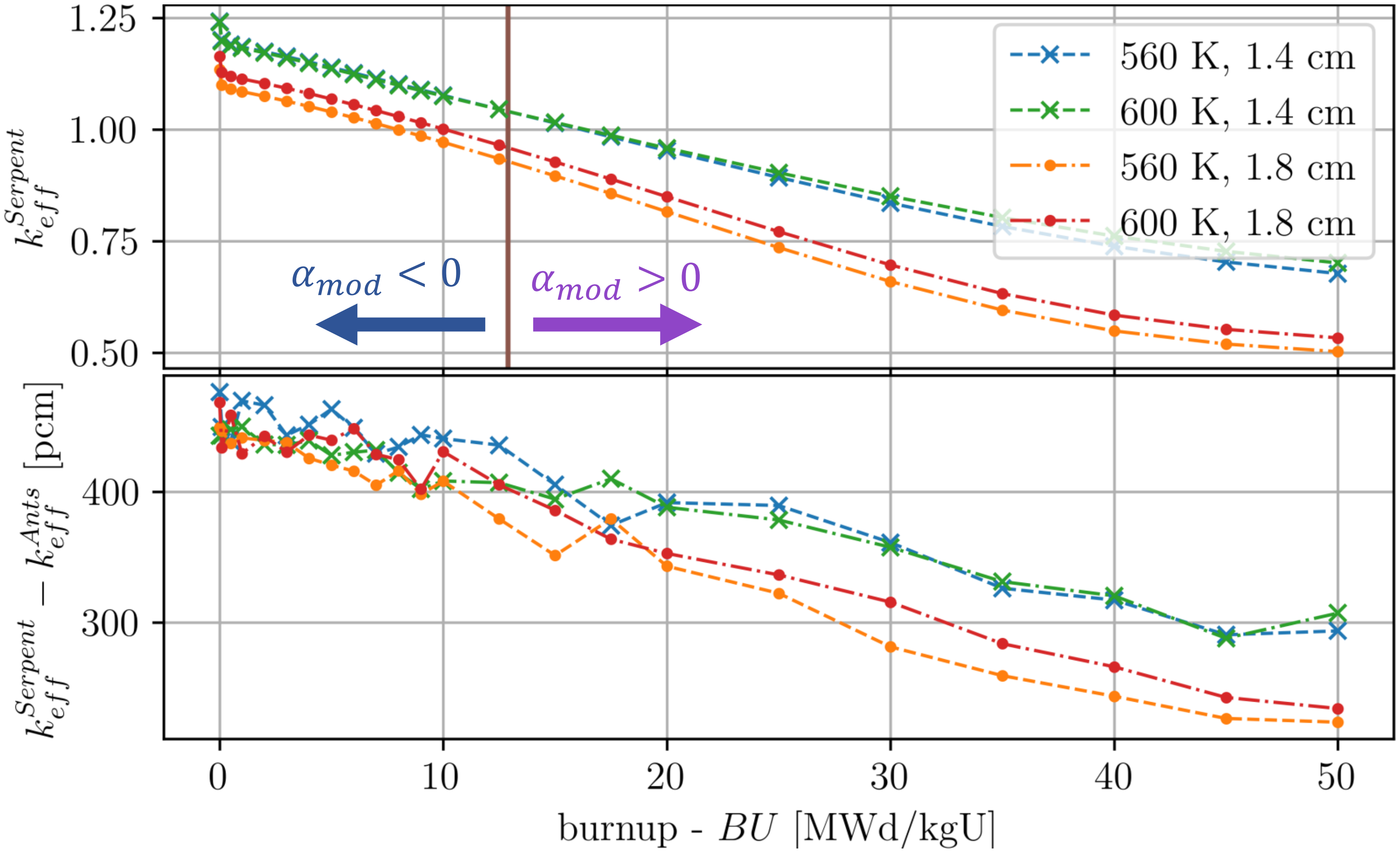
Moderator temperature



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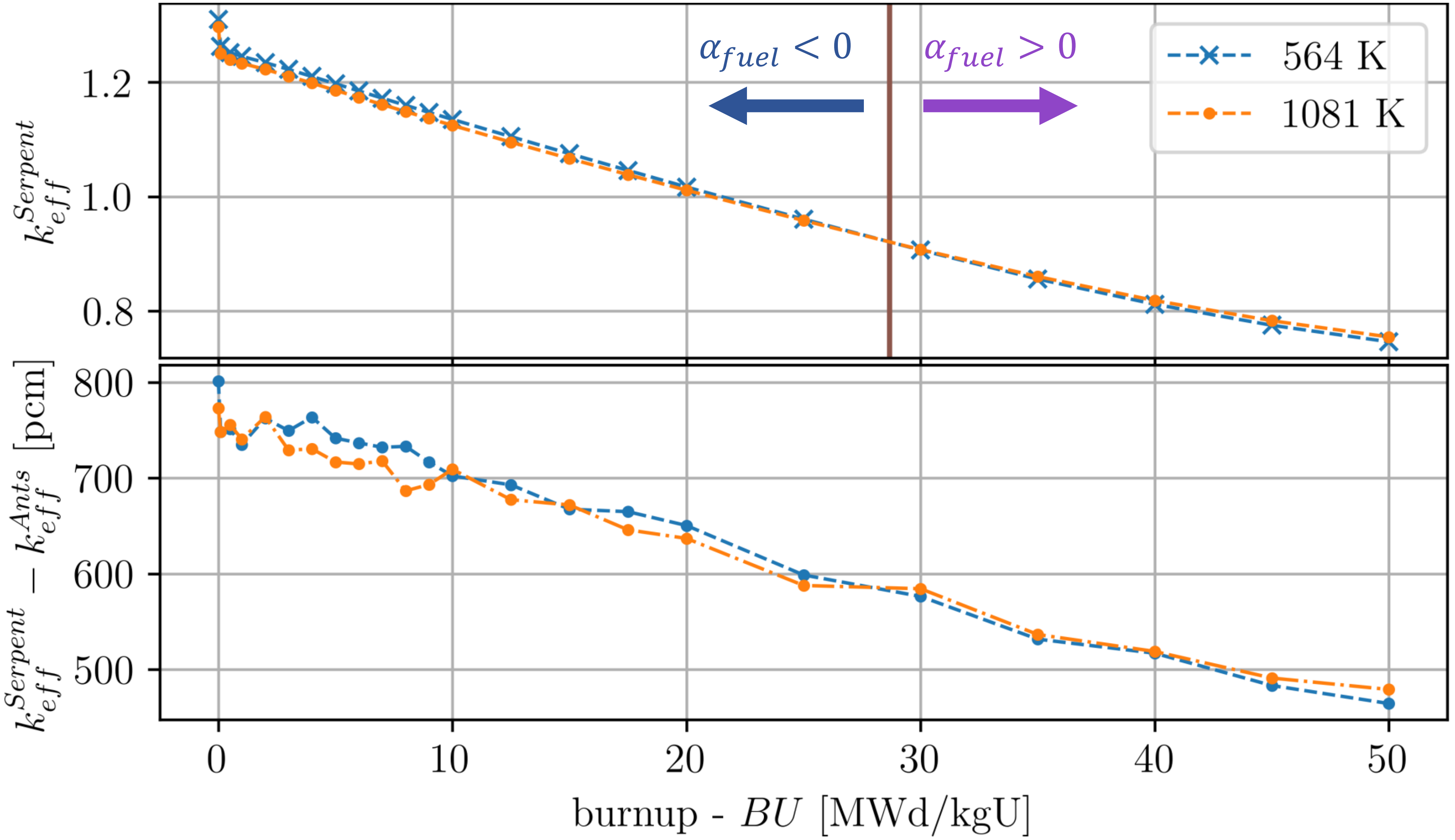
Fuel temperature



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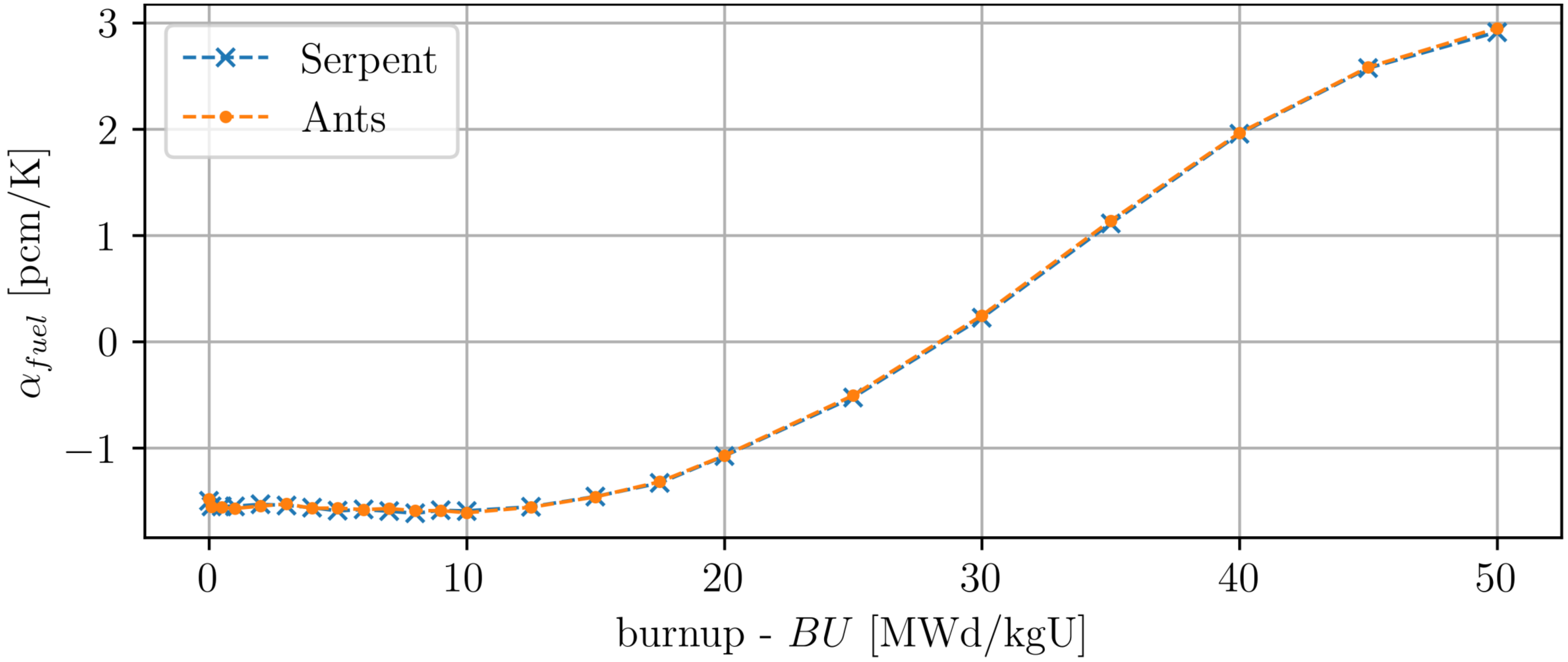
Fuel temperature



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