Modeling of Thermophysical Properties in a Uranium Silicide Dispersion Fuel to Support Conversion of HFIR to LEU Fuels

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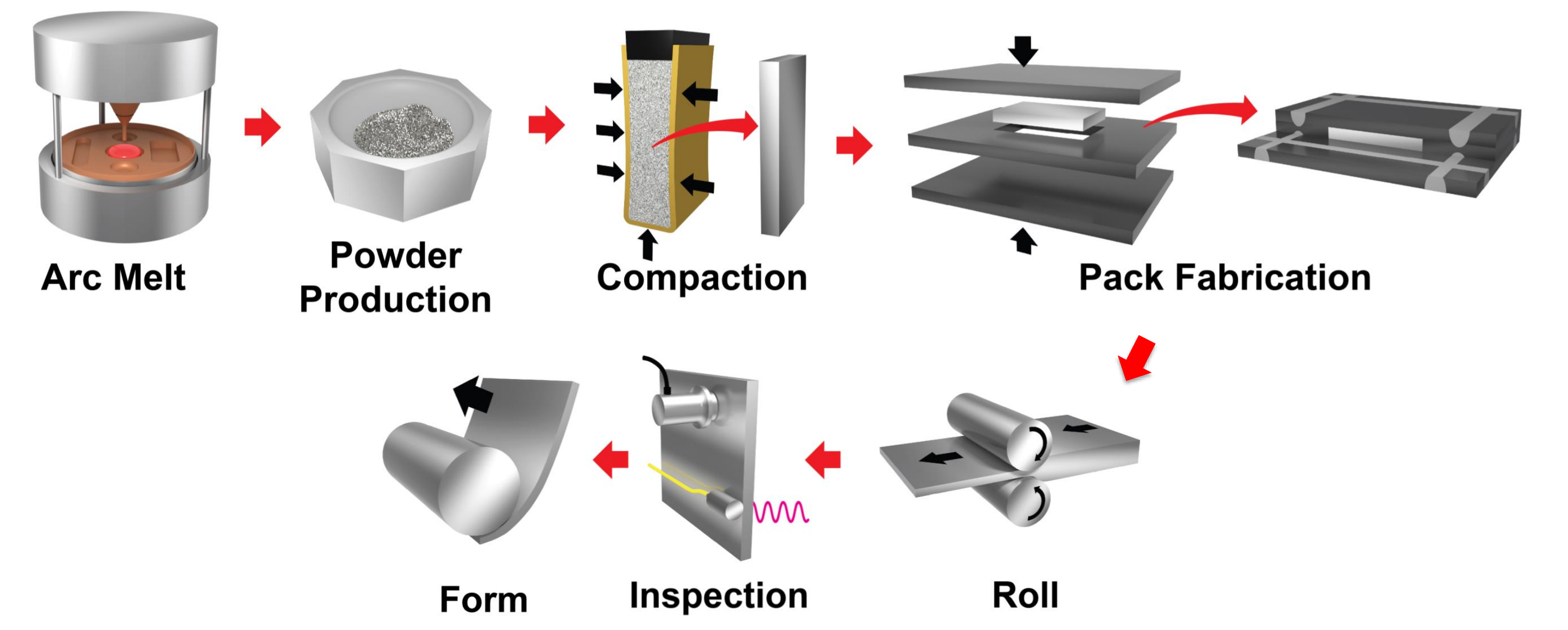
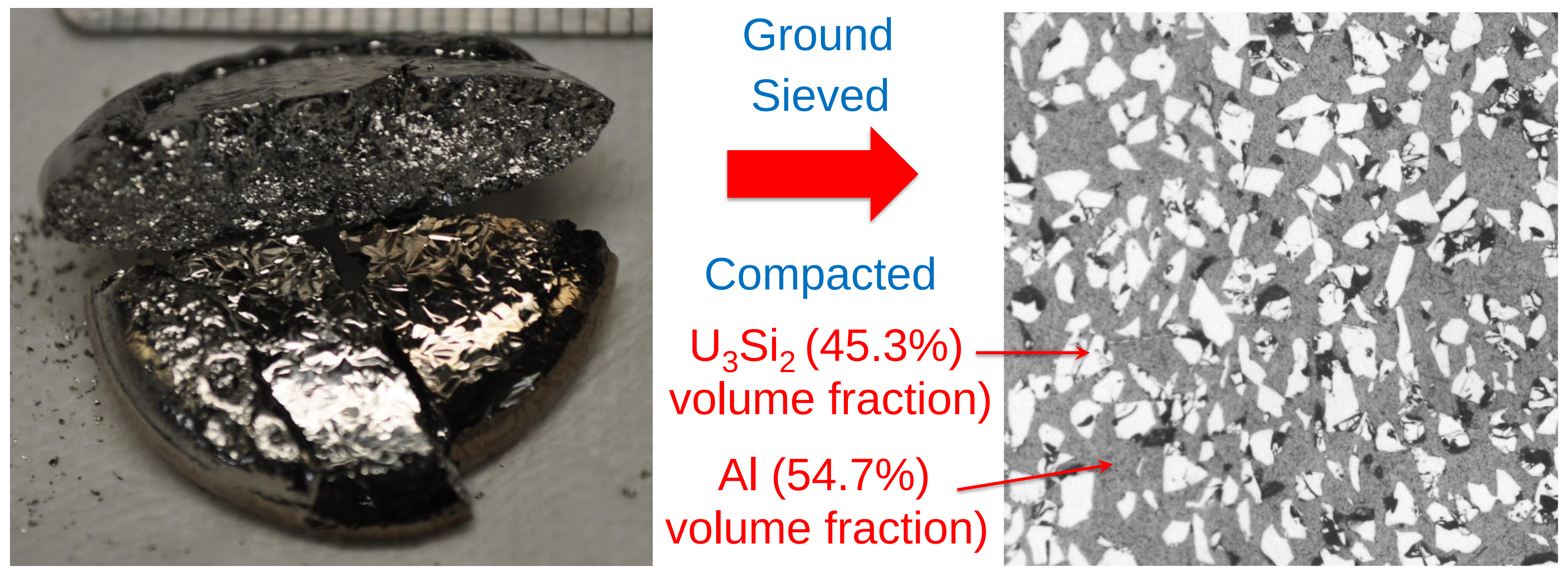
Objective & Motivation

- U_3Si_2-Al dispersion fuel is proposed to convert the U.S. High Flux Isotope Reactor (HFIR) to a High Assay Low Enriched Uranium (HALEU) fuel.
- Numerically predicting the thermophysical properties of U_3Si_2-Al dispersion fuel, such as thermal conductivity (TC), temperature (T), and heat flux (HFL), is fundamental to the efficient and safe operation of nuclear reactors.
- Modeling the thermophysical properties of U_3Si_2-Al dispersion fuel is complicated by the inhomogeneous nature of dispersion fuels in fuel composition and microstructure.



Fuel Microstructure and Finite Element Model Setup

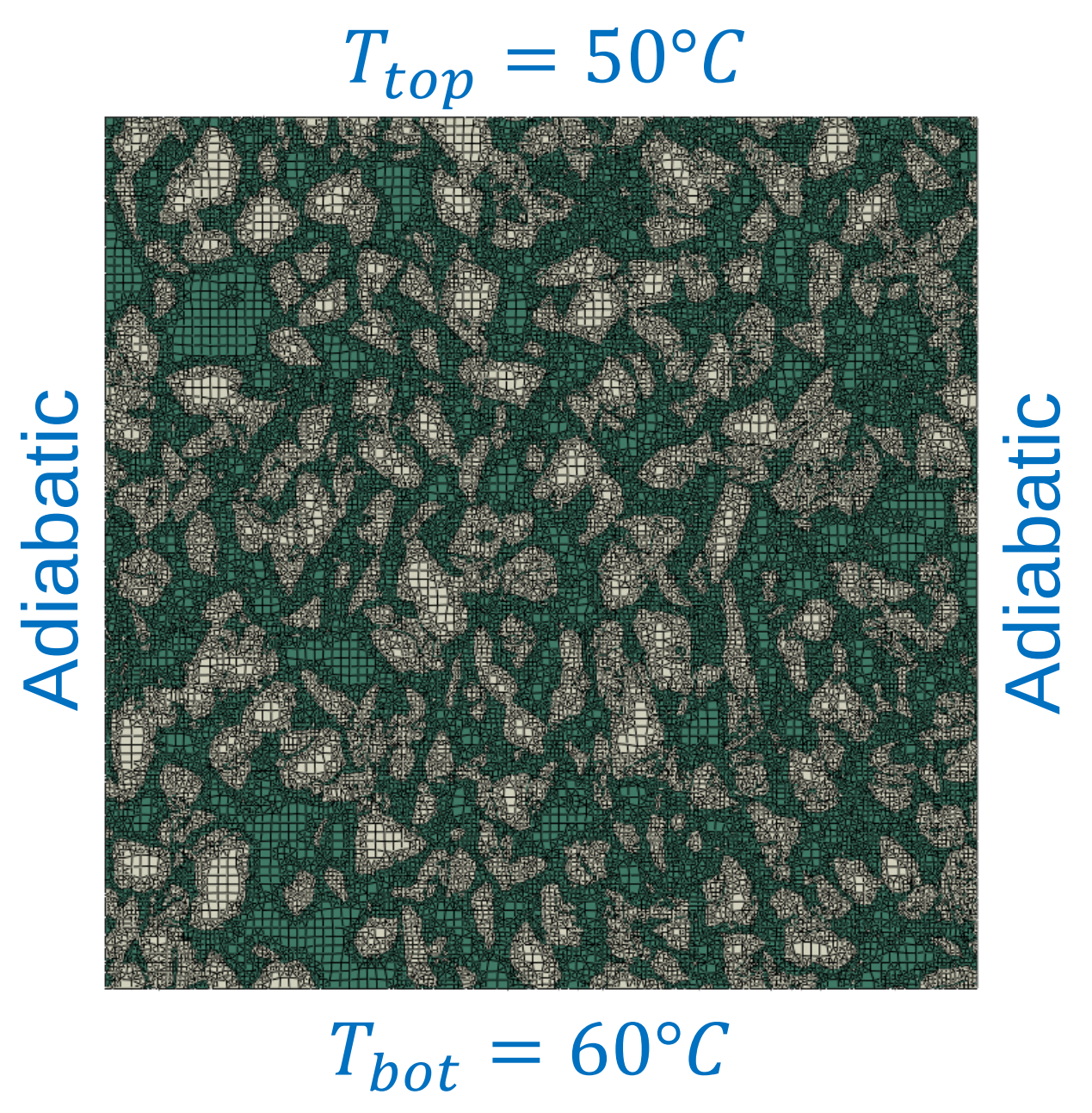
- Homogeneous U_3Si_2-Al dispersion fuel made through controlled particle size distribution (PSD).



Arc melted pure U_3Si_2

U_3Si_2-Al fuel microstructure (1mm x 1mm)

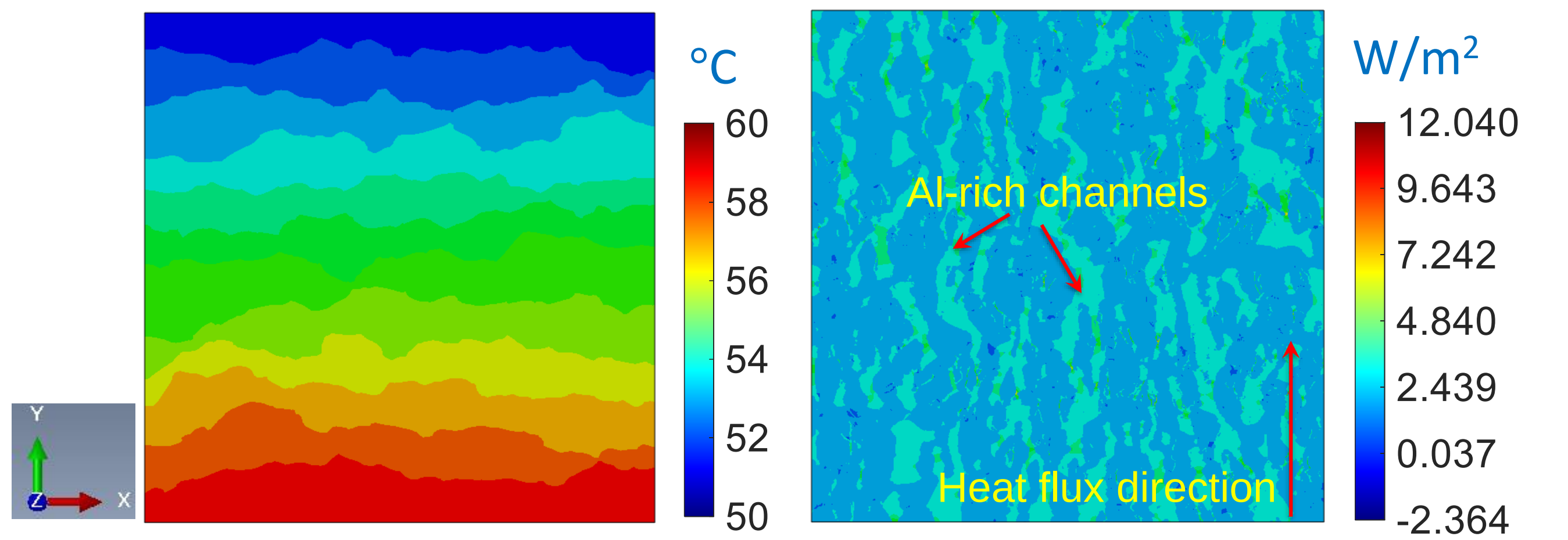
- U_3Si_2 and Al material phases are **conformingly meshed** with mixed quadratic/triangle elements for an increased numerical accuracy.



- Max/min element sizes are 10/5 μm, leading to **47,003 nodes and 71,555 elements**.
- Thermal boundary conditions are applied on the studied fuel microstructure.
- Density, thermal conductivity, and heat capacity properties of Al and U_3Si_2 used in the finite element method (FEM) model are obtained from literature.
- Simulations were run with **8 CPUs on HPC workstation equipped with 16 cores (32 processors) and 192 memory.**

Simulation Results

- Steady-state temperature is non-uniformly distributed because of the inhomogeneous material microstructure.
- Heat fluxes in y-direction mainly through channels where Al is rich.



Temperature

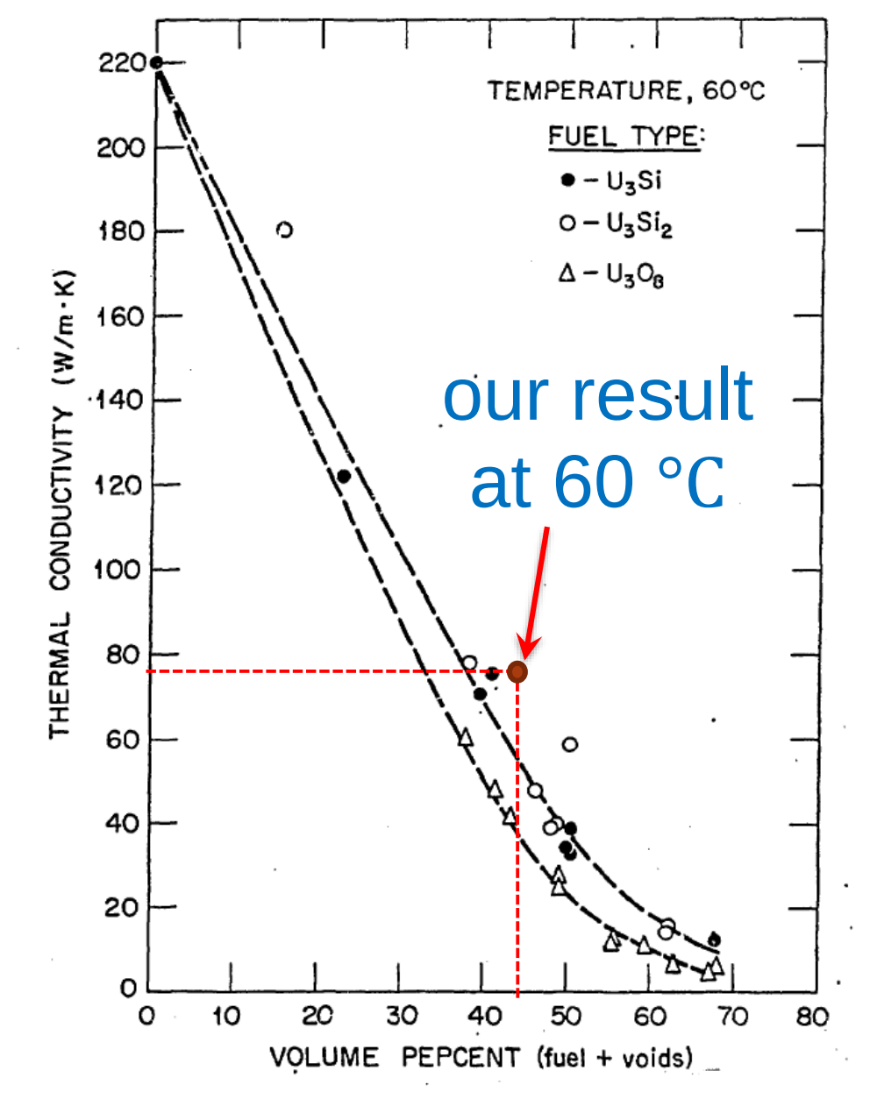
Y-heat flux

- Effective U_3Si_2-Al fuel thermal conductivity at 60°C is $\kappa_e = 78.57$ W/m·°C using following equation[1].

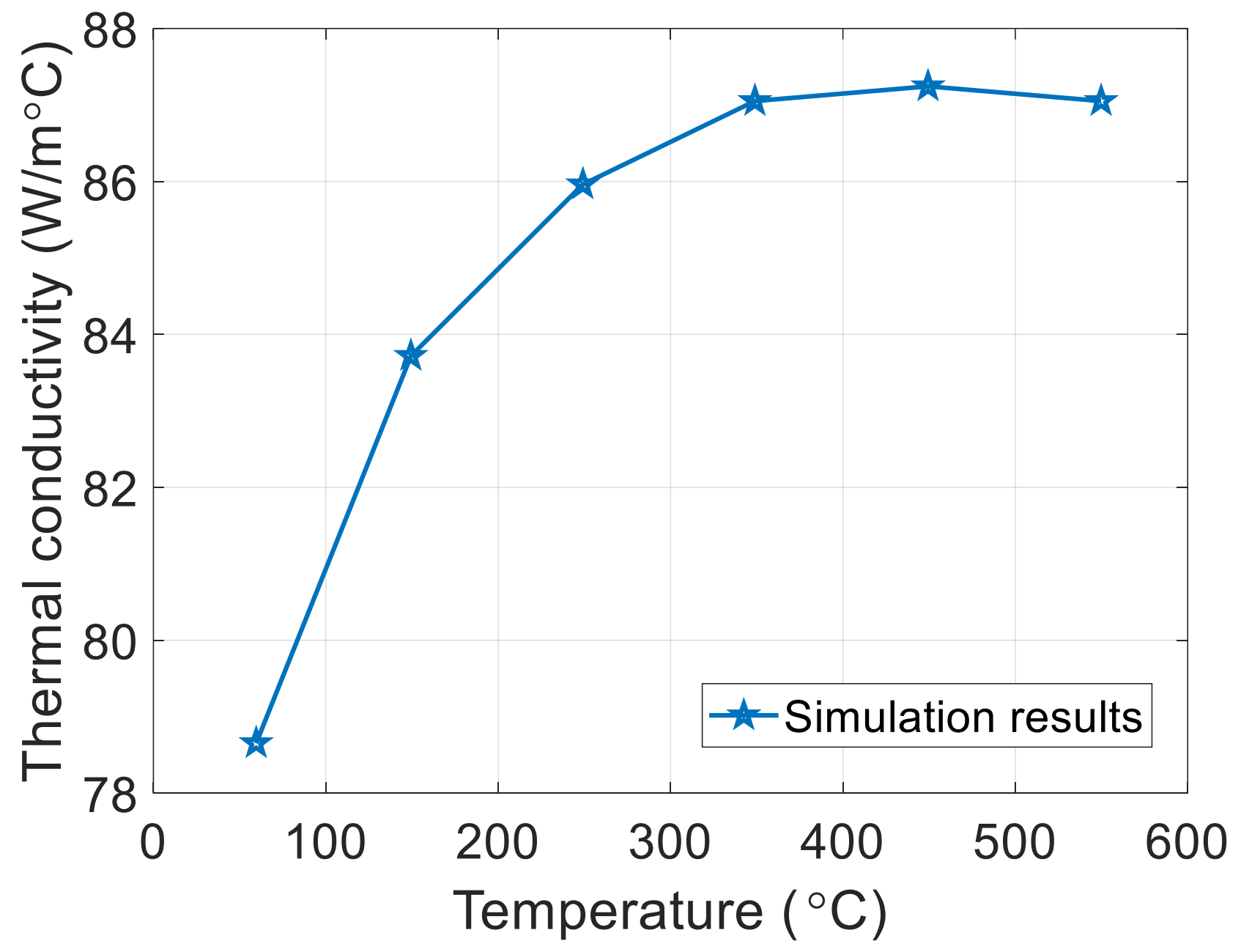
$$\kappa_e = \frac{\sum_{i=1}^{n} q_{ai} v_i}{(T_{bot} - T_{top})A}$$

q_{ai}: Y-heat flux for element i
v_i: area of element i
A: total fuel microstructure area

- Model predicted TC are slightly higher than experimental results, because pores are not considered in the current model.
- TC of U_3Si_2/Al fuel is nonlinear with respect to temperature.



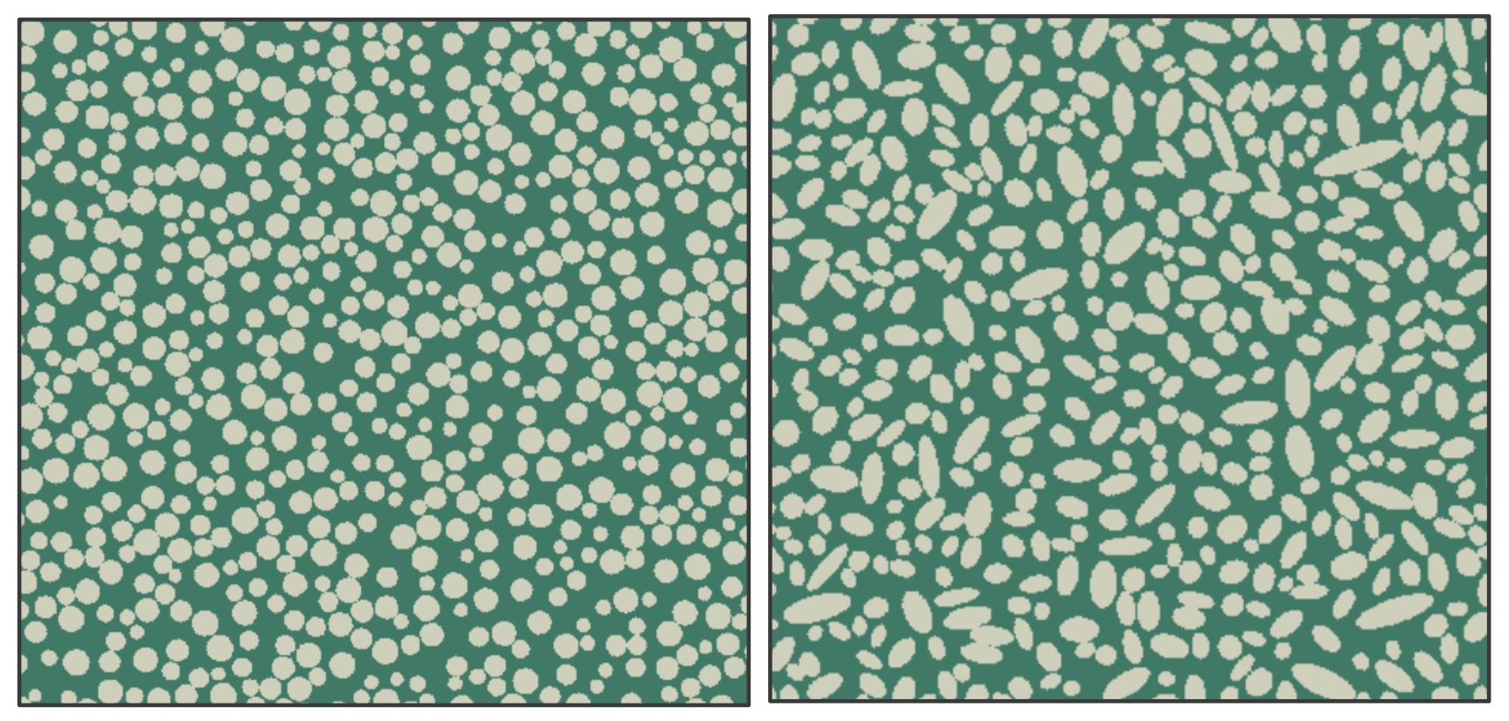
Comparison with literature[2]



Model predicted TC at different T

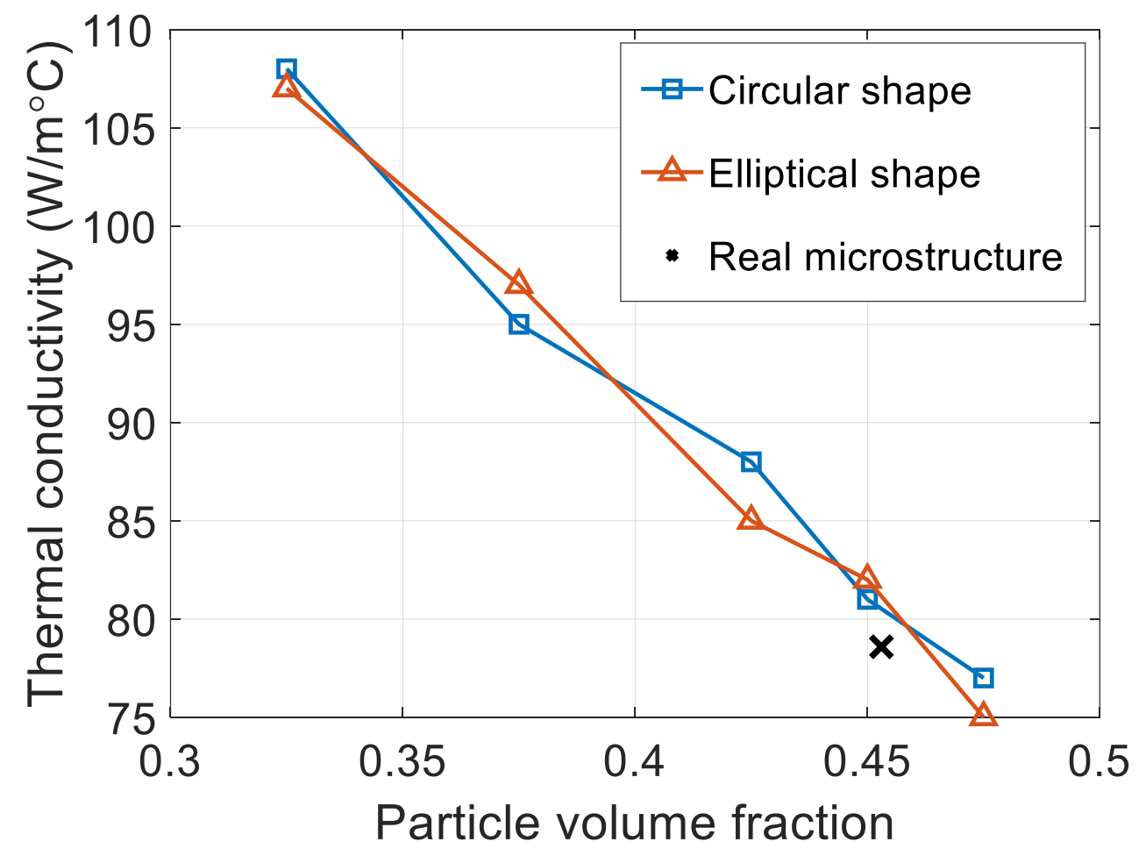
Surrogate U_3Si_2 particle Shapes

- Surrogate circular and elliptical shapes are used to rapidly generate the microstructure to study influence of particle VF on fuel TC.



Circular shape (**1M elements**)

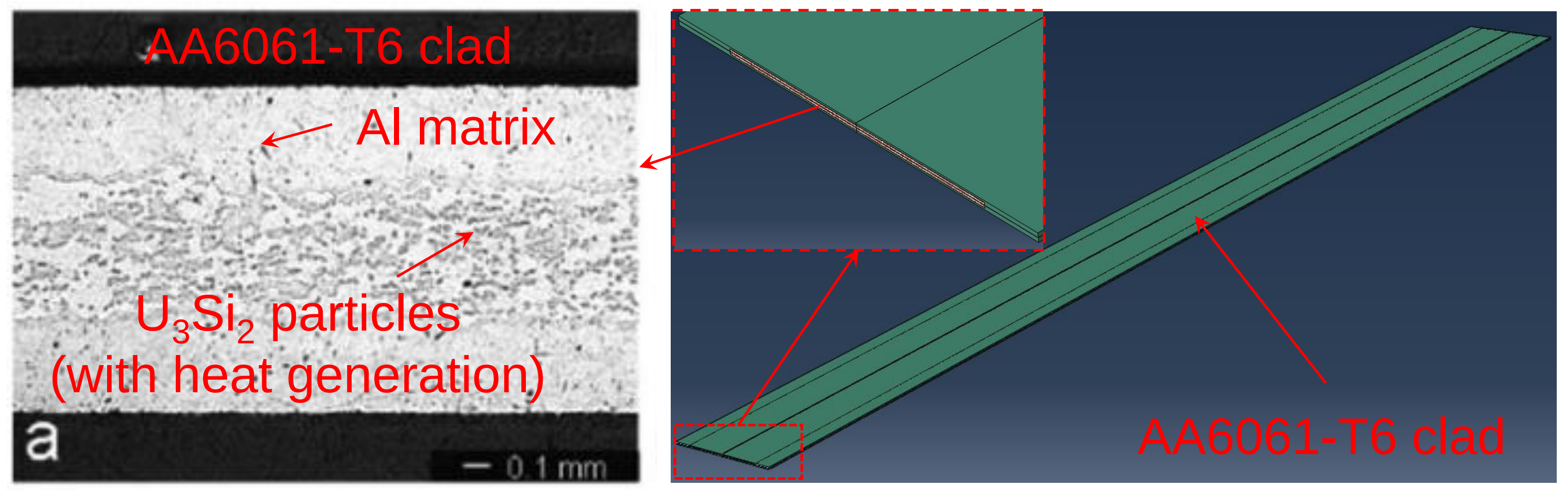
Elliptical shape (**1M elements**)



- Fuel domains with circular and elliptical particle shapes have higher TC compared to the domain with real particle shape.
- U_3Si_2-Al fuel TC increases with decrease of U_3Si_2 volume fraction.

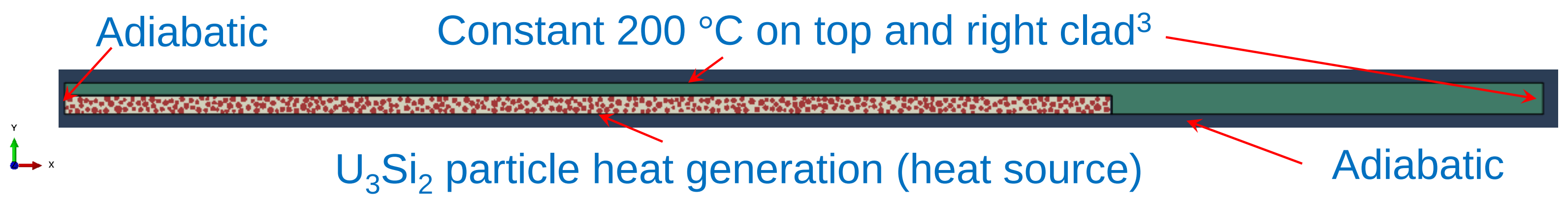
Heat Generation Model for Cladded U_3Si_2-Al Fuel

- Goal: develop a FEM model to understand temperature and heat flux distribution in U_3Si_2-Al dispersion fuel during irradiation.

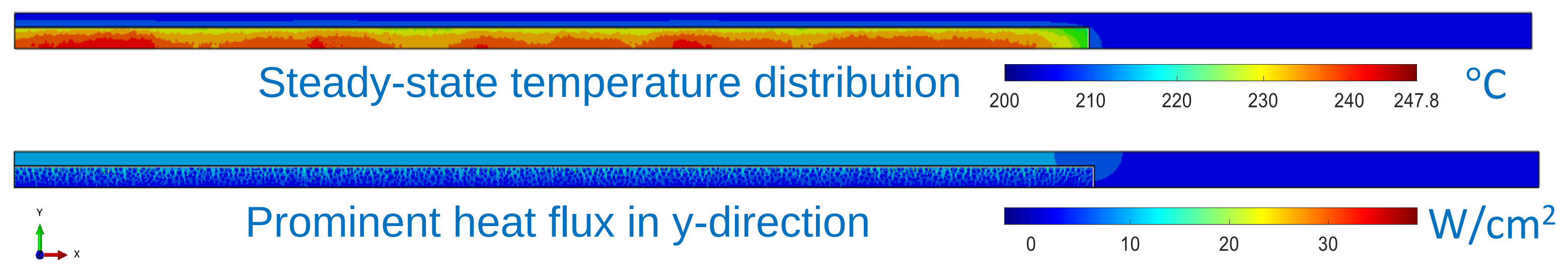


U_3Si_2 dispersoid fuel plate during irradiation

- A quarter-sized heat generation model is developed with surrogate circular particle shape and thermal boundary conditions.



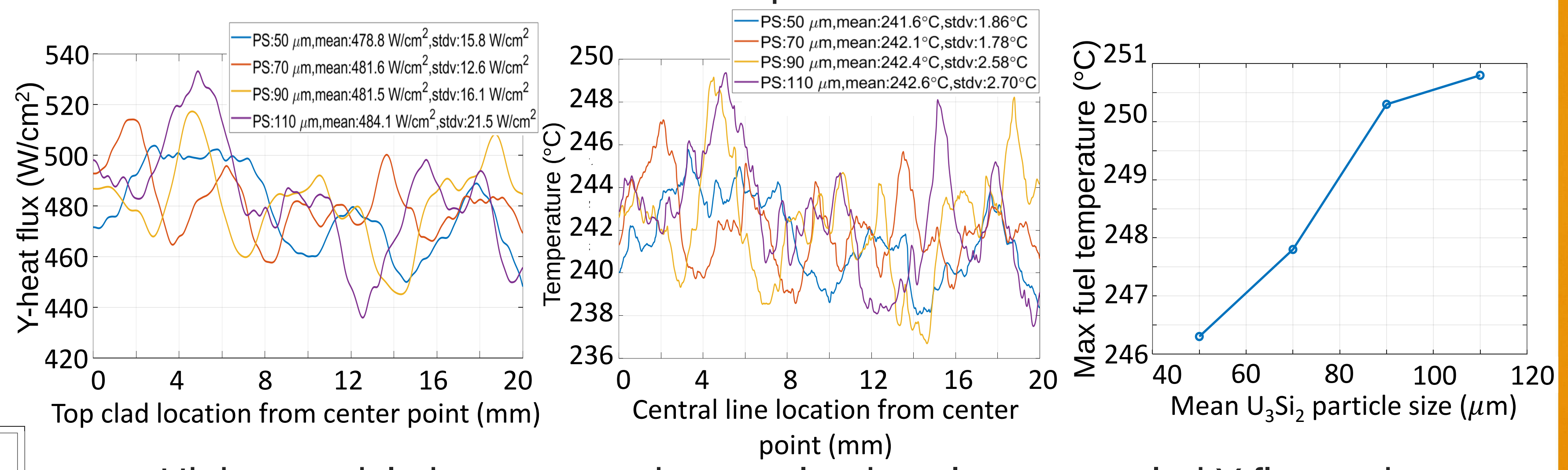
- Simulation results with mean particle size (PS) 70 μm, standard deviation 17μm, particle VF 42.5%, and particle heat generation (HG) rate 30 kW/s.m³.



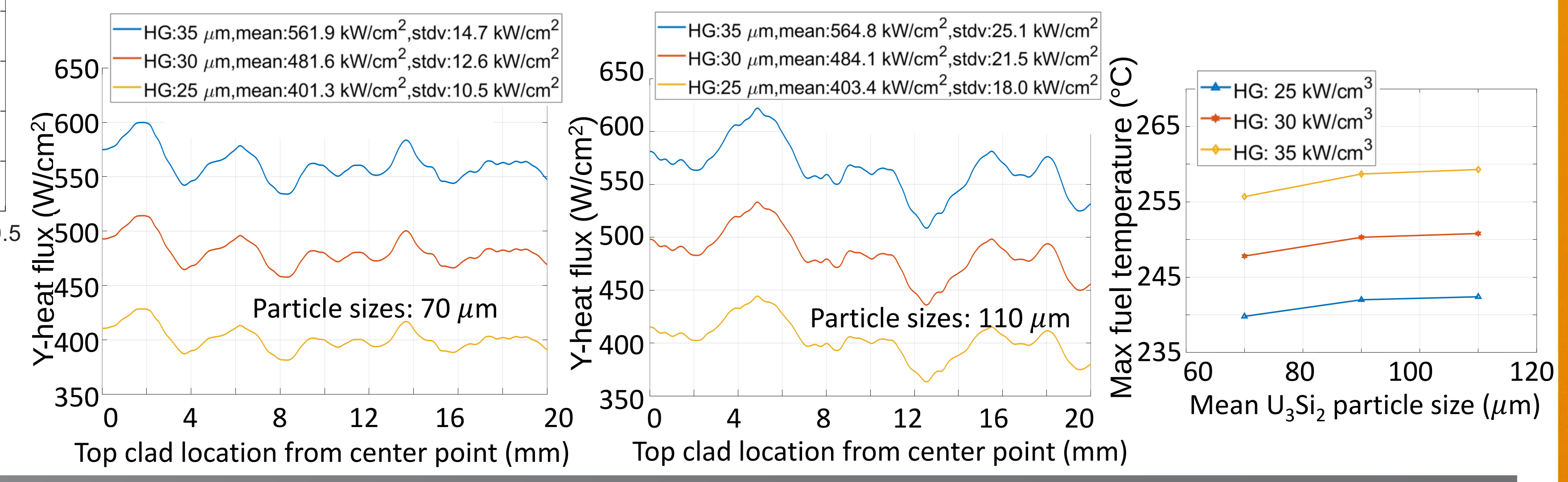
Steady-state temperature distribution

Prominent heat flux in y-direction

- Model predicted fuel core temperature is around 231.9 to 247.8 °C, the Y-heat flux on top clad surface is around 450-500 W/cm², which are consistent with the experimental results[3].
- Parametric study shows larger particle size leads to larger top clad Y-flux and maximum fuel central line temperature.



- Higher particle heat generation rate leads to larger top clad Y-flux and maximum fuel central line temperature.



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2. Williams, R. K., et al. Thermal conductivities of U 3 Si and U 3 Si 2-Al dispersion fuels. No. CONF-851021--1. Oak Ridge National Lab., 1985.
3. Leenaers, A., et al. "Microstructure of U3Si2 fuel plates submitted to a high heat flux." *Journal of nuclear materials* 327.2-3 (2004): 121-129.

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