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Title: Challenges in Explicit Modeling of TRISO in MCNP

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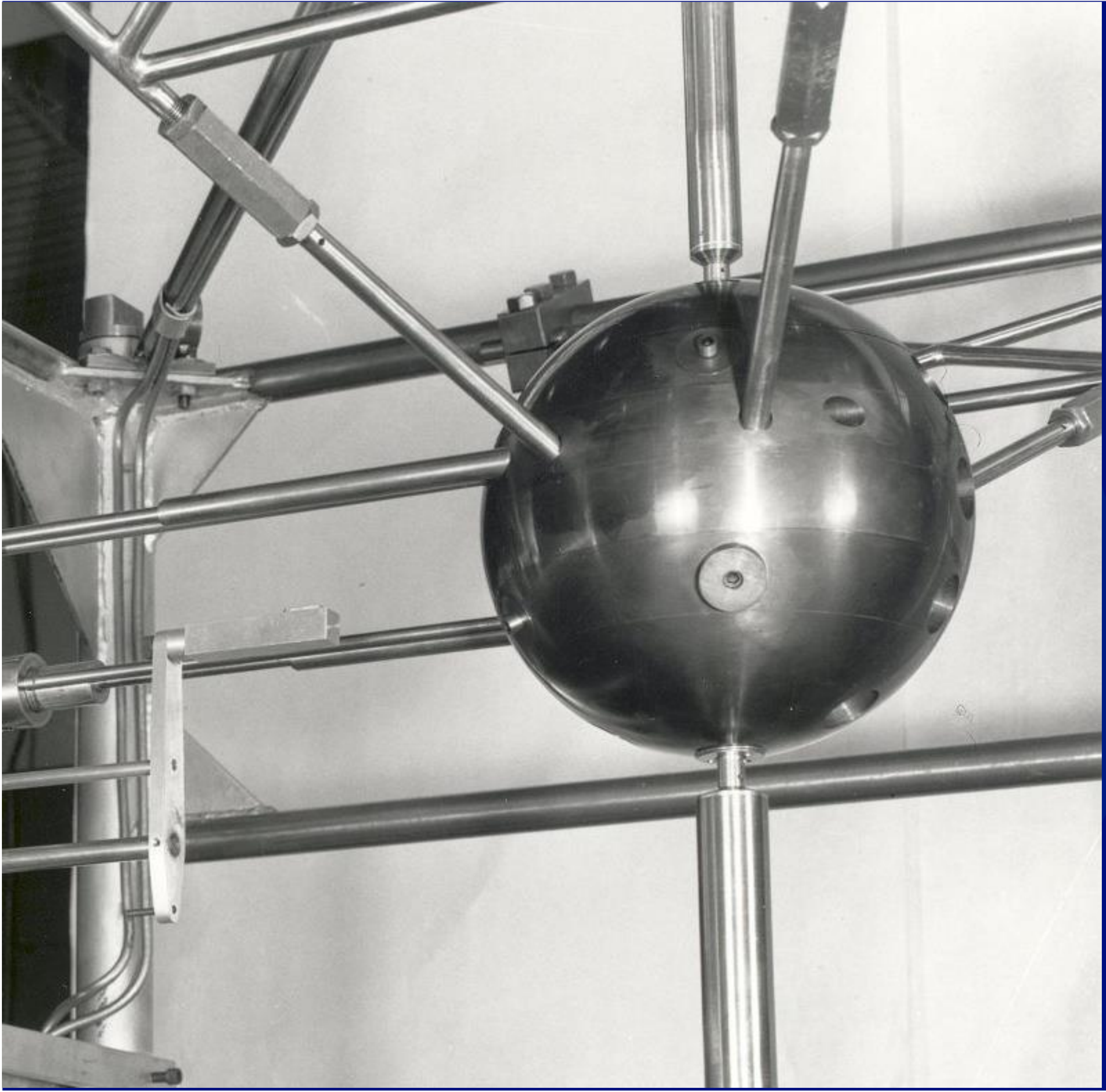

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Challenges in Explicit Modeling of TRISO in MCNP

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and Adrien Terricabras

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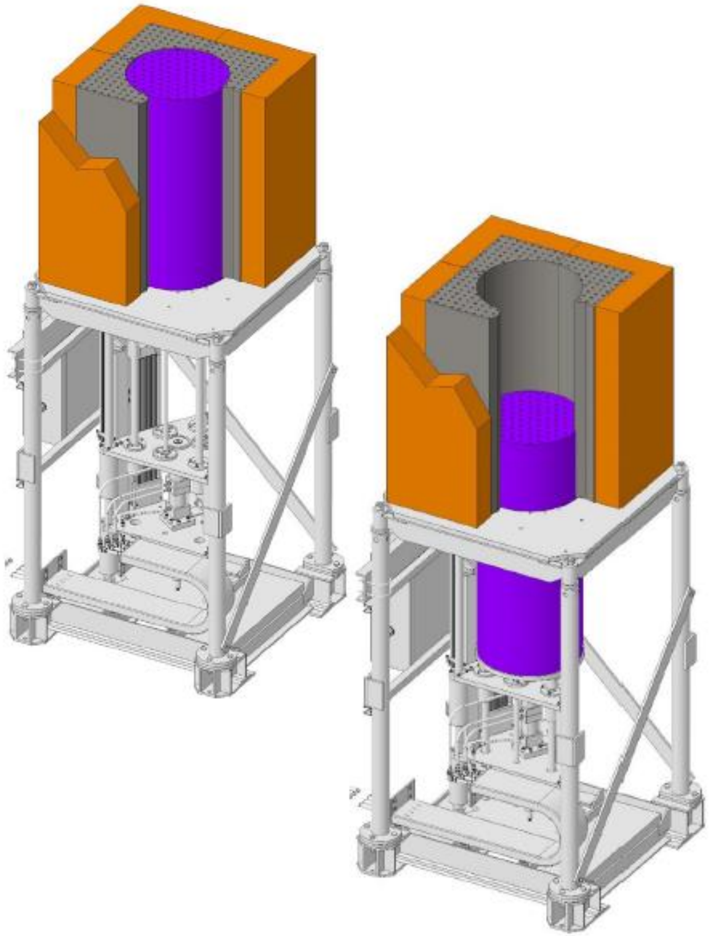
MCNP User Symposium 2025
Los Alamos, NM, USA
LA-UR-25-XXXXXXX

Overview

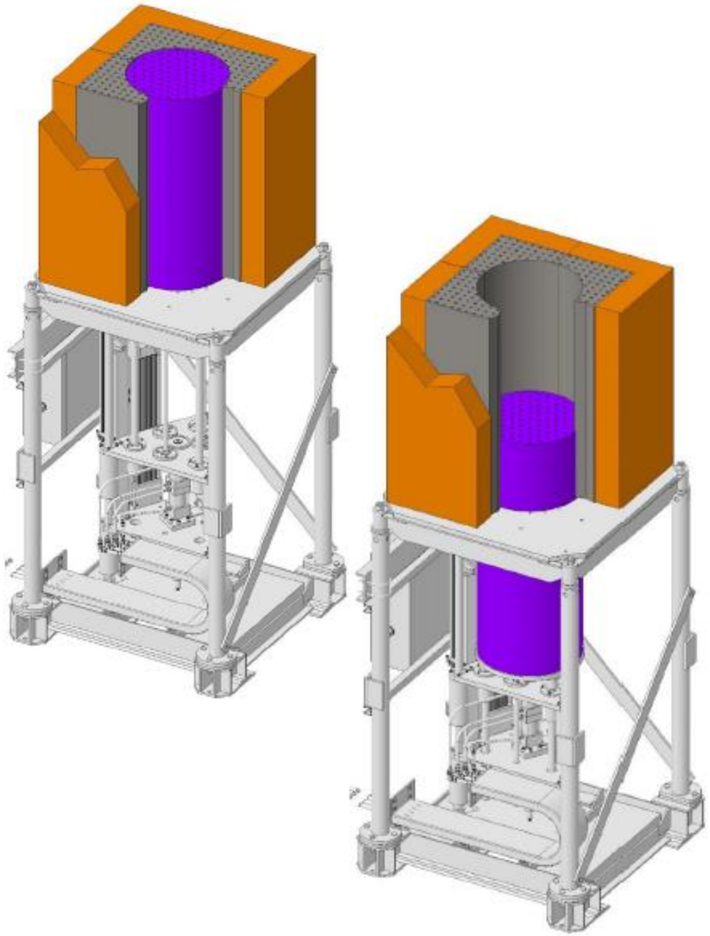
- Motivation and DNCSH
- Individual Particle Measurements
- Infinite Lattice Study
- Application Study
- Conclusions



Deimos Experiment

Advanced Reactor Testbed

- Los Alamos National Laboratory (LANL) Laboratory Directed Research and Development (LDRD) for advanced reactor testbed performed at National Criticality Experiments Research Center (NCERC)
- Graphite-moderated, beryllium reflected, HALEU TRi-structural ISOtropic (TRISO)
- Utilizes fuel from the Compact Nuclear Power Source (CNPS) experiments from LANL circa 1990s



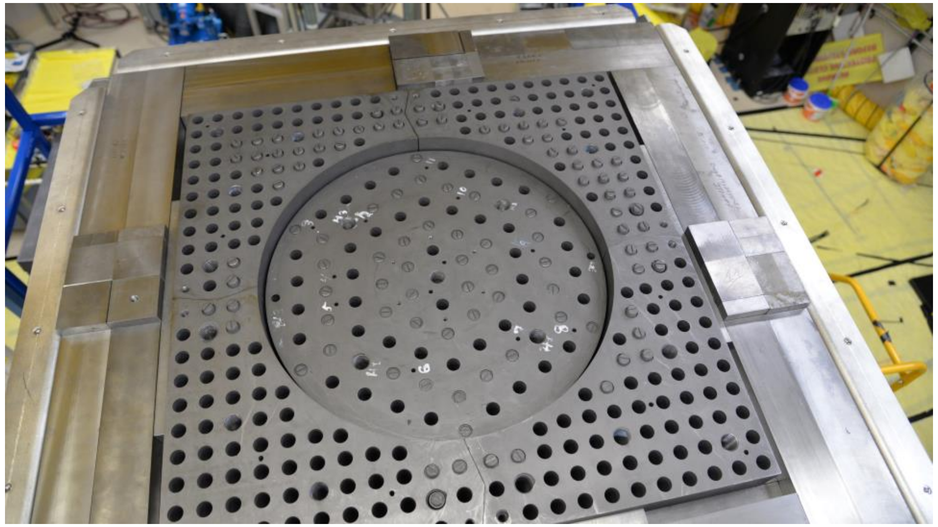
Deimos DNCSH

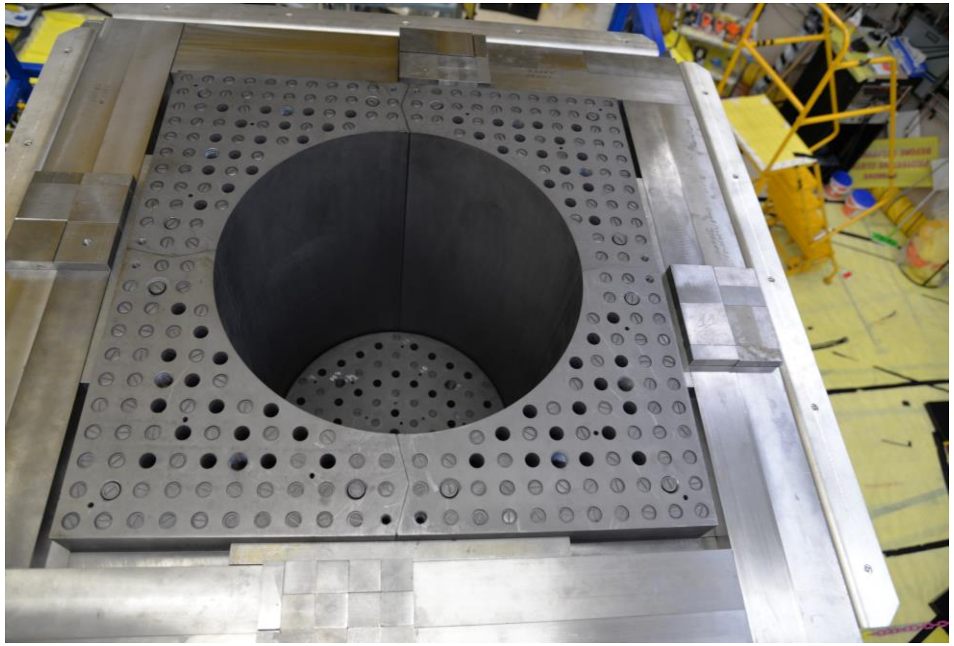
HALEU Transport Benchmark

- DOE NRC Collaboration for Criticality Support for …HALEU… (DNCSH) funded benchmarking of unheated core.
- **Five** configurations achieved for various void conditions of inner/outer core
- Foundation for Theta (Kairos) and eDeimos (Westinghouse)

Deimos Experimental Setup

- Both heated and unheated experiments
- Unheated configurations headed to ICSBEP for inclusion
- 5 critical configurations + 2 reproduction measurements (swap fuel cups) and 1 reconfiguration measurement (full core rebuild)



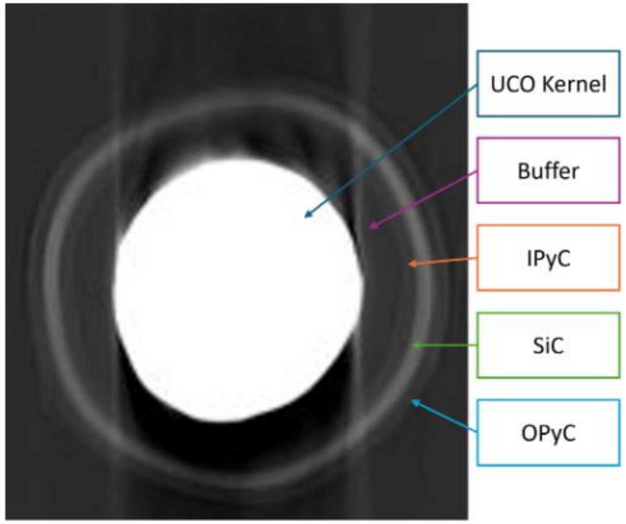


CNPS TRISO Compacts

Literature survey

- Manufactured by General Atomics in 1988
  - Packing Fraction ~60%
  - Enrichment ~ 19.9 w/t% U-5
  - 2” long x 0.5” diameter
  - 5 layers (kernel, buffer, Pyrolytic C, SiC, Pyrolytic C)
- Various literature through the years has vague and/or conflicting information
- Needed to perform various chemical and radiograph analysis of the CNPS compacts for benchmark

HALEU Fuel at NCERC



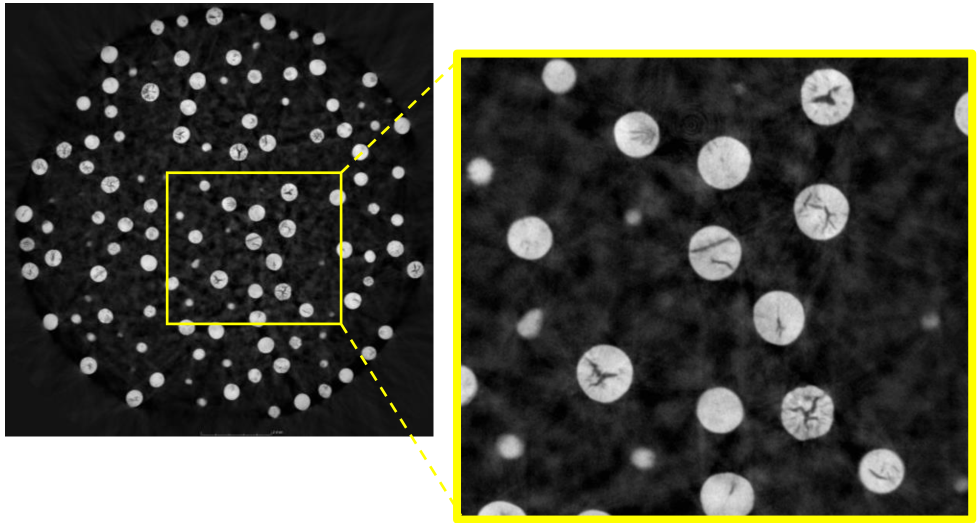
- TRISO particles are comprised of 5 concentric layers
- Innermost fuel kernel is 0.5 mm in diameter

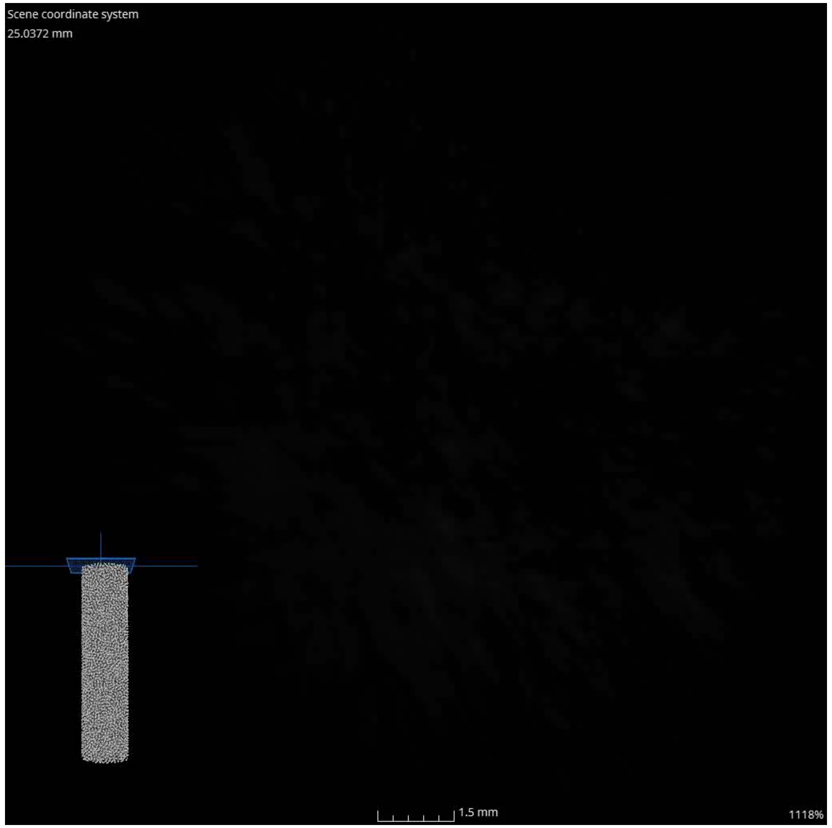
- ~11,500 TRISO particles are placed into a green graphite matrix and fired to form compact

- 19 CNPS compacts are then stacked into a fuel cup (fuel rod) made of graphite
- These cups serve as the discrete fuel for Deimos

Compact Tomographs

- CT scans show that almost all particles
  - Have voids/cracks
  - Are not perfectly spherical
  - Have varying kernel size (includes fully overcoated partial kernels)





Then and Now

Comparing Quantities of Note

PARAMETER	Literature	2024/2025 Analysis
Packing Fraction	60-66%	62.2%
Sphericity	N/A	0.90* ± 0.04
Kernel Diameter	506.5 µm	493.06 ± 17.53 µm
Buffer Thickness	79 µm	82.07 ± 10.53 µm
Inner Pyrolytic Carbon (IPyC)	33 µm	30.7 ± 2.88 µm
Silicon Carbide (SiC)	35 µm	33.67 ± 2.06 µm
Outer Pyrolytic Carbon (OPyC)	33 µm	33.27 ± 4.16 µm
Enrichment	19.894 ± 0.002%	19.906 ± 0.01%
Isotopic Impurities?	N/A	Obtained
Phase Mixture?	N/A	~89% UO_2, 1% UC, 10% UC_2

*Under Review

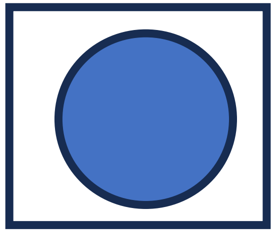
K-Infinity and Keff Studies

- CNPS TRISO compacts have much higher packing fraction than modern TRISO → What is the impact?
- Sphericity is normally neglected → How can this be investigated?
- TSL Treatment of UCO kernel?
- Transport speedups (Woodcock Tracking)?
- Fully randomize with distributions

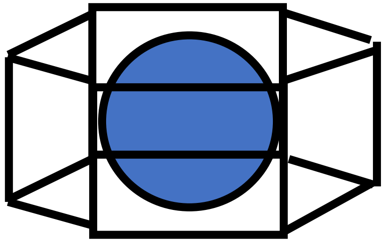
Packing Fraction in MCNP

How to generate high packing fraction in MCNP

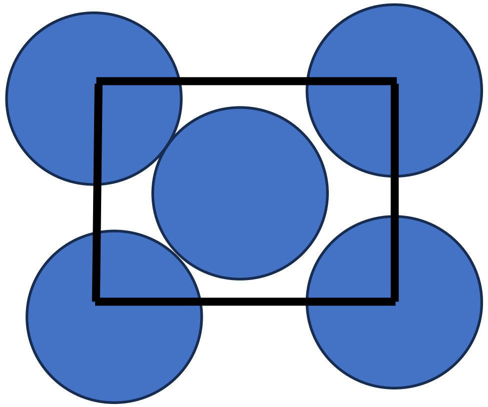
- In 3D geometries, Face Centered Cubic (FCC) has highest packing fraction
- However, using only two surfaces, MCNP can only get to 60.1%
  - FCC needs 14 surfaces, so not a killer on a small problem but explicitly loading a massive lattice starts to be a factor
- Is there a way to add a third lattice and shape (dodecahedron)?



PF ~ 50.1%



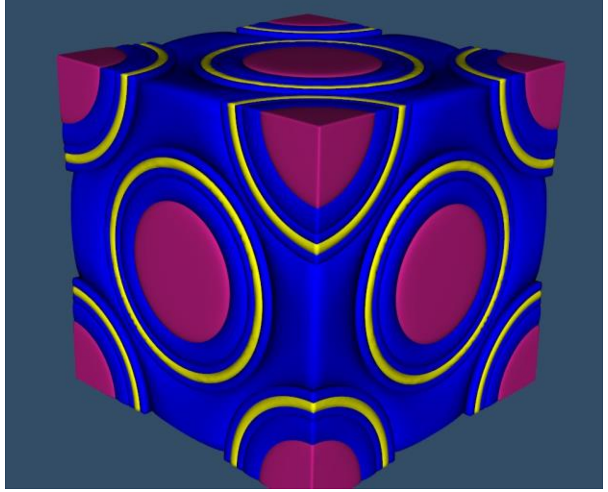
PF ~ 60.1%

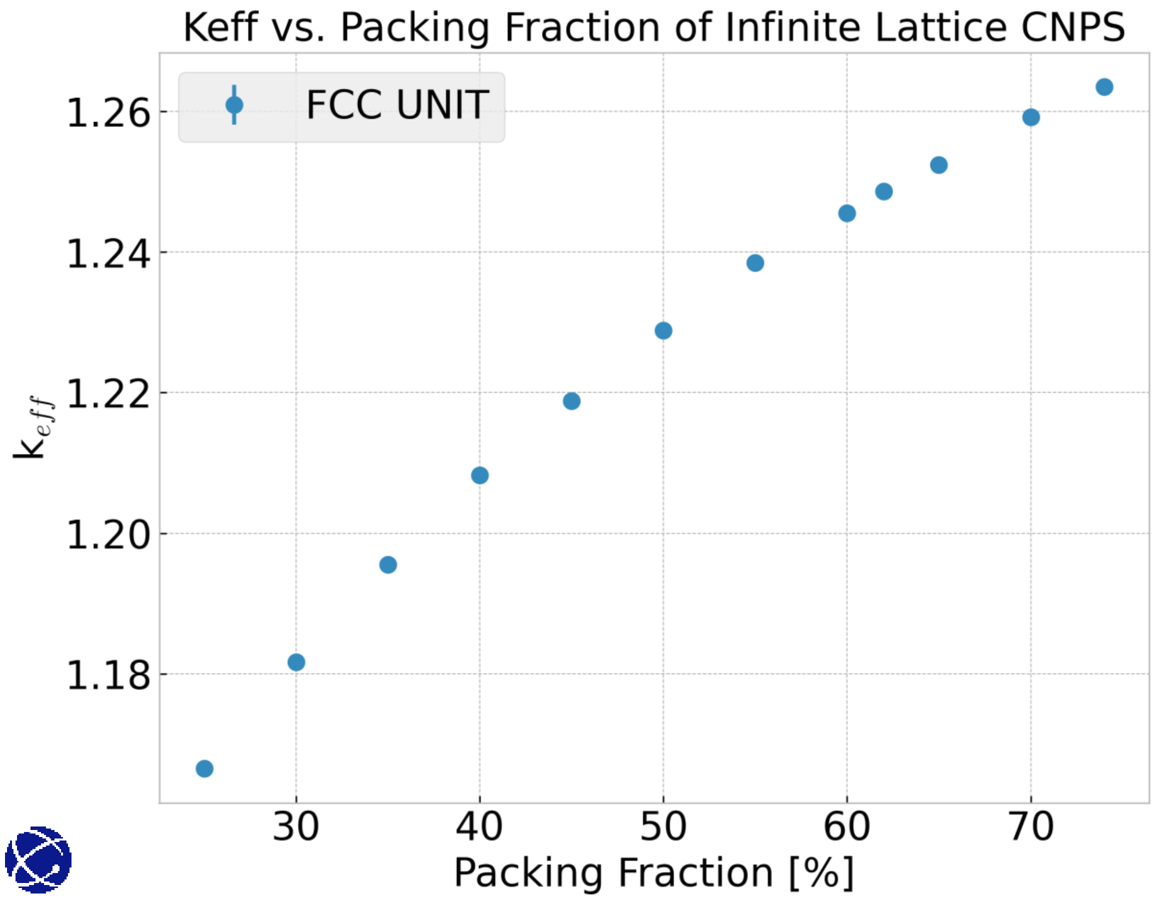


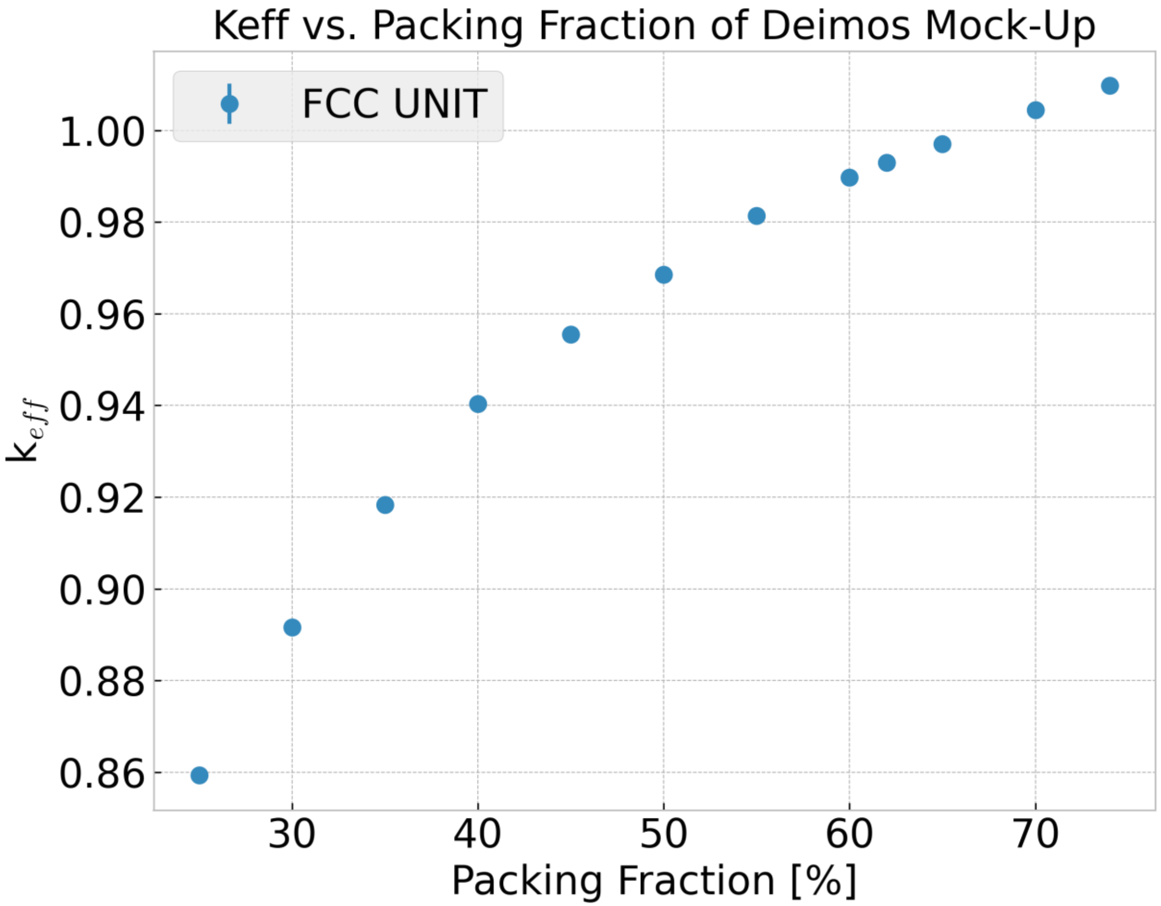
PF ~ 74.05%

Packing Fraction

- FCC lattice cell utilized in both simulations
- Deimos more sensitive due to neutron spectrum

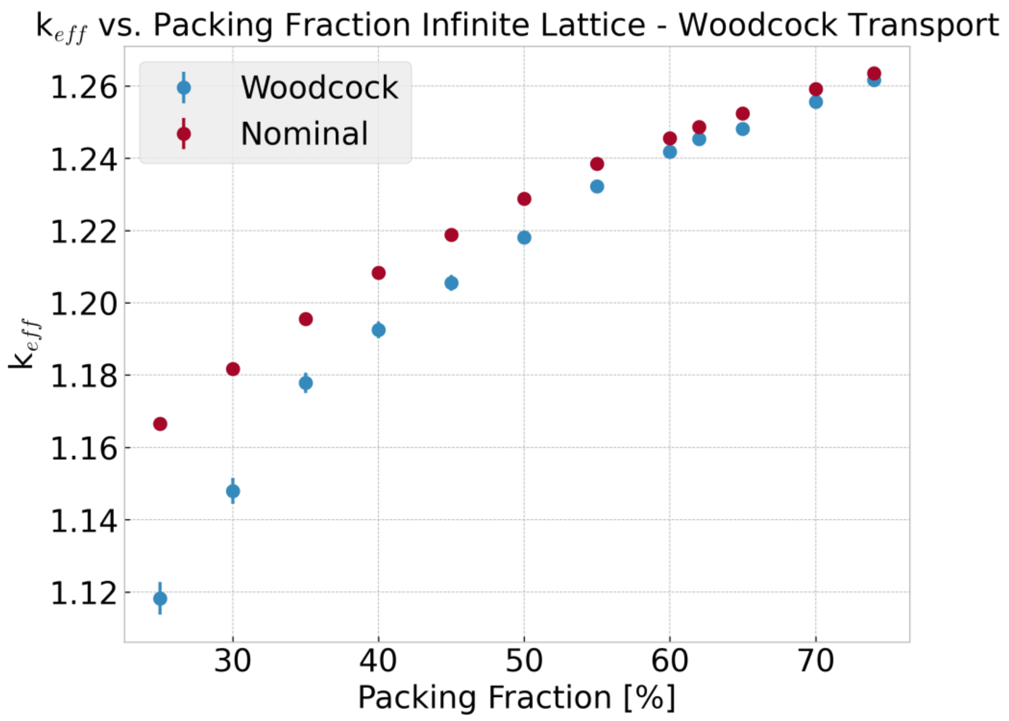


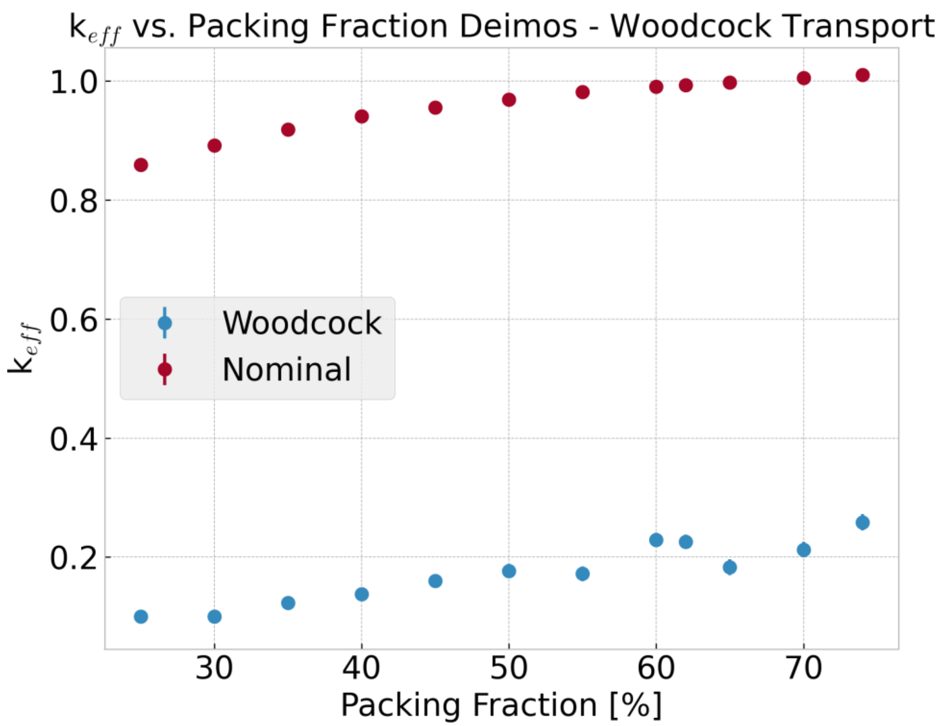




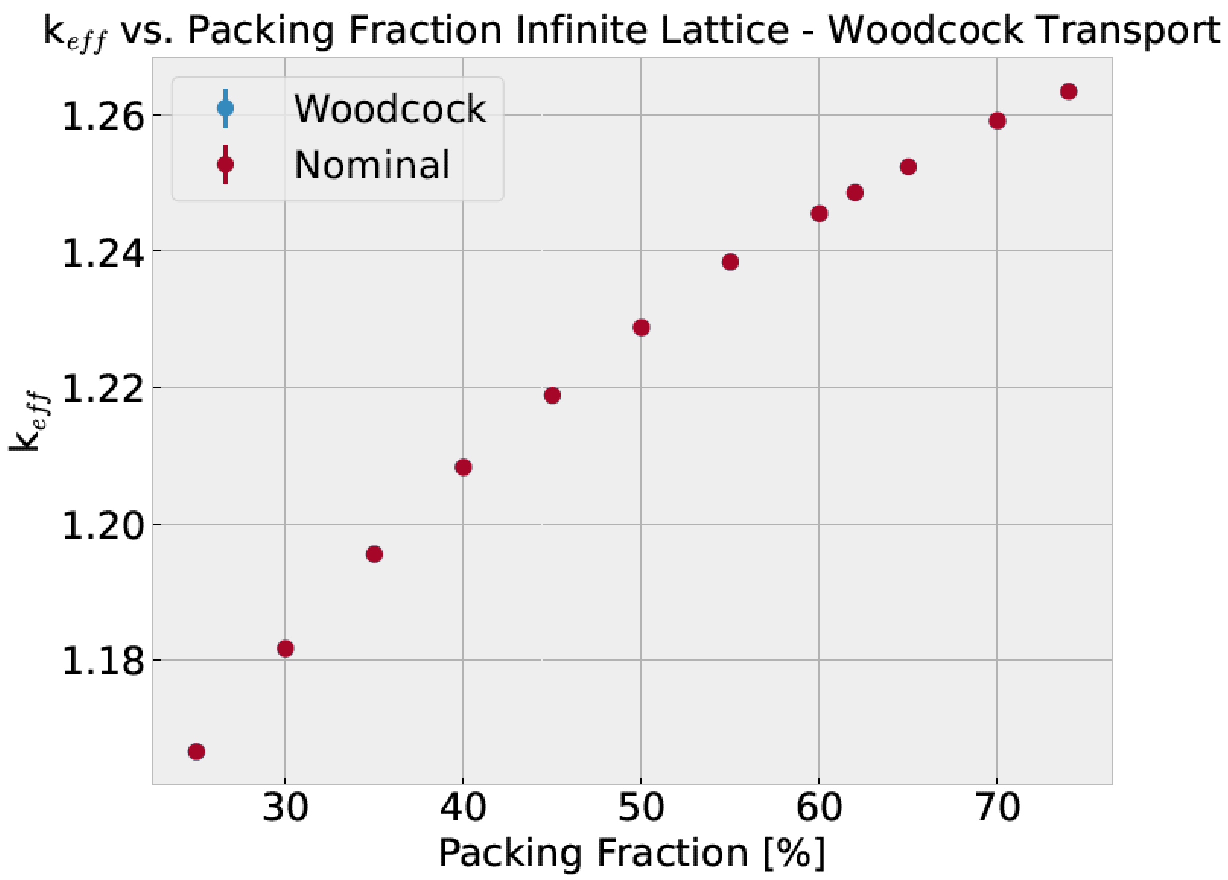
Woodcock Transport (Delta Tracking)

- On average, Delta tracking speeds up FCC infinite lattice by 10x and Deimos by 5x
- Answer no longer the same, most likely an issue with majorant cross section

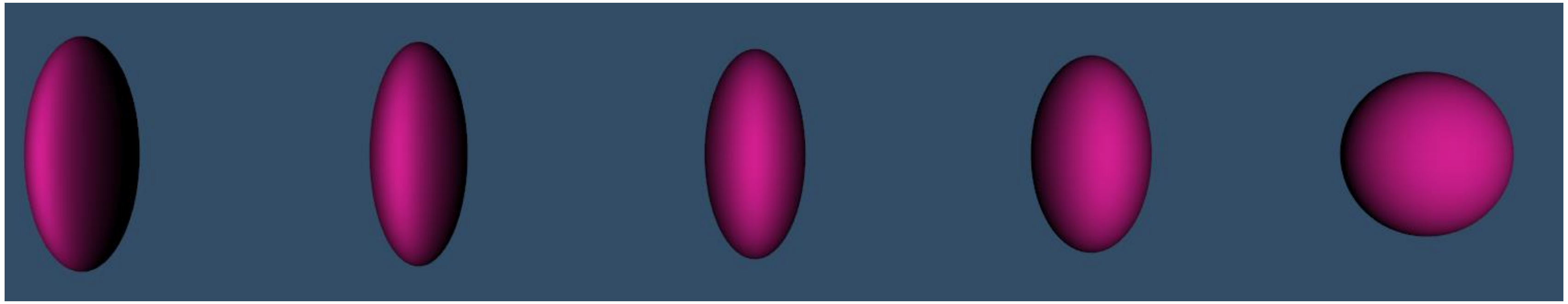




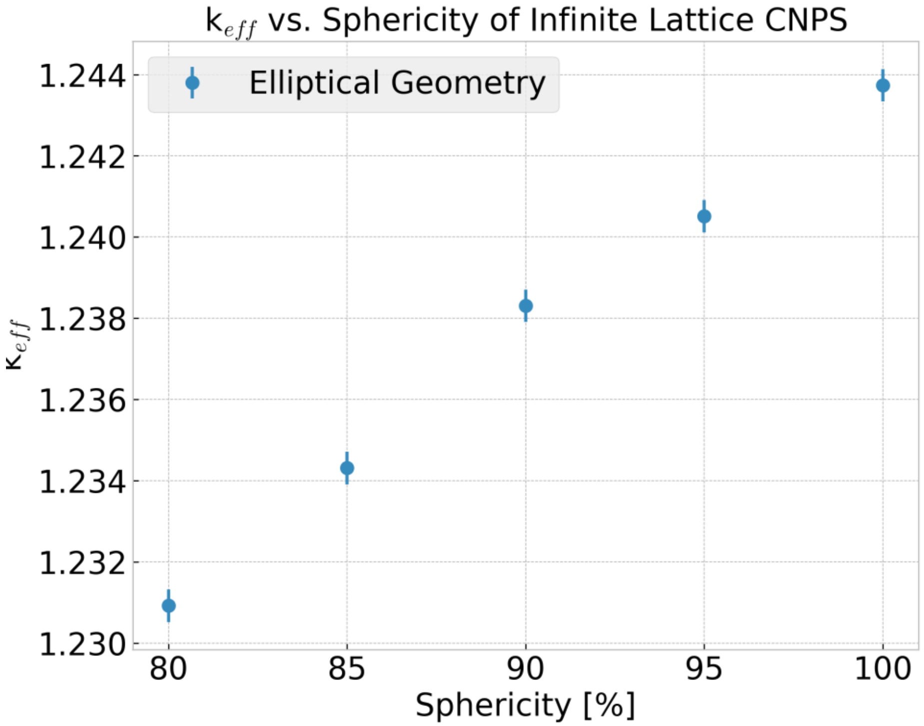
- Turned out to be an issue with adding UO_2 TSL data to the calculation
- Removing U- UO_2 fixed the calculation, maybe it's a leftover of the previous TSL issues with MCNP?

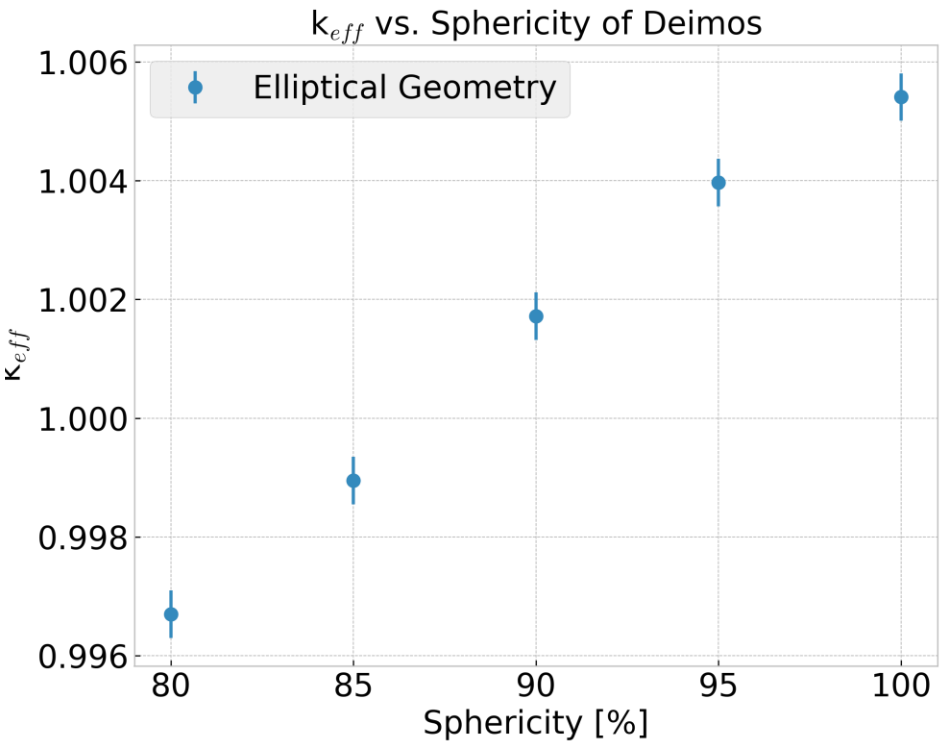


Sphericity



- Sphericity has large impact on reactivity
  - Infinite lattice ~ 65 pcm/%, Deimos shows ~45 pcm/%

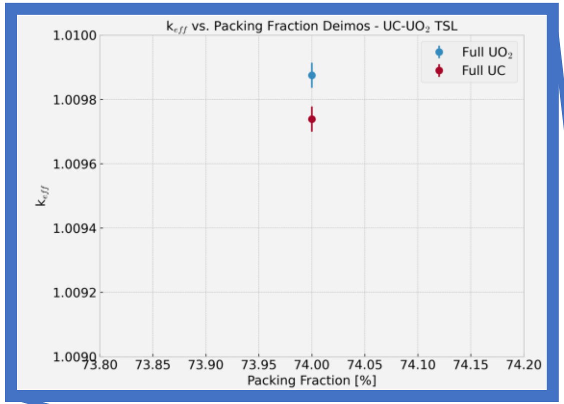


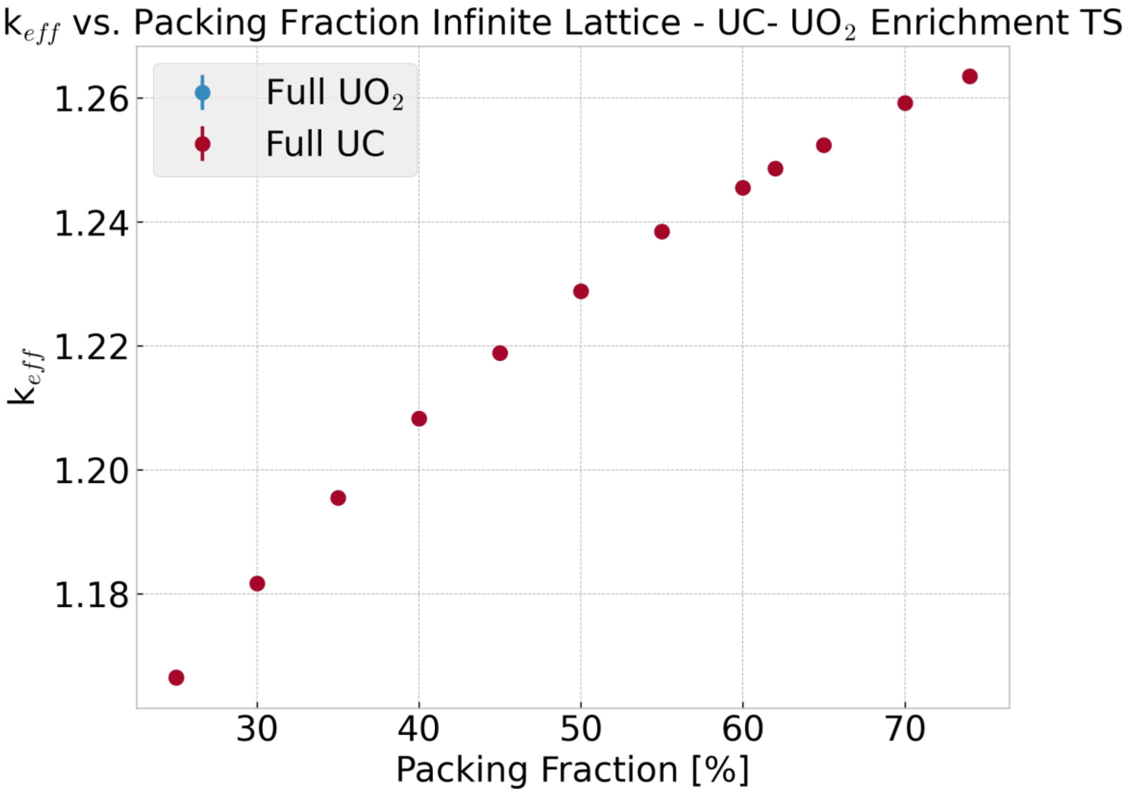


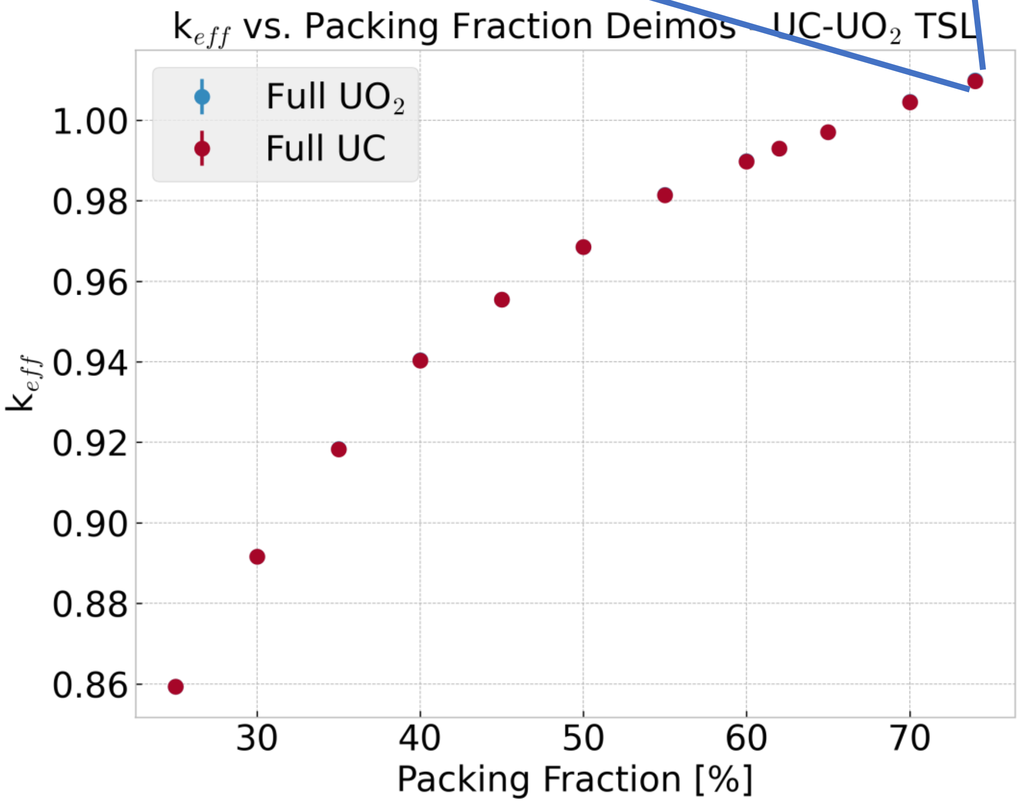
TSLs for Uranium Phases

Does the UC/ UO_2 / UC_2 matter?

- Above 60% there is a slight difference between full UC and UO_2 TSLs for Deimos – max 14 pcm
- Otherwise, UC and UO_2 calculate the same

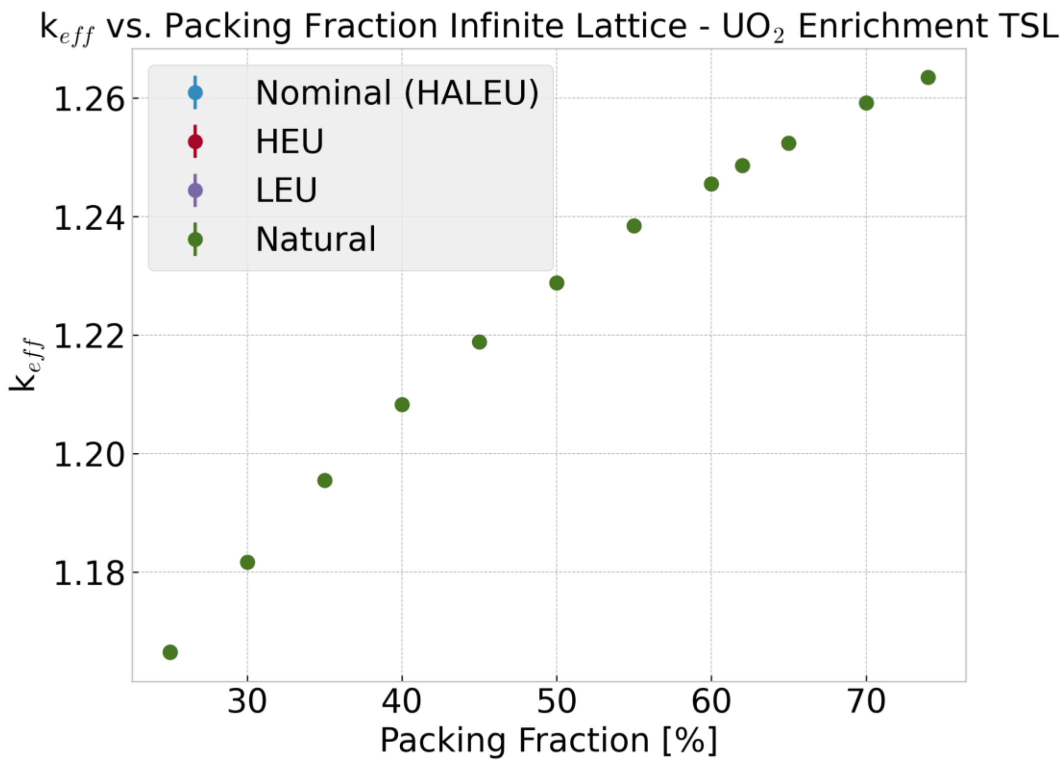


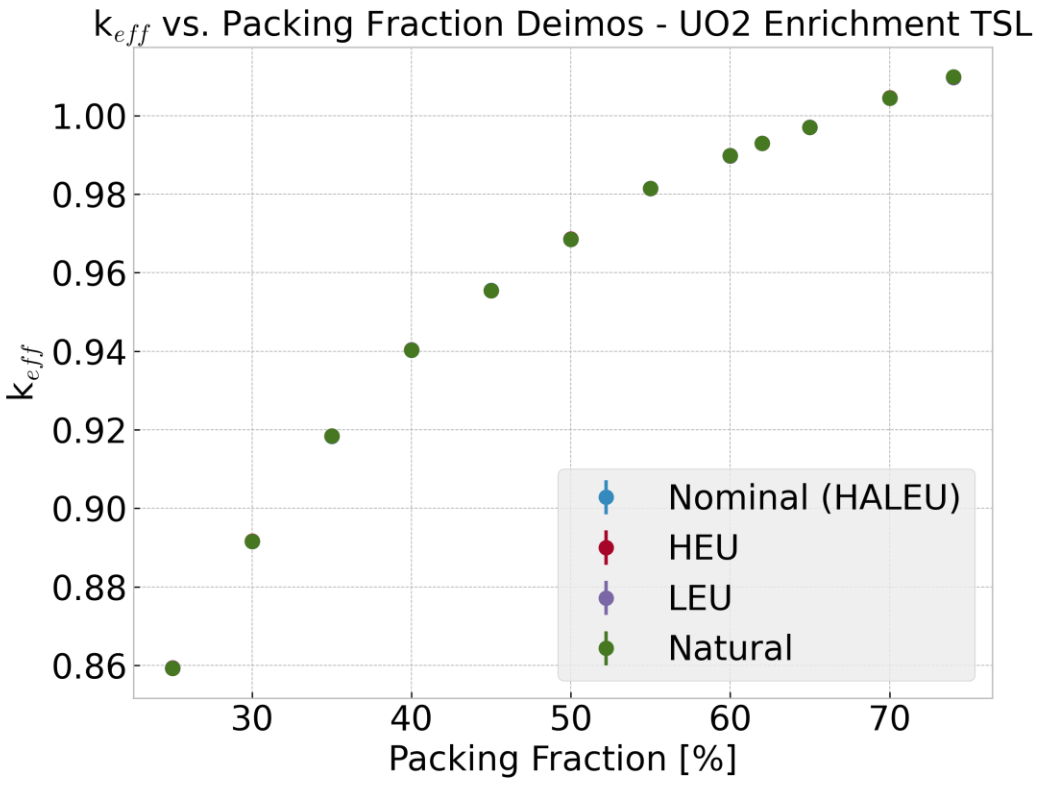




TSLs for Uranium Enrichment

- With ENDF/B-VIII.1 release, there are now enrichment specific uranium TSLs
- All TSLs performed within their combined uncertainty < 8 pcm





Mixed Material Card Capabilities

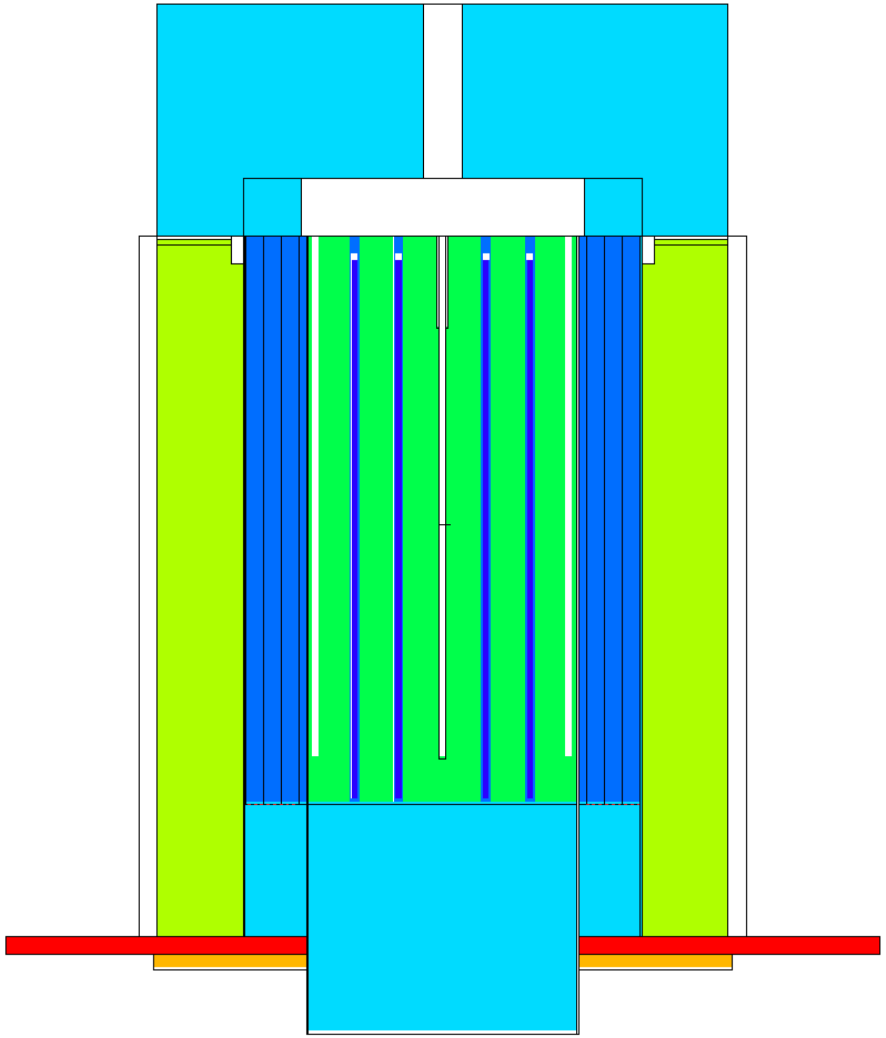
Linearly combine different material cards

- While the TSLs of enrichment and uranium phases don't impact keff in these studies
- Material mixing would be helpful for other applications (get around TSL per every degree, phase, enrichment)
  - Aqueous processing applications (HF + H_2O)
  - FLiBe transmutation in advanced reactors
  - Hydride moderators during accident scenarios (ZrH_x, YH_x)

Photon Transport in Eigenvalue Problems

Be (y,nx) reactions

- Need to handle delayed photons from fission contributing to neutrons in kcode problem
- Experimentally, we’ve seen the baseline neutron population double when in shutdown
- Application of shutdown dose and restarting advanced reactors



Conclusion

MCNP is adequate at modeling TRISO

- Current capabilities in MCNP allow for full modeling of TRISO particles to handle uncertainties
- Areas of work that would be beneficial
  - Material mixing (TSL, Heterogeneous materials)
  - Photoneutron reactions in eigenvalue problems (D_2O, Be)
  - Dodecahedron lattice structure

Acknowledgements

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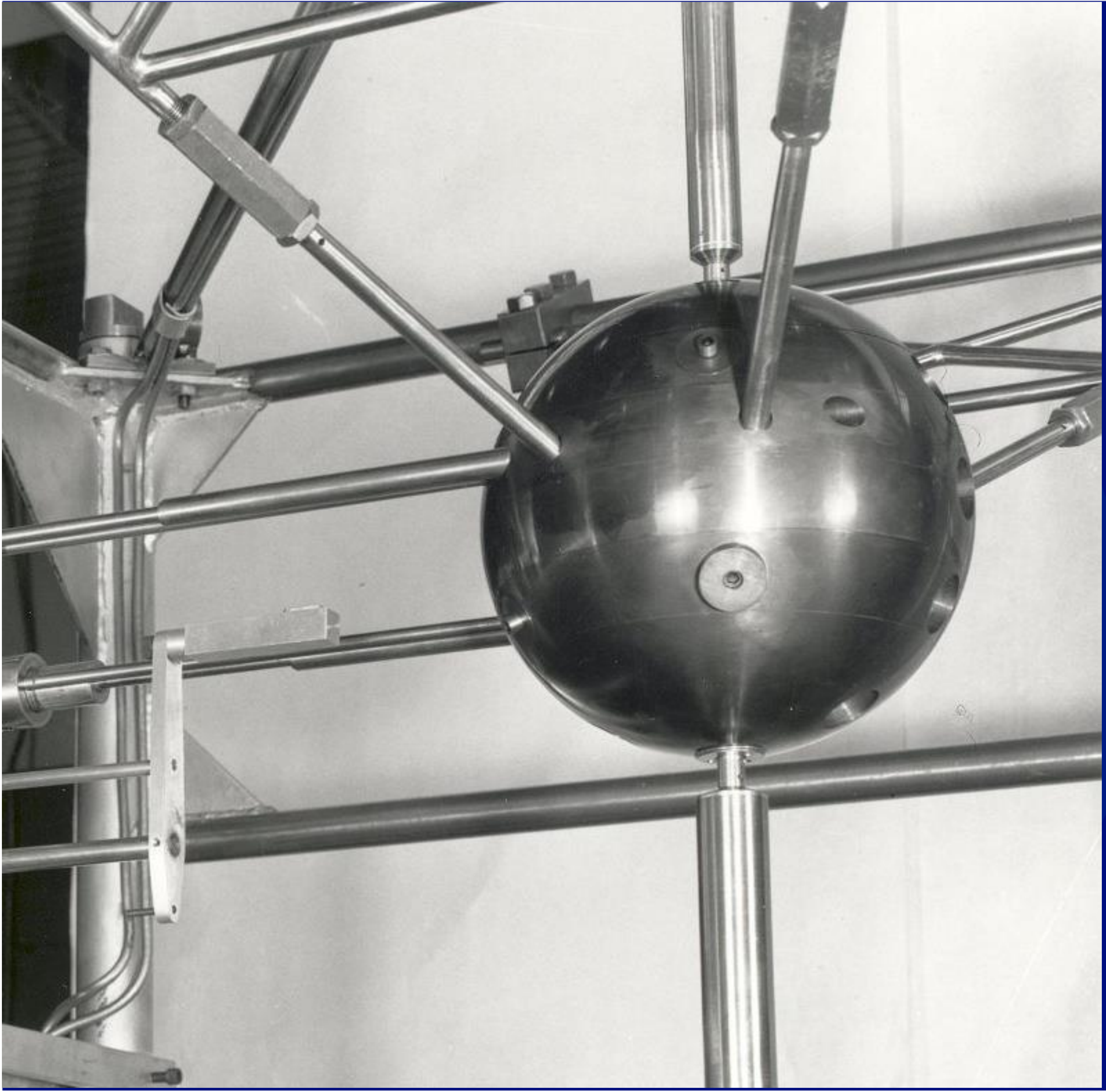

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