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Title: Small Fission Reactors for Space and Terrestrial Applications

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Small Fission Reactors for Space and Terrestrial Applications

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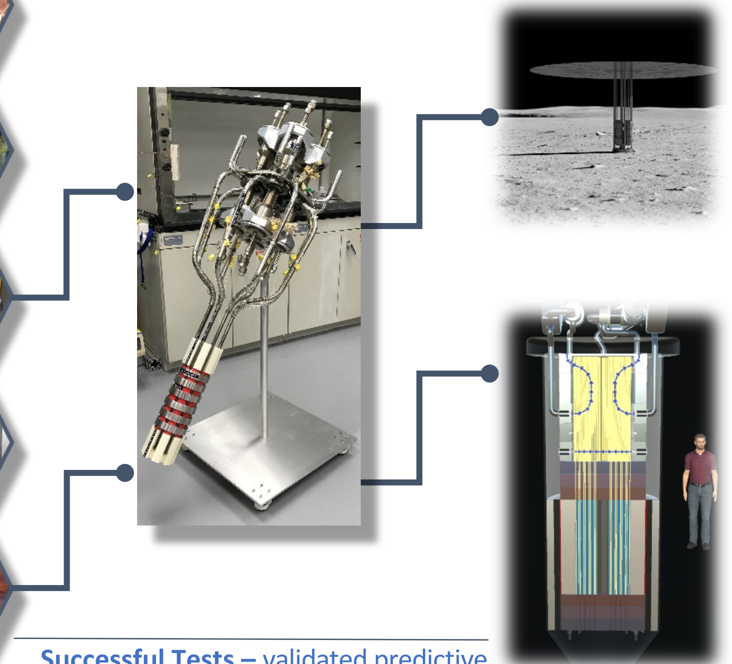
Outline

- History and overview of LANL capabilities
- Overview of microreactor program
- Space reactors
- Terrestrial reactors
- Critical experiments
- Computational modeling

KiloPower prototype tested at the National Criticality Experiments Research Center (NCERC) in collaboration with NASA [1]



Successful Tests – validated predictive computational models & simulations, served as a proof-of-concept

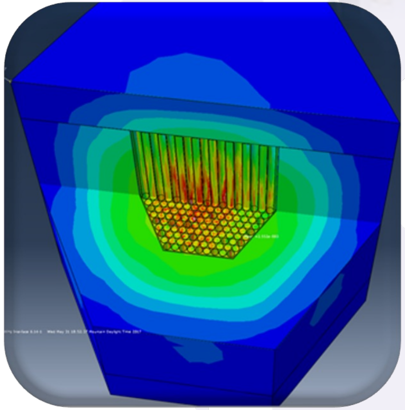
Heritage Space Reactors

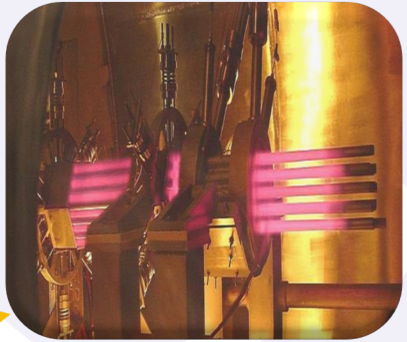
- 1965 USA
  - **SNAP 10A**
    - High-enriched uranium (HEU) moderated system
    - 1 flown – first nuclear reactor in orbit
    - Suffered moderator hydrogen loss
- 1967 – late 1980s Soviet Union
  - **BUK**
    - HEU fast system
    - 31 flown
    - 1 crashed over Canada
  - **TOPAZ**
    - HEU moderated system
    - 2 flown
    - Design addressed hydrogen loss
    - USA purchased and tested 6 units without fuel

Systems for Nuclear Auxiliary Power (SNAP 10A) [2]

Science-based Design & Testing

- National Nuclear Security Administration (NNSA) resources [3]
  - Nuclear experiment testing at NCERC
  - Collaboration with multidisciplinary experts
  - High-Performance Computing





High-fidelity methods

Neutronics

MCNP (XCP-3, XCP-5)

- Flux/power
- Fuel depletion
- Cross sections

$q'''(\vec{r})$ →

← $T(\vec{r})$, $\rho(\vec{r})$

Thermomechanics

ABAQUS

- Temperature
- Density
- Stress/creep

Integrated transient multiphysics

$\Sigma\,(\vec{r}, E)$

MOOSE (MST-8, INL, ANL)

- Flux/power
- Temperature
- Density
- Pressure
- Stress/creep
- Fuel performance

Reduced-order methods

Integrated transient multiphysics

FRINK

- Power
- Temperature
- Stress/creep

Integrated transient multiphysics

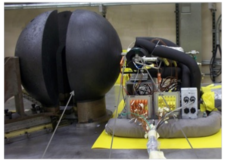
TRACE (NRC)

- Power
- Temperature
- Density
- Pressure

V&V

Experimental reactor operation

DUFF

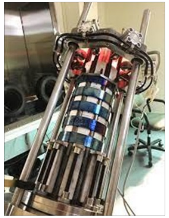


NASA
NNSA
NNSS
NSTec
LDRD

- Attached heatpipe w/ Stirling engine to existing critical experiment (Flattop)
- Operated at 24 watts
- Demonstrated heatpipe and Stirling engine fission heat removal

- Brand-new reactor experiment
- Monolith U-Mo core, heatpipes, and Stirling engines
- Steady-state and transient testing

KRUSTY



NASA
NNSA
NNSS
Y-12

R&D areas:

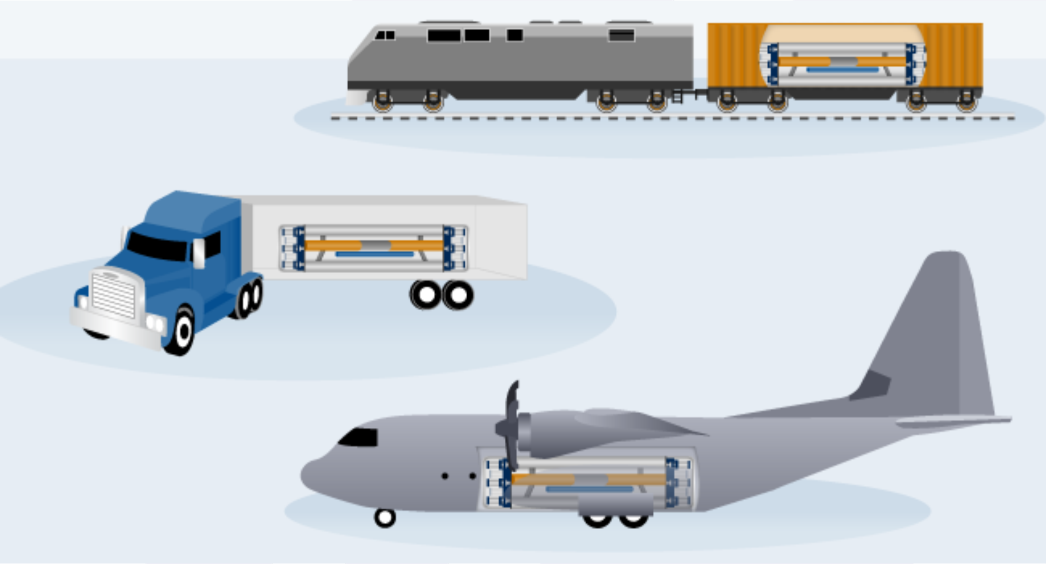
- Reactor concept development
- Predictive performance
- Nuclear criticality testing
- Component advancement
- Safety and security

NCERC
NATIONAL CRITICALITY EXPERIMENTS RESEARCH CENTER

Los Alamos
NATIONAL LABORATORY

Microreactors

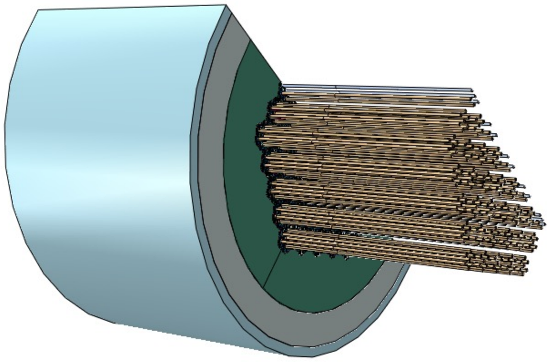
- Advanced reactor concept, compact, less than 20 MW_{th}
- Smaller size means easier to ship to remote regions
  - Arctic environments, military operations, oil exploration, disaster relief
- Reactor core and heat transfer mechanisms fully contained
  - Does not require environment to aid in cooling fuel, such as large bodies of water

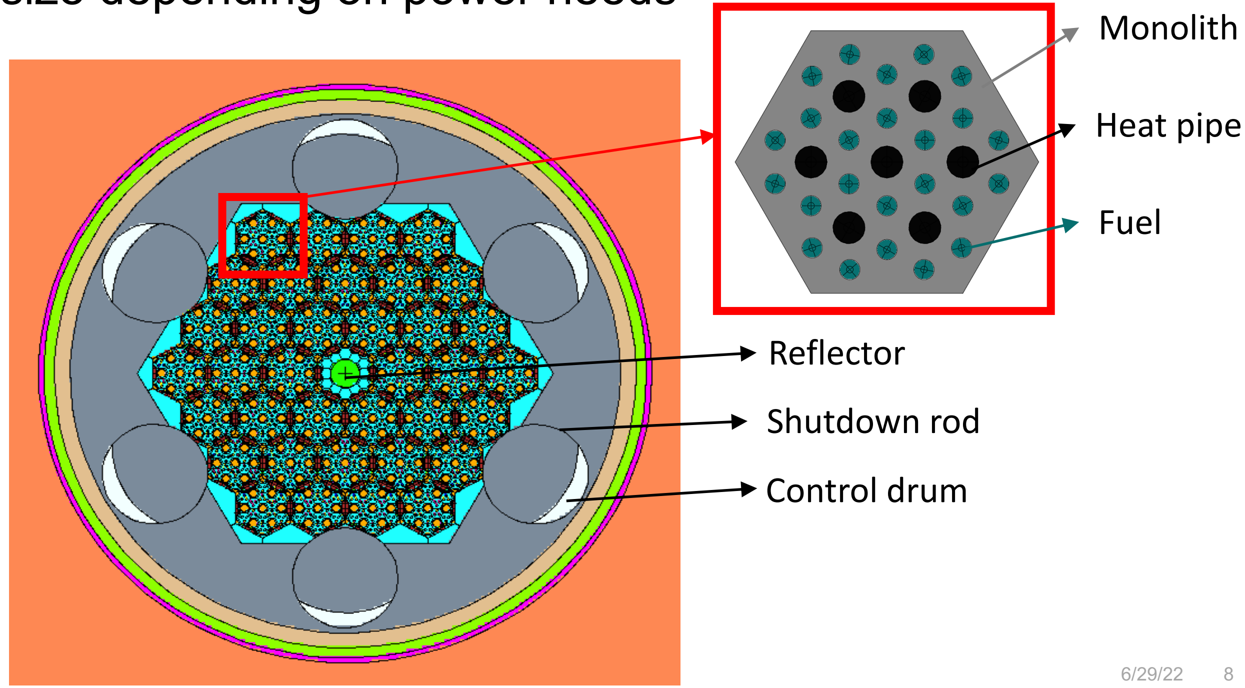


Microreactor shipping options [4]

Conceptual Microreactor Design, Snowflake

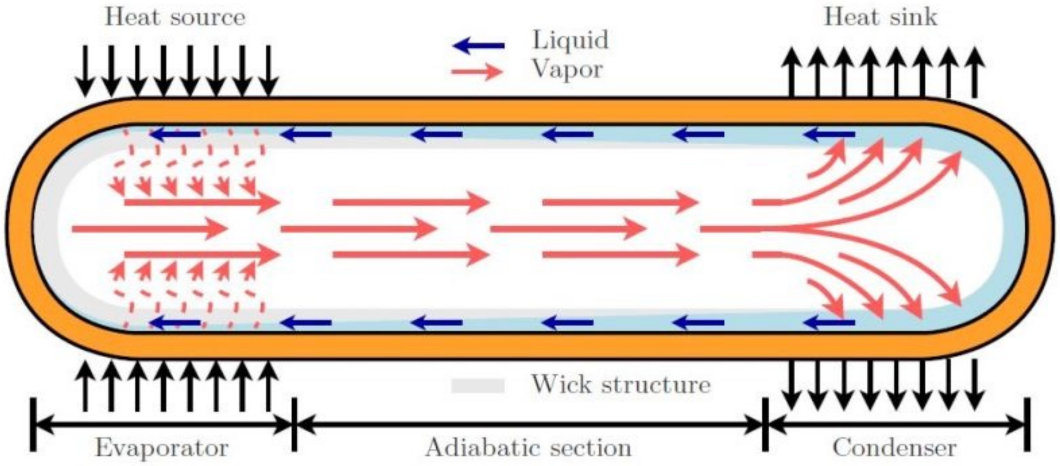
- Solid graphite block with holes for fuel, heat pipes, and moderator [5]
- Can be built to specific size depending on power needs





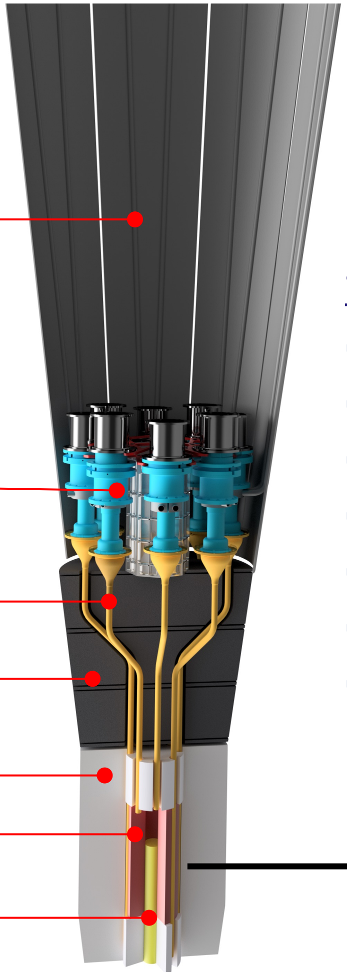
Heat Pipes – LANL technology

- Primary heat transfer mechanism
- Capillary design utilizes wick to separate two-phase fluids
- Working fluid dependent on reactor temperature
  - Sodium is chosen for Snowflake
  - Fully-contained in rod
  - No pumps, works in any orientation
- Hundreds of heat pipes in a microreactor



Heat Pipe Schematic [6]

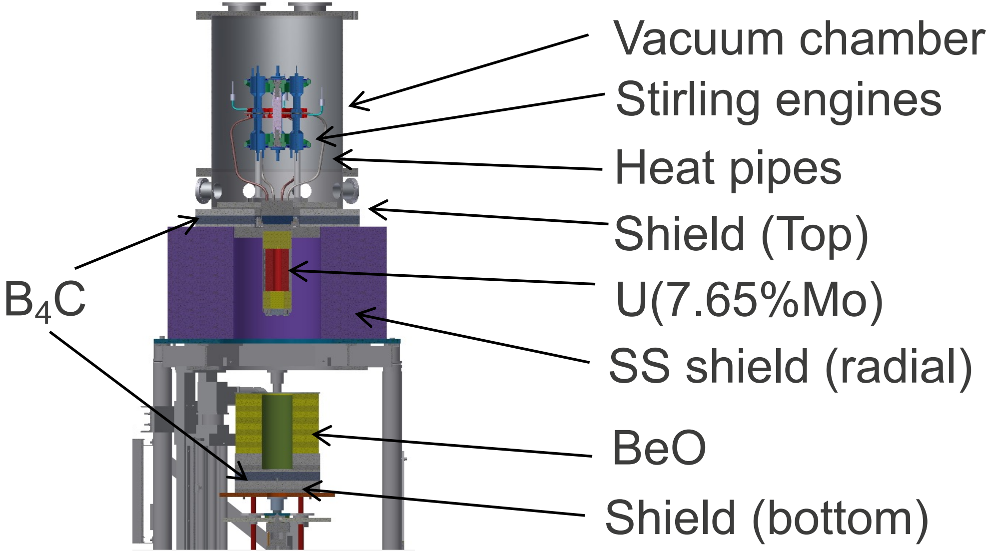
KRUSTY Design

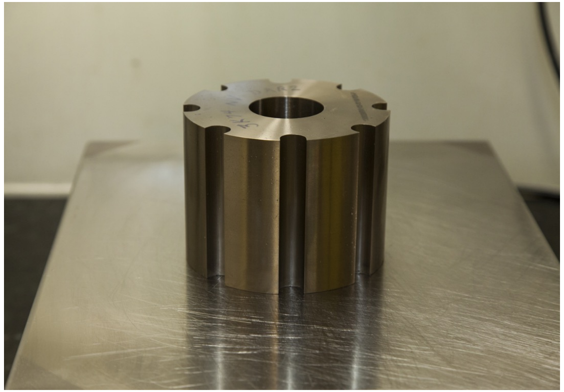


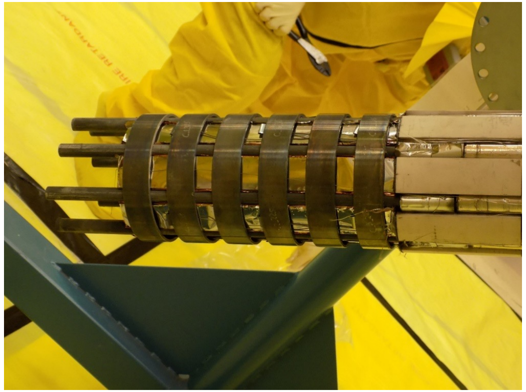
<u>7 COMPONENTS</u>

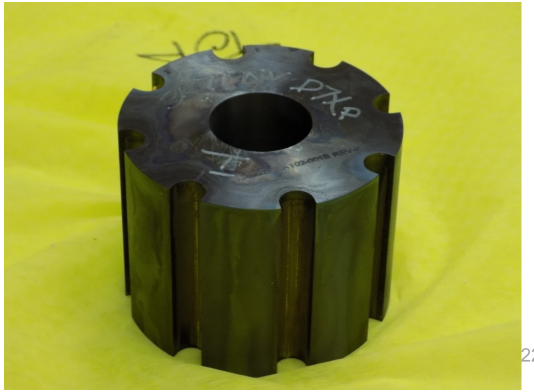
- Core
- Neutron reflector
- Heat pipes
- Radiation shielding
- Start-stop rod
- Stirling engine convertors
- Radiator to remove excess heat

Kilopower Reactor Using Stirling Technology (KRUSTY)







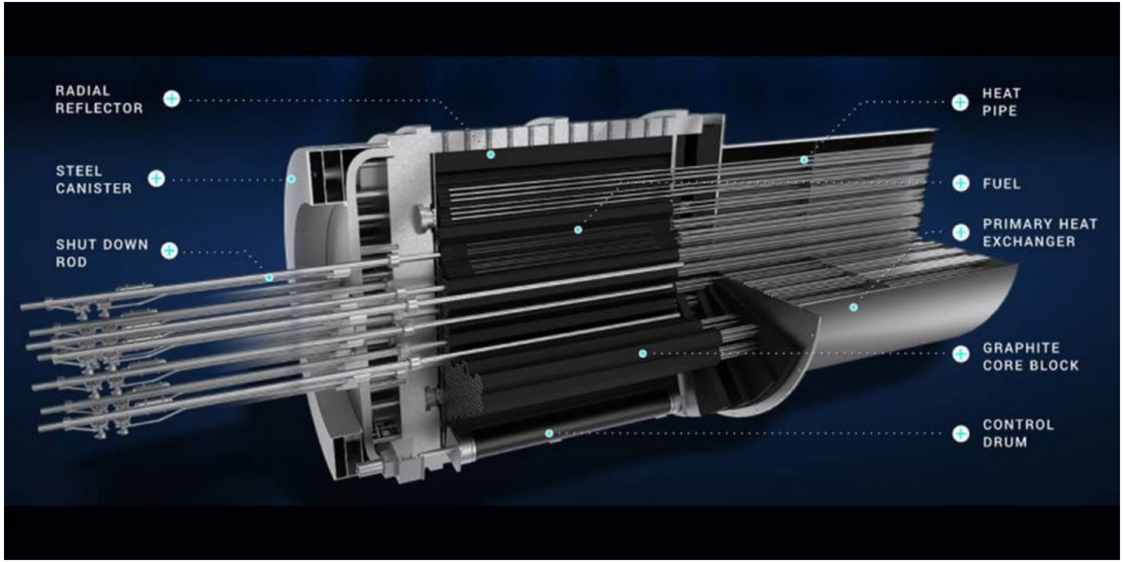


Artemis Program
Fission Surface Power on the Moon 2027

- Collaboration with NASA
- Nuclear fission reactor, will provide 40 kWe for a base [7]
- LANL assisting with reactor design development and materials technology maturation

Terrestrial Microreactors

- Commercial partner: Westinghouse Electric Company [8]
- LANL assisting with overall reactor and component design, as well as nuclear experiment design, planning, and execution

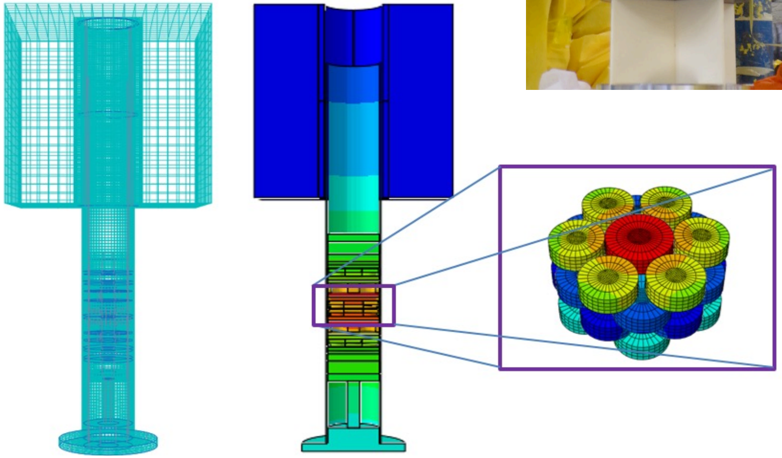


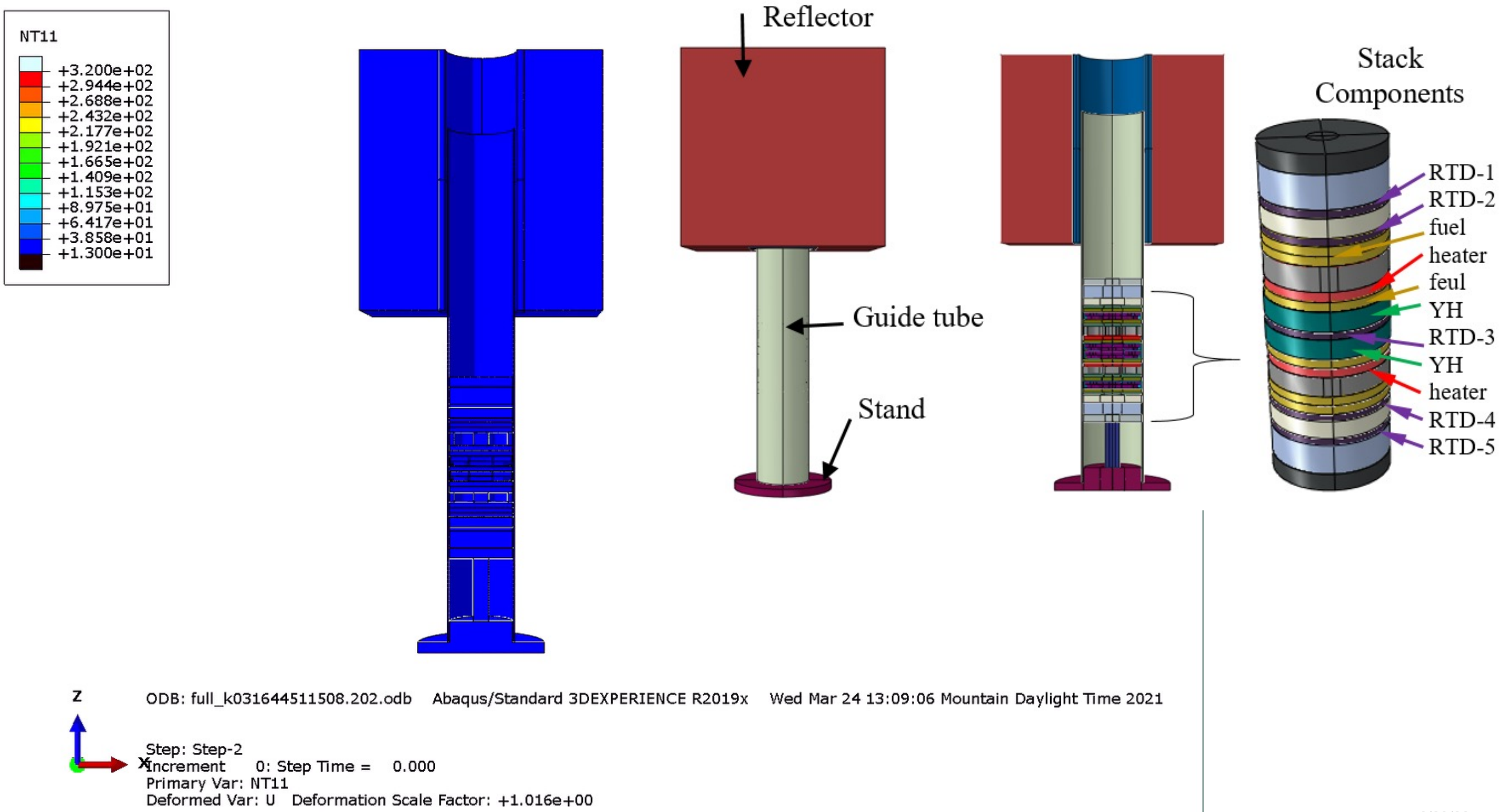
Why conduct a nuclear experiment?

- Nuclear experiments are necessary for validating predictive physics codes and data
- Serve as a precursor to a full-scale prototype
- Limitations:
  - Small volume to work with – need sufficient reactivity in small space
  - The size, configuration, and materials of the experiment will affect the similarity between the two systems
  - Facility limitations on excess reactivity, activation, safety, etc.

Hypatia – Metal Hydride Moderator Advancement

- Hypatia is a critical experiment conducted at NCERC in Jan 2021 [9]
- A measurement campaign for Yttrium Hydride (YH) – a high-temperature moderator material for advanced systems [9]
- Purpose: Validate temperature dependent reactivity feedback for YH
- Planning additional material maturation nuclear experiments to support small reactor designs

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+1.409e+02
+1.153e+02
+8.975e+01
+6.417e+01
+3.858e+01
+1.300e+01
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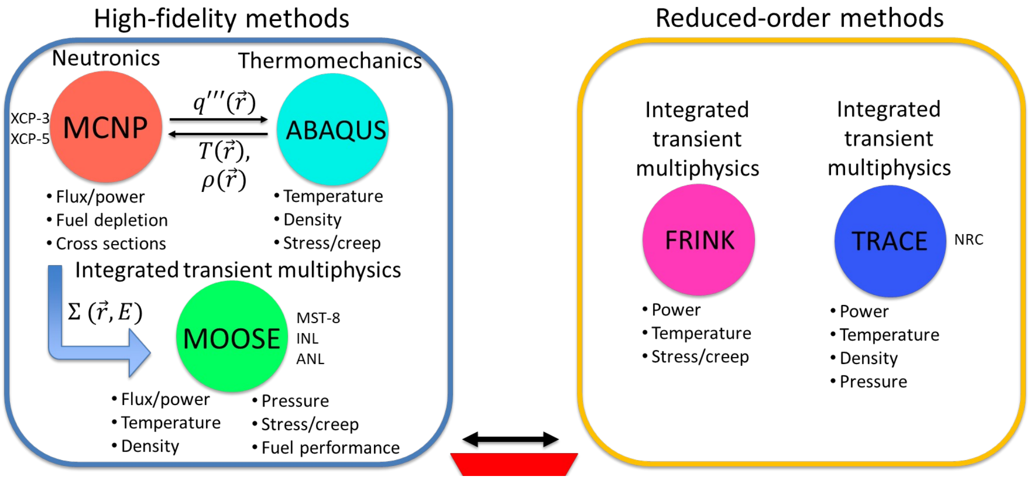
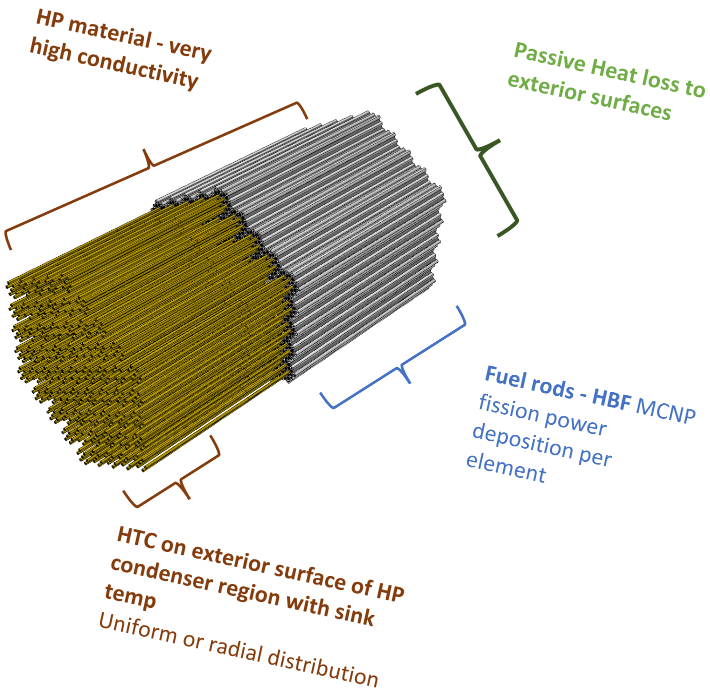
Multiphysics Modeling & Simulation

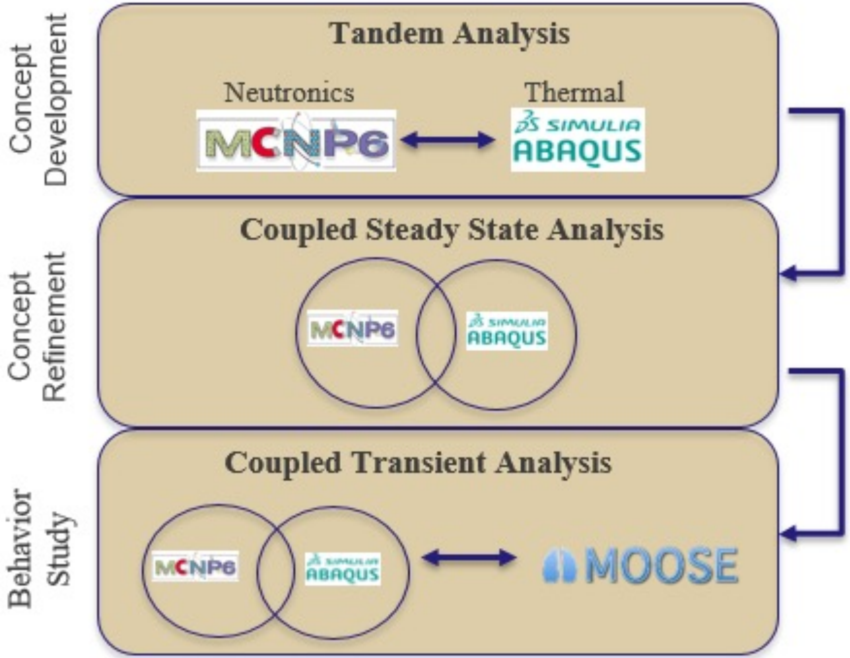
- Small nuclear systems are particularly tightly-coupled systems – each physics of the system talks to each other
- This requires multiphysics M&S

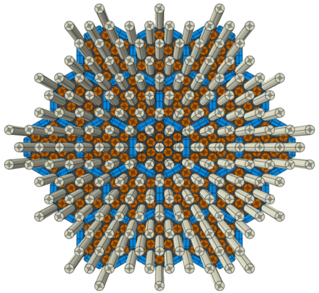


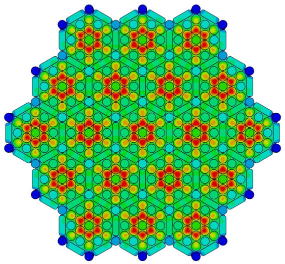


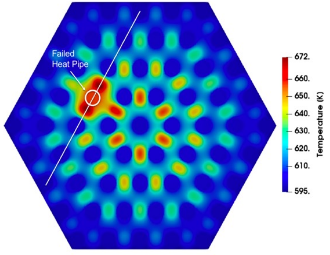
M&S Capabilities

- Novel reactor concept development
- High fidelity modeling of full and partial 3-D reactor cores
- Heat pipe modeling (characterization and failure modes)
- Modification to MCNP for unstructured mesh geometry
- Reactor behavior
- Comparison of different code suites
- Validation (nuclear experiments)









Summary

- History and overview of LANL capabilities
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- Terrestrial reactors
- Critical experiments
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References

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High temperature 28 hour run, with transients