Deimos Critical Experiment Next Generation Small Nuclear Reactors

Theresa Cutler
Alexis Maldonado, Kristin Stolte, Rene Sanchez, Holly Trellue, Justin Lee, Erik Luther, Nicholas Wynne, John Downey, Scott Stinson

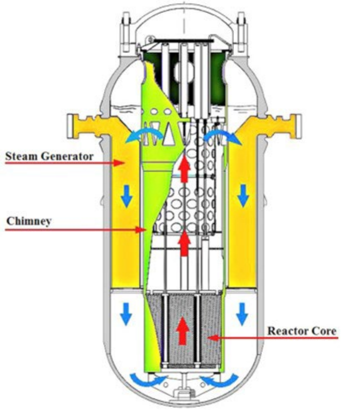
NCSP TPR February 2023

LA-UR-23-21620

Microreactors – overview

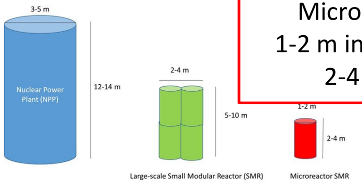
- Emerging new nuclear technology around the world; LANL wide breadth of knowledge allows us to play role in technology maturation.
- Type of small modular reactor (SMR), which is integral (i.e. all parts of the system in one container) and can be built as modules and shipped.
- Power is 0.1-20 MWt (0.03-6 MWe) to provide small, mobile power sources.
- Applications include:
  - Defense
  - Microgrids/ground operations
  - Mining/industrial (i.e. oil exploration).
  - Remote villages/disaster relief
- Can be transported on the back of a semi-truck or transport aircraft such as C-17 or C-130.

- Experiments needed to support fuel fabrication, storage, transportation and operation
  - Noted lack of HALEU validation for all of these areas



CAREM integral reactor (courtesy of sciencedirect.com)

Commercial:
3-5 m diameter,
12-14 m tall

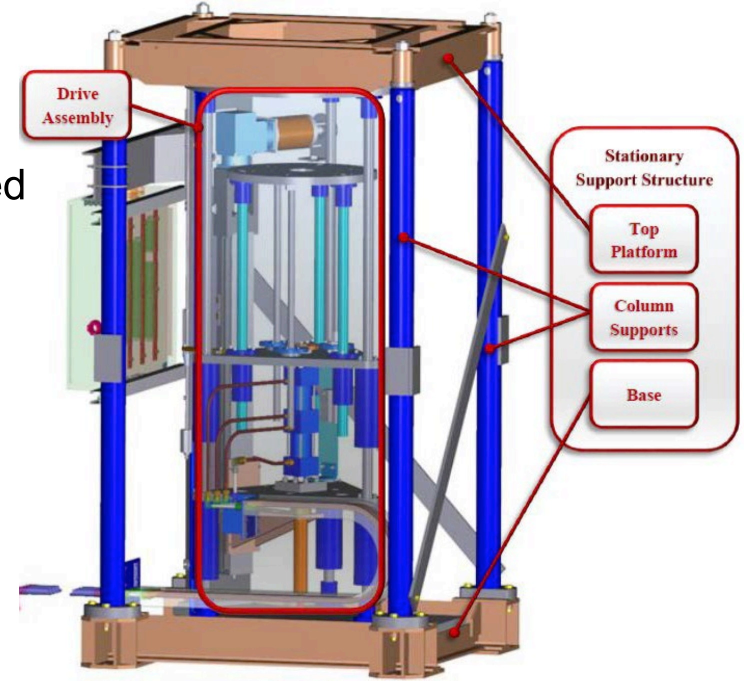


Microreactor:
1-2 m in diameter
2-4 m tall

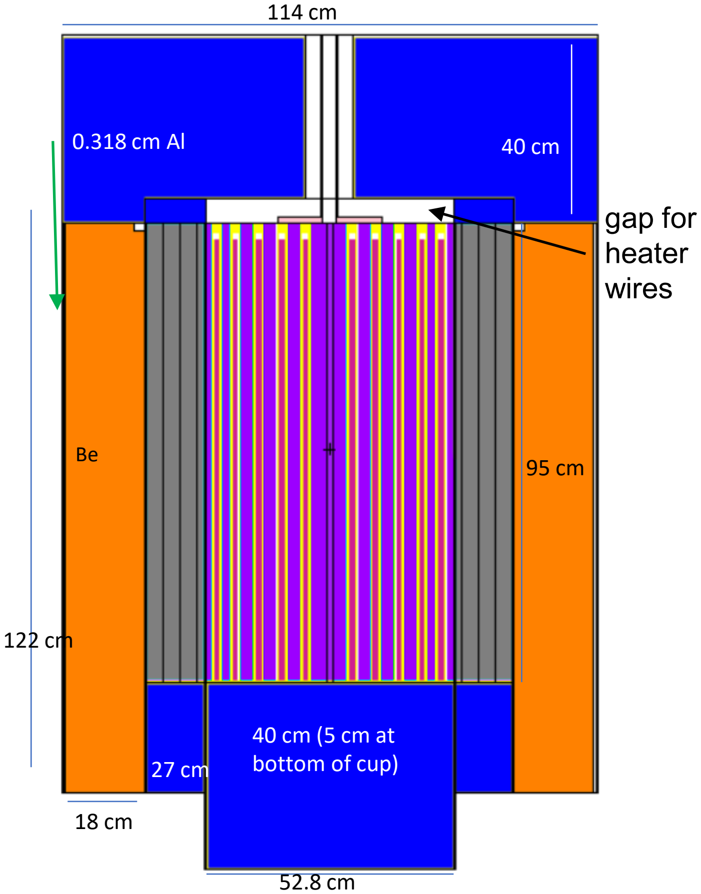
SMR:
2-4 m diameter,
5-10 m tall

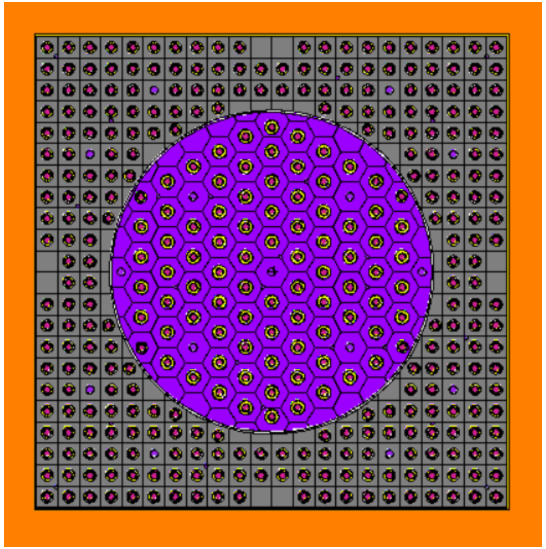
Deimos Objectives and Overview

- Part of the LDRD Project “Next Generation Small Nuclear Reactors”
- Establish thermal spectra HALEU fuel testbed for advanced reactor demonstration/ deployment
  - Reestablish use of CNPS TRISO fuel in NCERC inventory
- Testbed fit within Comet critical assembly limitations
- Capability includes framework for electrically heated tests
  - Deimos goal: 150 ℃, $\Delta\rho$~ 50 ¢
- Build upon lessons-learned from KRUSTY and Hypatia

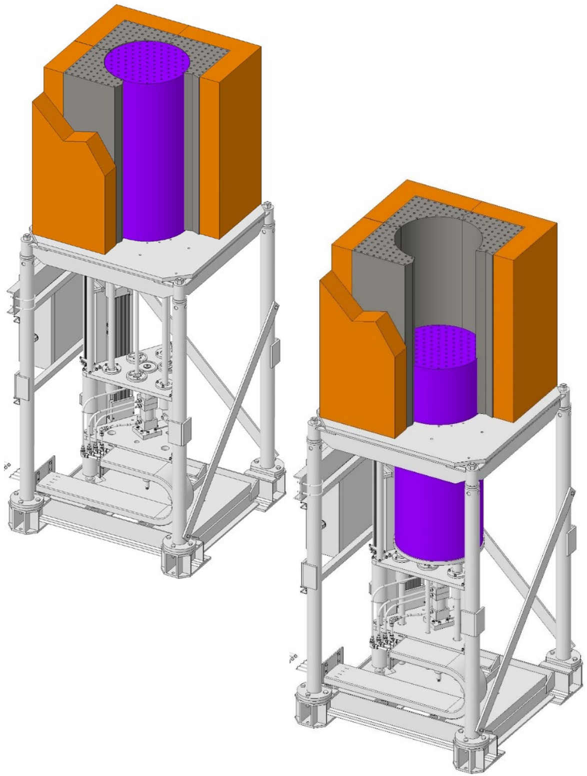


Deimos Overall Design





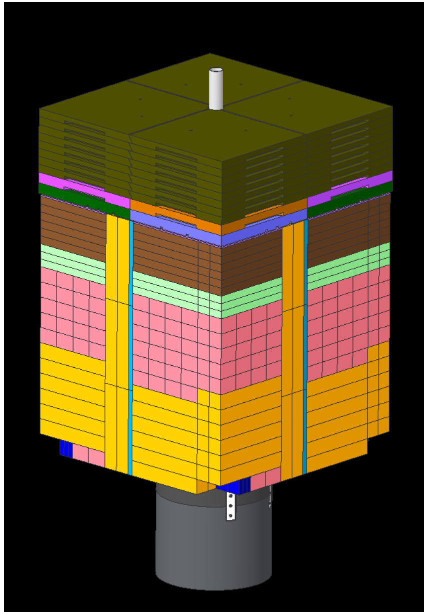
Central portion should be **changeable** for use as testbed



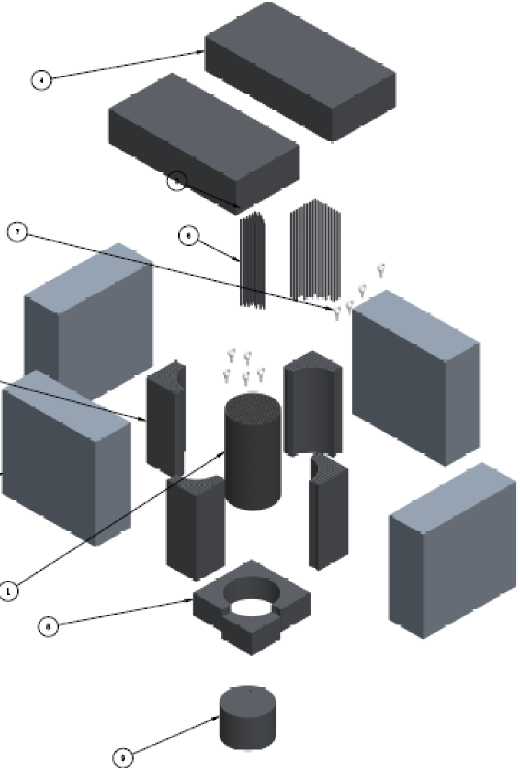
Blue – Graphite Axial Reflector; Purple – Center Core Graphite; Gray – Outer Core Graphite; Red – TRISO fuel; Yellow – Graphite Cup

Deimos Design

- Final geometry
  - Fabricable
  - Allows ‘zero’ positioning
  - Gap between inner and outer core
  - Can be run in a single shift
  - Mechanically stable
  - Thermally stable
  - Cable routing
  - Al safety surround for Be
  - Incorporates critical lift fixturing
  - Buildable on Comet, including multiple iterations for approach to critical



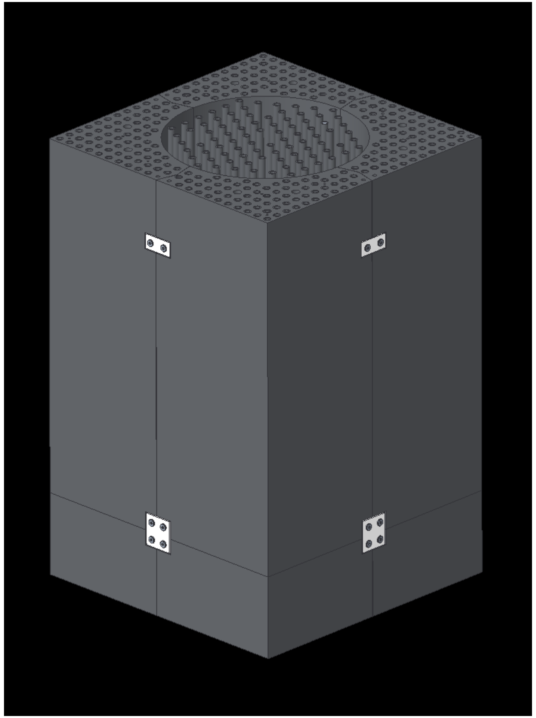
Assembled Core with Be Reflector

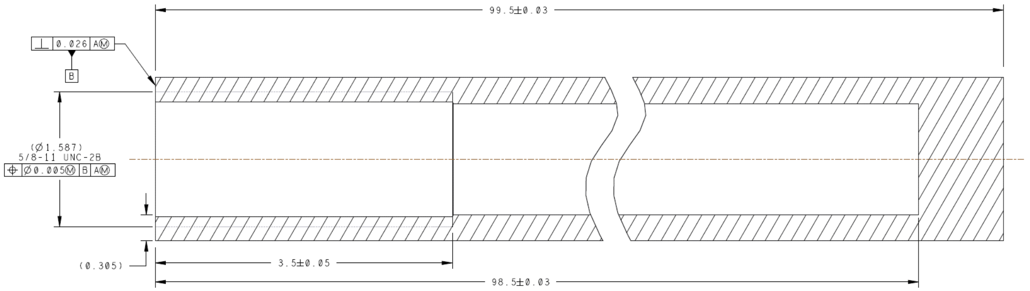


Graphite Core Exploded View

Deimos Design

- Graphite monolith reflector in a few primary components
  - Top reflector blocks, four quadrants of radial reflector, bottom axial reflector
- Radial Reflector components have holes for heaters, fuel, and thermocouples
- Be blocks as radial reflector beyond graphite
  - Necessary to achieve a critical configuration
  - Don't significantly impact neutron spectra
- Central moveable portion is single graphite monolith with holes for heaters, fuel, and thermocouples
- Fuel (CNPS pellets) is in graphite "cups"





NCERC HALEU CNPS fuel

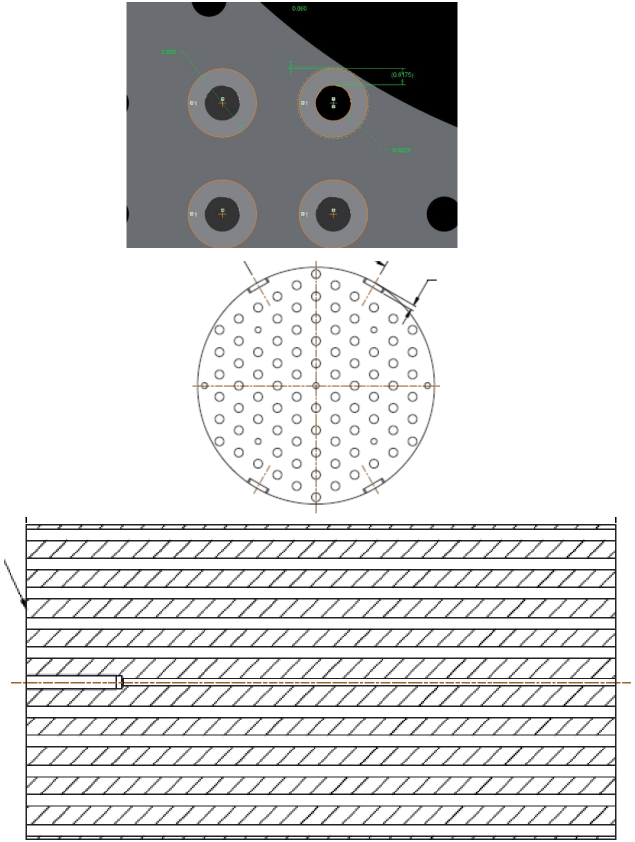
- Obtaining HALEU is difficult, *but*
  - NCERC has extensive inventory which can only be used at NCERC.
- The HALEU TRISO fuel used in CNPS has been stored at NCERC since 2004 but not opened.
- Discovered that some of the TRISO kernels were falling out of the compacts.
- The packing fraction of CNPS ~60v% vs ~40v% used for stable TRISO fuel compacts today.
- Need to contain CNPS pellets in cups/ cladding (note that cladding materials other than graphite penalized reactivity).

Deimos NCERC Improvements

- Graphite monoliths
  - Fabricating monoliths with tight pitch (2.5 cm) and long depth (1 m) is quite challenging and timely to procure
  - Available for use in many different experimental and validation needs
- Heating system
  - System designed to heat entire assembly and monitor/ record temperature
  - Heater type: stainless steel, 36” long x ½” diameter
  - Complex system to operate/ monitor/ collect heater power and temperature data from 20+ TCs
- Continued use of Be, making use of existing assets

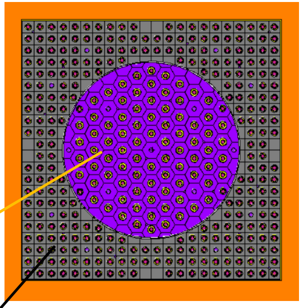
Be

Cartridge Heaters



Graphite Monoliths

Design Optimization

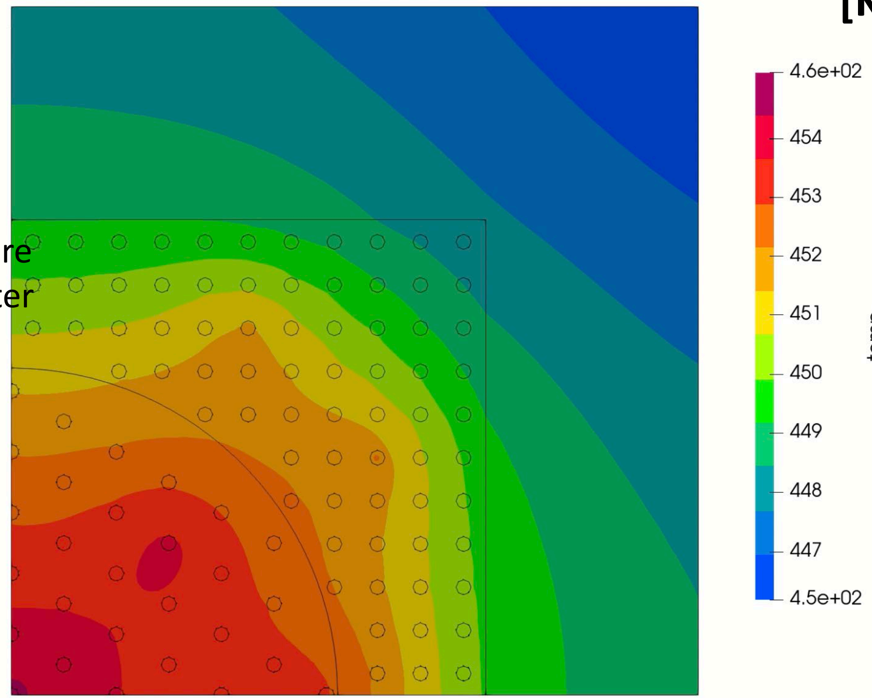


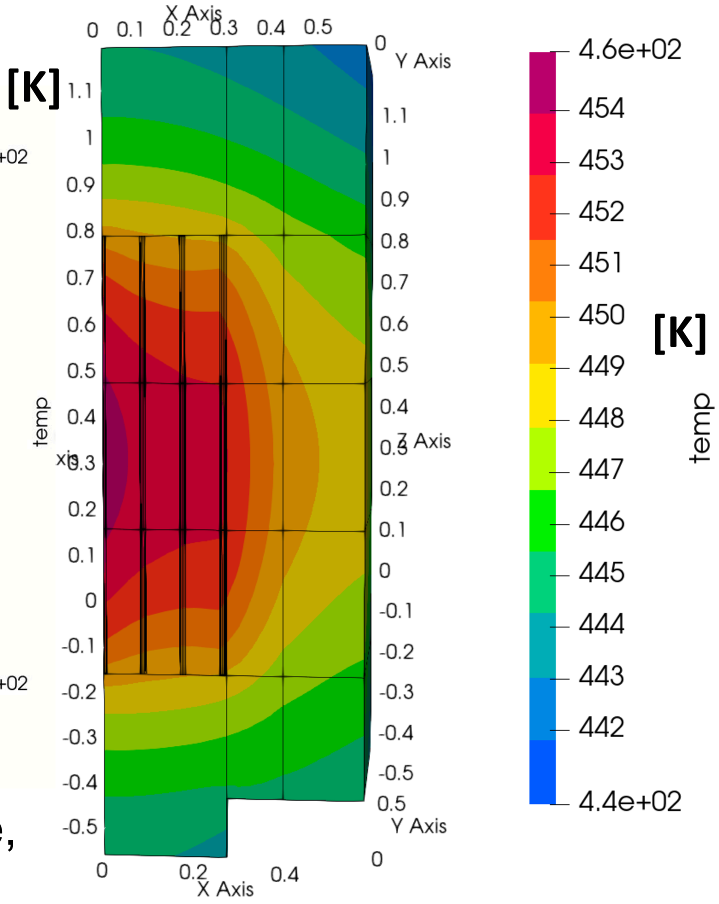
- Radial reflector only fits within Comet top plate if we use Be (orange) instead of graphite
- Axial reflector: 25-40 cm of graphite
- Pitch of graphite between fuel rods:
  - Large in the inner core region (purple) = highest k_{eff}
  - Small in the outer core region (gray) = highest k_{eff}
- Electrical heaters required for reactivity temperature coefficients.
  - Cartridge heaters are cylindrical and available as commercial off the shelf
  - Material is Stainless Steel, which is a reactivity penalty.

Inner Pitch (cm)	Outer Pitch (cm)	k_{eff} (neutron reactivity)
4.2	3.6	1.060
4.2	4.2	1.045
4.2	5	1.045
4.6	3.6	1.063
4.6	4.2	1.047
4.6	5	1.044
5	3.6	1.064
5	4.2	1.050
5	5	1.056

Heat Transfer Modeling

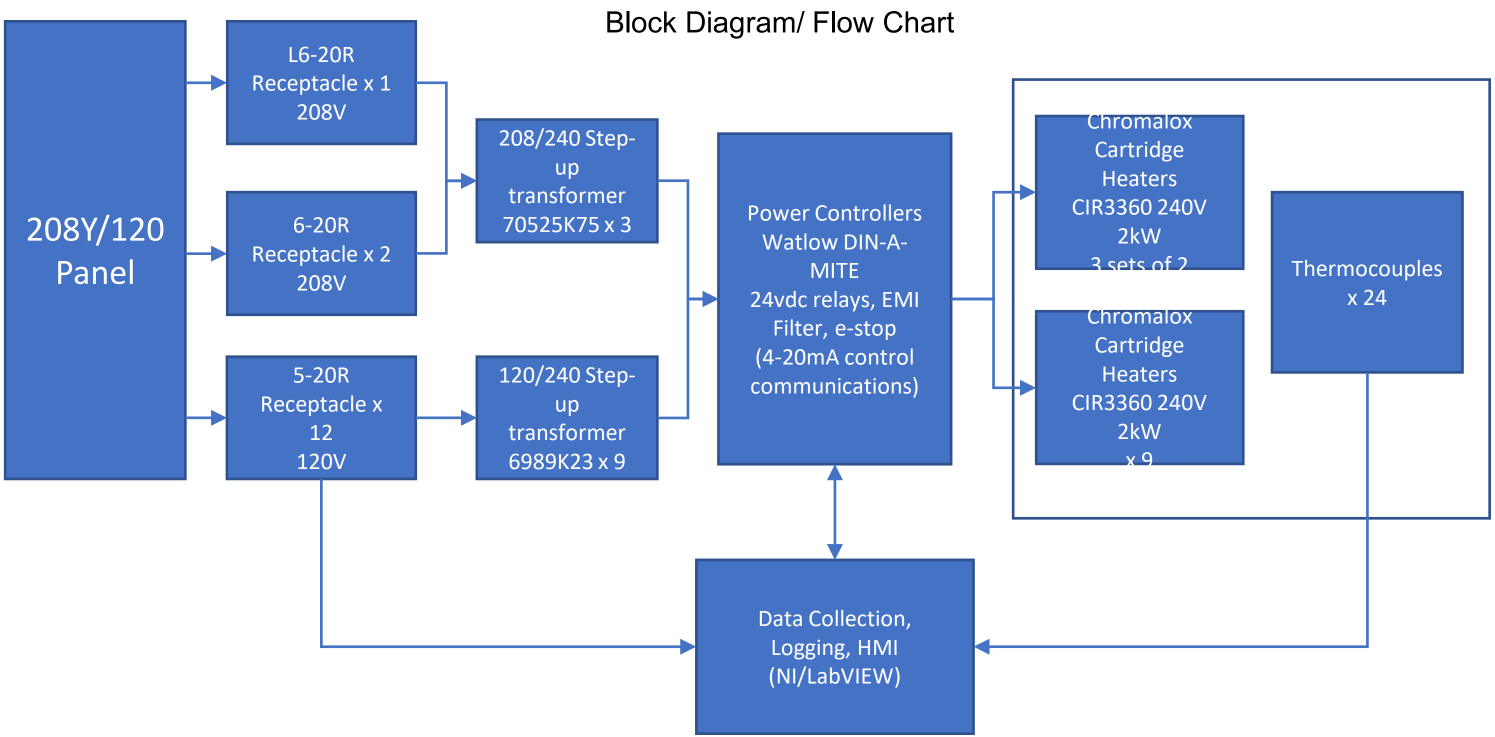
Thermal calculations performed by Alexis Maldonado determine temperature distribution with heater location/size/power.





Even at 450 K average fuel temperature, temperature spread is about 14 K/°C

Deimos – heater and controller block diagram



Electrical Design Review
Control System

- Data Collection and export
- User Interface
- Control Room operation: Limited ethernet
- Distance of TC probes from device to cDAQ
- High temperature application: Wire and cable insulation selection
- Thermocouple proximity to heaters
  - 2-3 TC in proximity to each heater
  - LabVIEW program determines best data for heater control
  - LabVIEW program filters bad data (broken TC)

Critical Experiment Personnel Growth

- Neutronics
  - Pitch calculations written in reusable C++ code and performed by Kristin Stolte
  - Approach to Critical calculations performed by Kristin Stolte
- Experiment Plan
  - Mentoring early career staff
- Mechanical Design
  - Modeling performed, under mentorship, by Scott Stinson and Justin Lee
  - safety calculations performed, under mentorship, by Scott Stinson
- Heat transfer and Reactivity Coefficient predictions
  - Mentored and performed by Alexis Maldonado
- Electronic Design
  - Led by John Downey

→**Training for Future FMHs, Crew Members, Design Engineers for NCSP**

Schedule and Future Work

- Schedule
  - Finalize Design and MLD: January 2023
  - Complete Safety Calculations: February 2023
  - Complete Experiment Plan: April 2023
  - Component Receipt: August 2023
  - Experiment Execution: October 2023

- Future Work
  - Finalize Experiment Plan
  - Compile Safety Calculations
  - Management Level Determination by Mechanical Engineer and FDAR
  - Finish Opening CNPS Fuel
  - Finish Inspecting and Sorting Be blocks

Questions?

Acknowledgements

- The Deimos experiments are supported by the US Department of Energy through the Los Alamos National Laboratory and the Laboratory Directed Research & Development "Next Generation Small Nuclear Reactors", 20220084DR.
- NCERC is supported by the DOE Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.