Special Topic for Nuclear CLT: Kilopower Project

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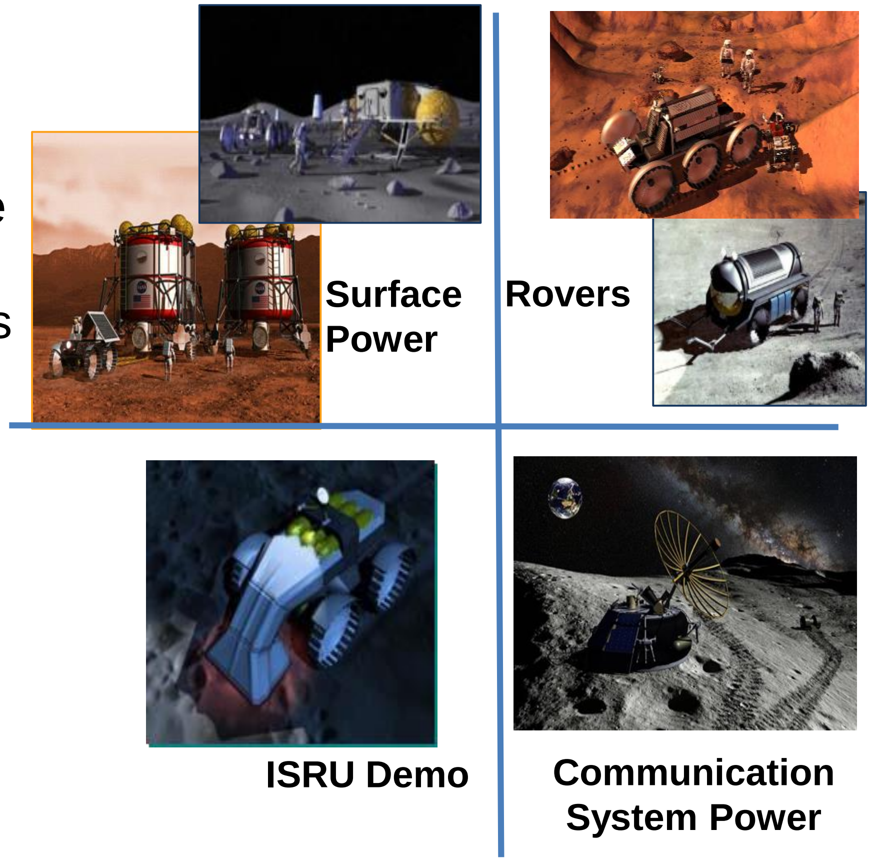
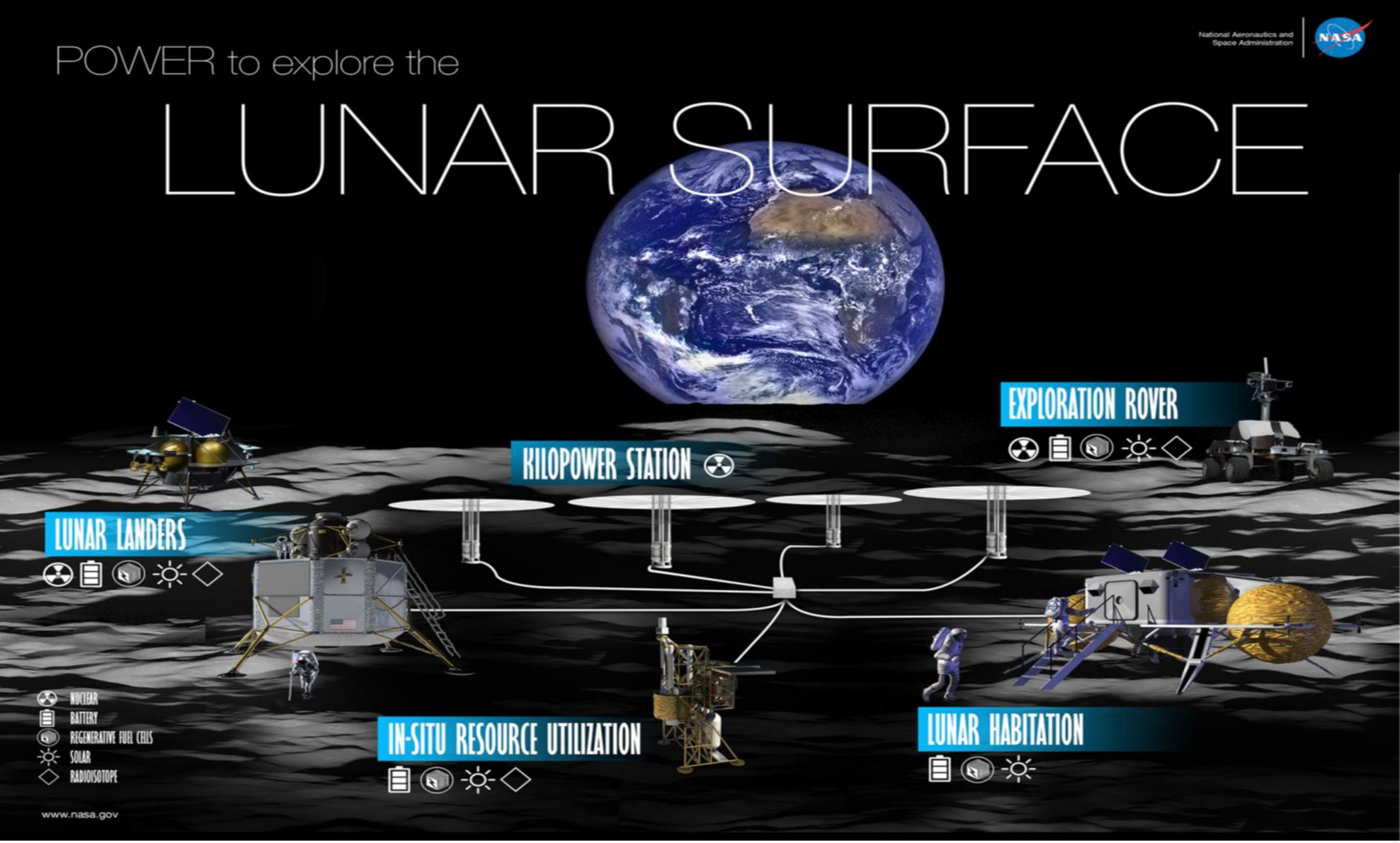
Kilopower Project

- **Big Idea:**
  – A compact, low cost, scalable fission reactor for science and exploration
- **Innovation:**
  – KiloPower: novel integration of available U235 fuel form, passive sodium heat pipes, and flight-ready Stirling convertors
- **Impact:**
  – Reduces NASA dependence on Pu238
  – Provides Modular Option for HEOMD Lunar and Mars Surface Missions
  – Enables SMD Decadal Survey Missions
- **Goals:**
  – Validate the scalability of Kilopower KRUSTY experiment to 1-10 kWe
  – Optimize and demonstrate power conversion for Lunar and Mars surface power

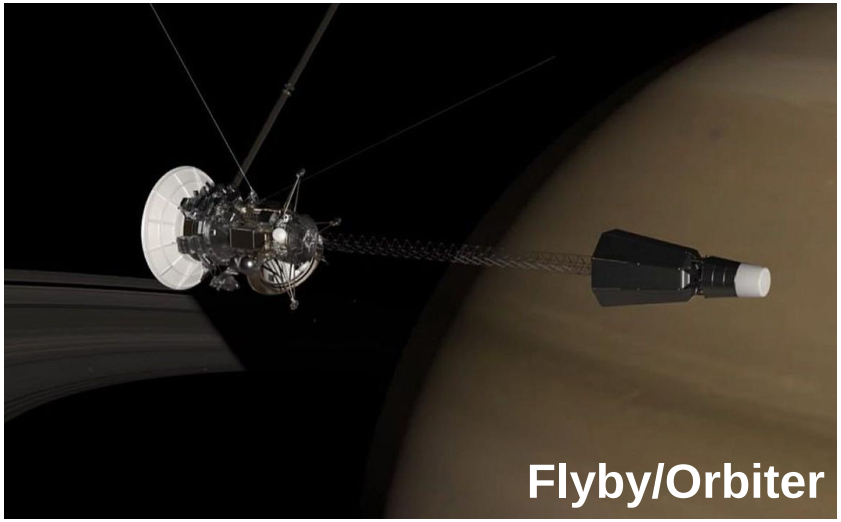
Applications

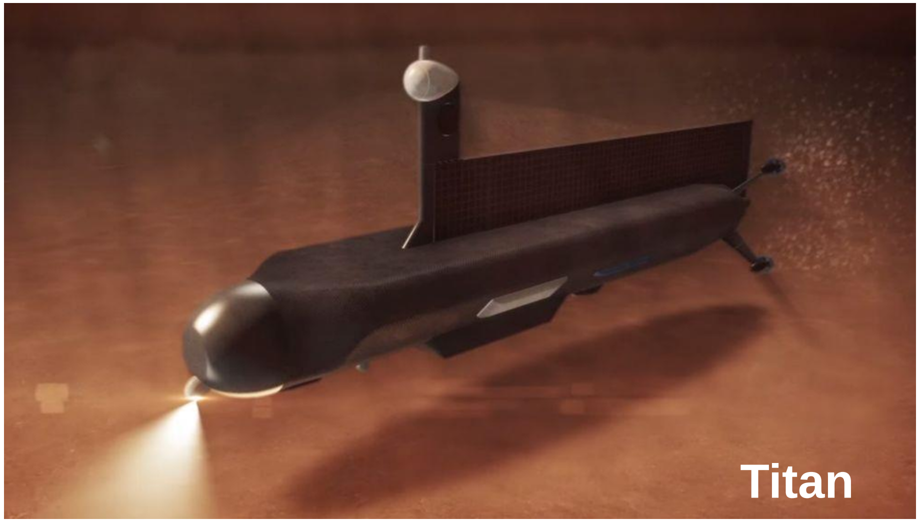


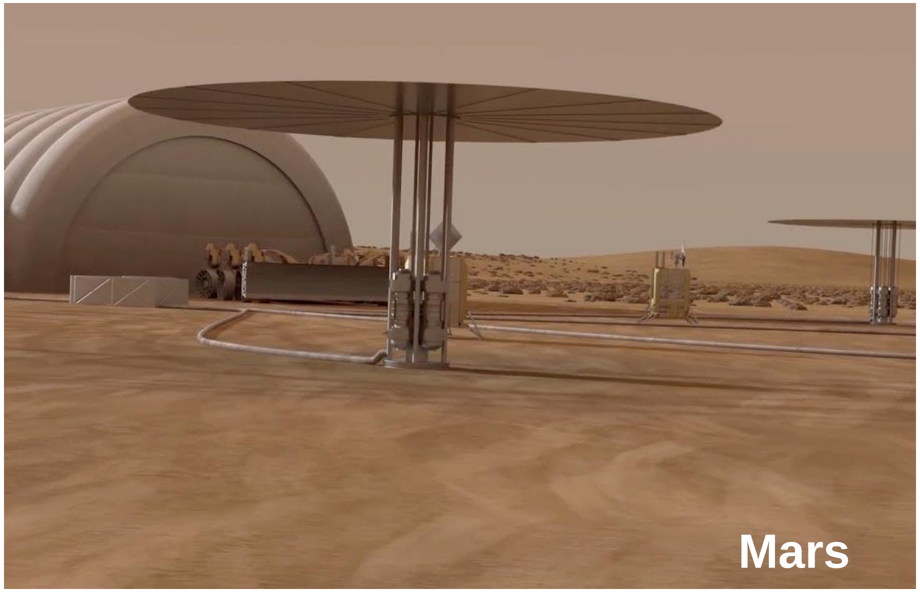


Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations

Other Kilopower Mission Concepts







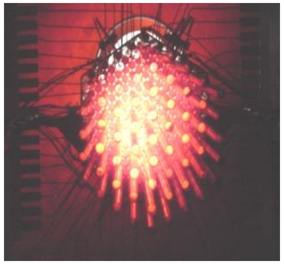
Technology Overview

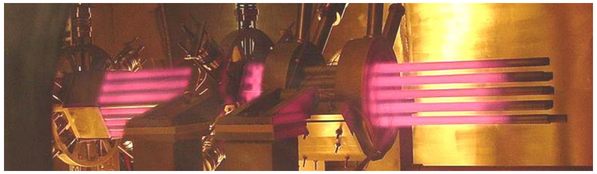
NASA needs nuclear power to achieve a sustainable human presence on Lunar and Mars surfaces

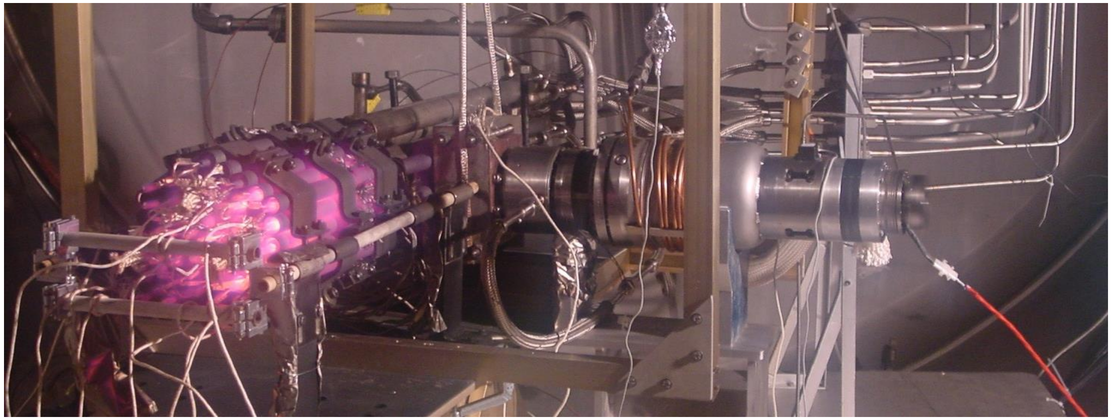
- Kilopower II addresses a gap in the NASA Technology Roadmaps (TA-03) for robust, sun-independent power generation in the 1 to 10 kWe range
- NASA needs a long-life, low-cost power option for missions where solar is not practical
- Future Exploratory Missions require a reliable source of power Lunar/Mars explorations including ISRU propellant production and crew life support and operations, for which there is no off-the-shelf solution
- KRUSTY serves as a baseline for on follow-on human missions with multiple stand-alone units that provide redundancy/fault tolerance and flexibility for re-use at multiple sites with power needs of 1 to 10 kWe throughout the solar system (e.g. permanently-shaded lunar craters, subsurface Europa science, deep space electric propulsion, others.)

How Did We Arrive at Kilopower, DUFF and KRUSTY?

- We wanted to find a space reactor concept that could be…
  - 1) Attractive to NASA for flight
  - 2) Proven with a rapid turnaround, low-cost nuclear test.
- Past work (HOMER/SAFE) convinced us that heat-pipe-cooled reactors provide easiest path to near-term, low-cost concept.
  - Passive reactor operation, modularity/reliability, ease of testing
  - Stirling engines allow simplest reactor (lower thermal power)







- The idea, and completion of the DUFF experiment added the crucial testing component that finally sparked “real” interest.

Demonstration Using Flattop Fissions = DUFF
A "Critical" Starting Point

Proof-of-Concept Test – Objectives

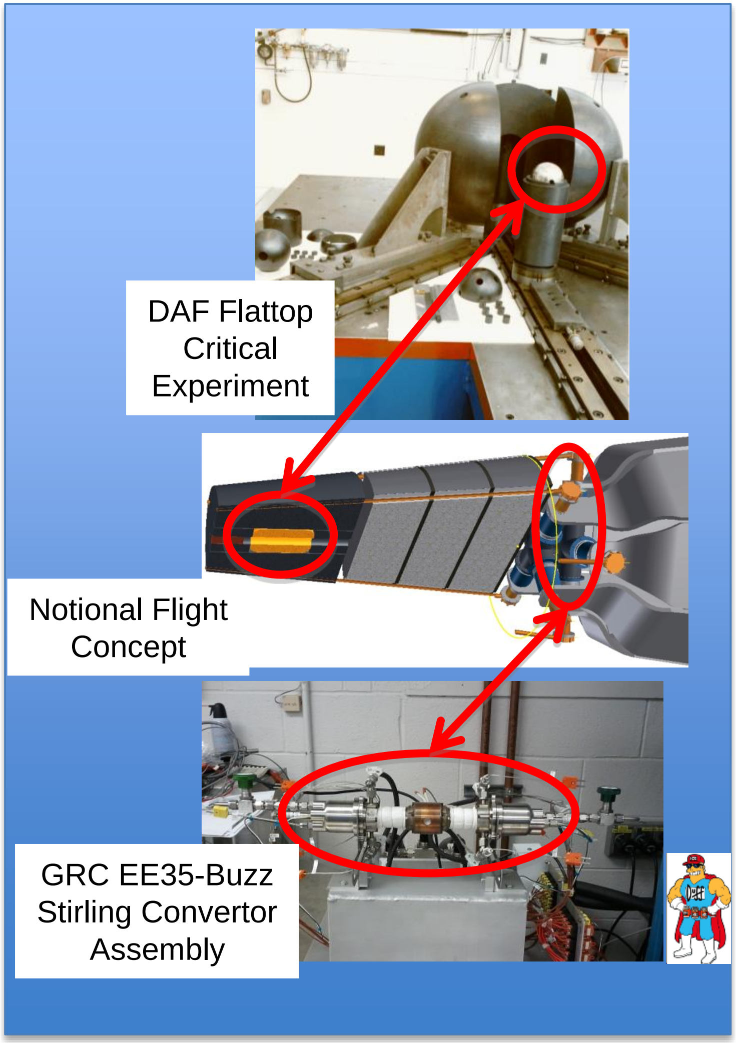
- Use electric power generated from nuclear heat to power a load (light panel)
- Demonstrate that basic reactor physics is well characterized and predictable using current analytic tools

Test Configuration

- Highly Enriched Uranium core with central hole to accommodate heat pipe
- Heat transfer via single water heat pipe
- Power generation via two opposed free-piston Stirling Engines

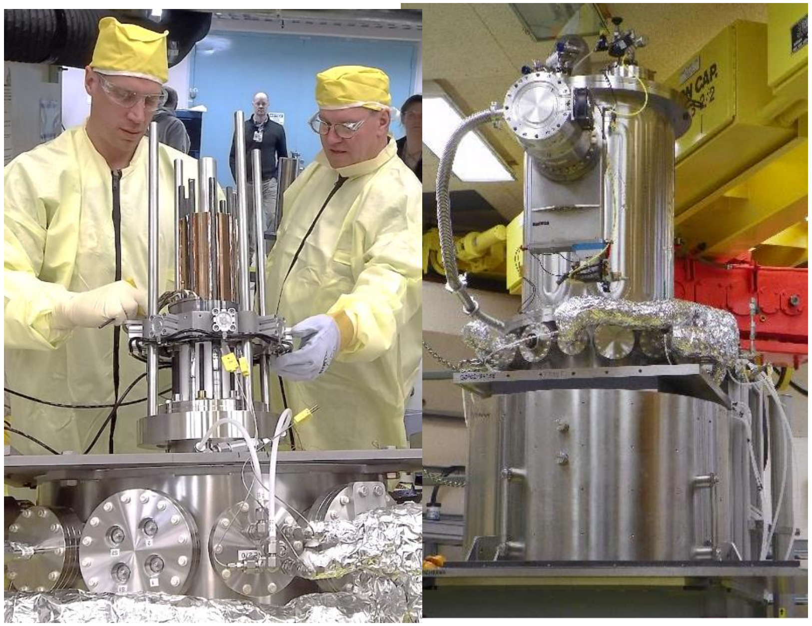
Significance

- First-ever heat-pipe cooled fission experiment
- First-ever Stirling engine operation with fission heat
- Demonstrated nuclear reactivity feedback was predictable
- Demonstrated that powered nuclear testing is not inherently expensive or time consuming – simplicity is paramount.

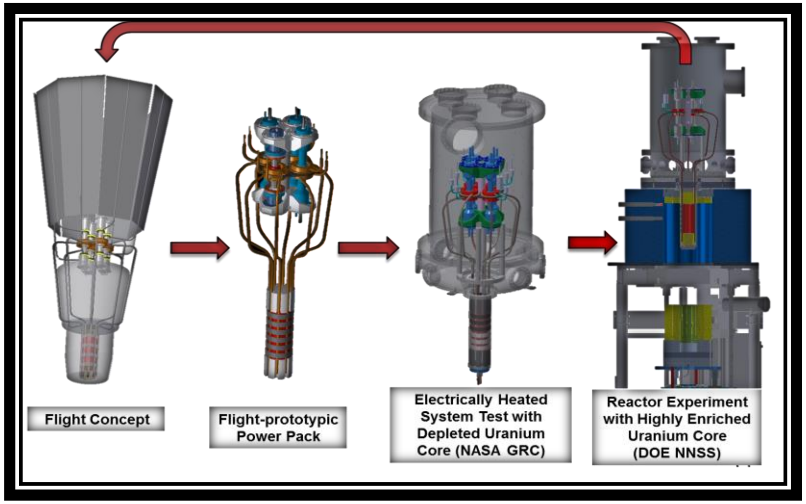


Kilopower/KRUSTY Accomplishments under GCD

- Demonstrated 1 kW_e nuclear reactor power system designed for space, first in >50 years!
- Modified convertors from the Advanced Stirling Radioisotope Generator project to accept heat from heat pipes
- Integrated high fidelity components and perform integrated system vacuum testing advancing the technology readiness level
- Worked with DoE to demonstrated reactor performance in the Device Assembly Facility
- Validated DoE analytical model with reactor experimental data, providing confidence in reactor modeling capability for future analysis and designs
- Changed the paradigm from previous (uncompleted) space reactor development efforts that were based on high power, high temperature, complicated heat transport, new test facilities that all required significant technology investments

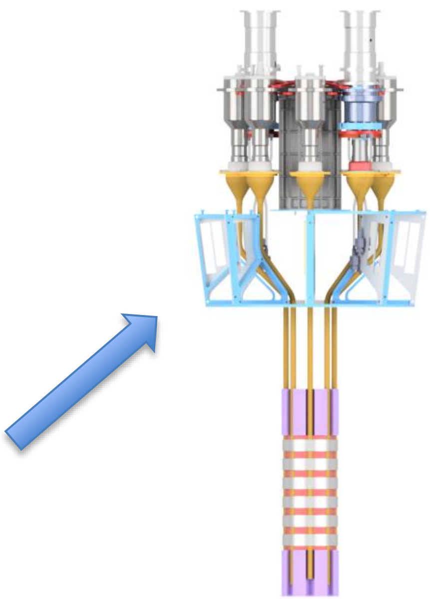


Kilopower I Test at DAF

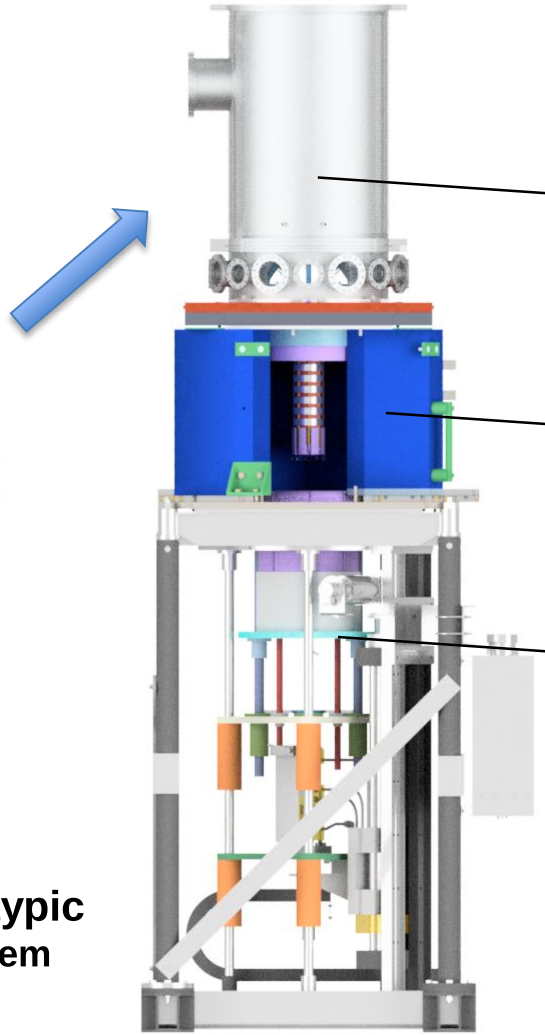


KRUSTY: Kilopower Reactor Using Stirling TechnologY

Kilopower Flight Concept



Flight Prototypic Power System



Kilopower Reactor Using Stirling TechnologY = KRUSTY

– Use fuel form that can be procured quickly and affordably (i.e. UMo at Y12)

– Testable in existing facility with experienced operations, safety, compliance teams (i.e. NCERC at DAF)

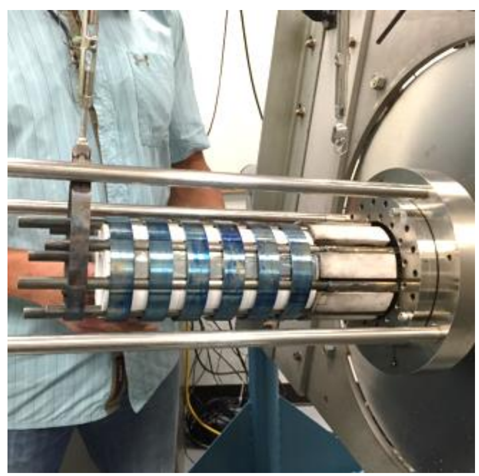
– Use existing critical assembly machine (e.g. COMET)

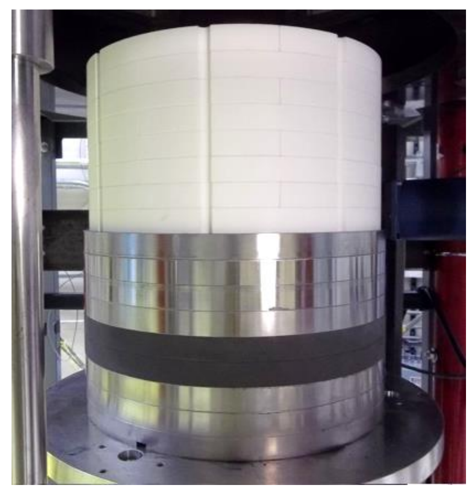
– Provide adequate safety and asset risk – to machine, room, facility (limit power to ~5 kWt)

– Use core dimensions that allow shipping in existing/approved container (i.e. 11-cm diameter)

– Simplify transport with fuel shipped separate from system, with simple assembly in hallway at test site

– Use Stirling simulators to reduce cost/schedule (i.e. 2 “real” converters and 6 thermal simulators)



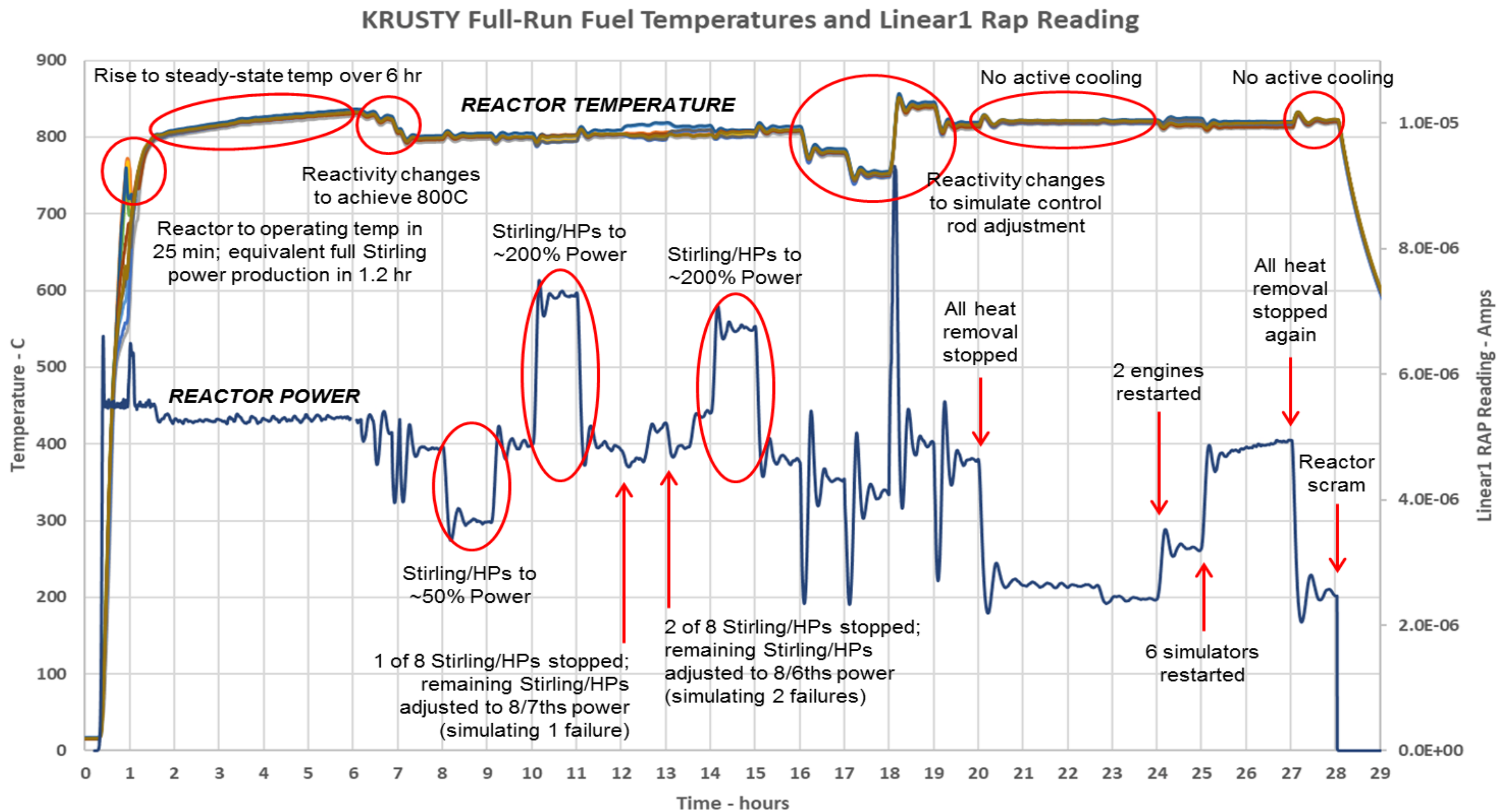


Reactor Assembly at DAF

KRUSTY Performance Metrics

Event Scenario	Performance Metric	KRUSTY Experiment	Performance Status
Reactor Startup	< 3 hours to 800 deg. C	1.5 hours to 800 deg. C	Exceeds
Steady State Performance	4 kWt at 800C	> 4 kWt at 800C	Exceeds
Total Loss of Coolant	< 50 deg. C transient	< 15 deg. C transient	Exceeds
Maximum Coolant	< 50 deg. C transient	< 10 deg. C transient	Exceeds
Convertor Efficiency	> 25 %	> 35 %	Exceeds
Convertor Operation	Start, Stop, Hold, Restart	Start, Stop, Hold, Restart	Meets
System Electric Power Turn Down Ratio	> 2:1 (half power)	> 16:1	Exceeds

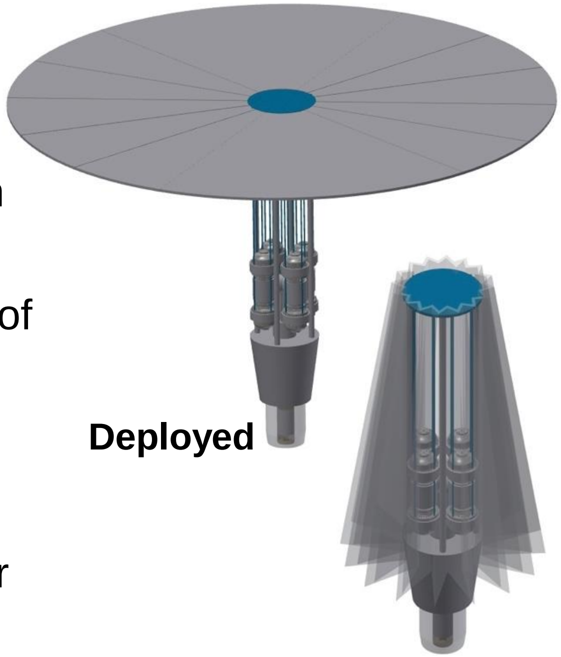
KRUSTY Full Power Run
PRELIMINARY DATA ANALYSIS



Actual test data from Kilopower nuclear test performed Mar 20-21, 2018 at Nevada National Security Site.

Proposed Follow-on: Kilopower II

- **FY18 STMD Bridge Project**
  - Reference Government Design of a Kilopower Flight System (3-10kWe)
  - Experiments to demonstrate in-core heat pipe integration
  - Initial steps for Launch Safety and Security
  - Test procedure for characterizing the radiation signature of SOA electronics



- **Potential Project content to include the following:**
  - 10kWe technology scalability study
  - Detailed reactor design using KRUSTY validated computer models
  - Contracts to design/build/test kilowatt-class power conversion units
  - Includes studies to evaluate nuclear launch safety and crew radiation safety
  - Includes option for possible nuclear flight demonstration on lunar or Mars precursor