Kilopower: Small & Affordable Fission Power Systems for Space

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What is Kilopower?

- **Small and simple approach for long-duration, sun-independent electric power for space or extra-terrestrial surfaces**
  - Produces from 1 to 10 kilowatts, continuously for 10 years or more
  - Weighs about 400 kg at 1 kW or 1500 kg at 10 kW, for complete system
  - Uses solid, cast uranium-235 reactor core, about the size of a paper towel roll
  - Transfers reactor heat with passive sodium heat pipes
  - Converts heat to electricity with high efficiency Stirling engines
  - Partnership with Department of Energy (DOE) leverages current DOE fuel production processes and material supply
  - Launches as a radiologically benign, non-operating (cold) payload

- **Represents NASA's first attempt at building and testing a REAL space reactor since the 1960s SNAP Program**

Why is it Different?

- **Designed for affordability rather than optimized for performance**
- **Low power, to simplify heat transfer and power management**
  - Lower operating temperatures and no new materials
  - High design margins for life and reliability
  - High redundancy for fault tolerance and graceful degradation
- **Adaptable, multi-use technology that minimizes integration burden**
  - Can be launched cold and turned on/off as needed during mission
  - Designed with inherent safety features to prevent inadvertent criticality and temperature run-away
  - Small enough that multiple units can be delivered on a single Mars lander and operated independently for human surface missions
  - Small enough to be packaged on planetary science orbiters and landers
- **Strong partnership with DOE/National Nuclear Security Administration (NNSA), leveraging infrastructure and expertise**
  - Available reactor fuel from existing DOE production and stores
  - Testable in existing DOE facilities, with minimal changes to safety basis

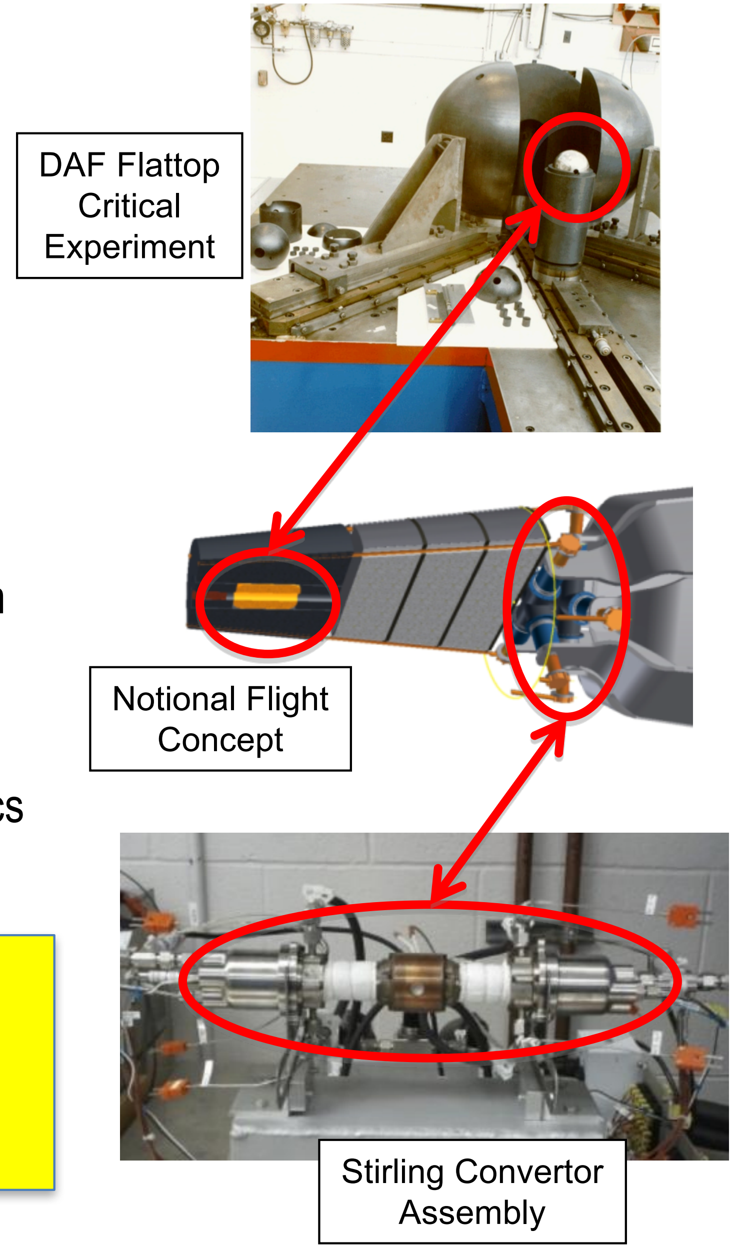
How Did We Get Here?

- **1970-2010: Many past NASA/DOE space reactor programs tried and failed**
  - Too complicated and costly
  - Too dependent on new materials and processes
  - Too long to develop, usually longer than the mission can wait
  - Too much optimism for out-of-the-box system performance
- **2010 Planetary Science Decadal Survey:** Technology assessment study to determine if fission reactors are practical for higher power science missions.
- **2012 Proof-of-Concept Test:** Demonstration Using Flattop Fissions; 24 watts produced; test prepared and executed in less than 6 months and $1M (next slide).
- **2014 NASA Science Mission Directorate (SMD) Nuclear Power Assessment Study:** No current planetary missions projected >1 kW and therefore no need for fission (however if available missions may use)
- **2014 NASA Human Exploration and Operations Mission Directorate (HEOMD) Evolvable Mars Campaign:** Small fission power baselined for pre-crew In-Situ Resource Utilization (ISRU) propellant production and post-landing crew operations.
- **2015 Kilopower Project starts under NASA Space Transportation Mission Directorate (STMD) Game Changing Development Program:** 3 years and $15M to design, build, and test a prototype reactor.

Demonstration Using Flattop Fissions

- **Proof-of-Concept Test**
  - Los Alamos National Laboratory-sponsored test at DOE
- **Test Configuration**
  - Highly enriched uranium core with central hole to accommodate heat pipe
  - Heat transfer via single water heat pipe
  - Power generation via two Stirling convertors developed during early phases of Advanced Stirling Radioisotope Generator Project
- **Significance**
  - First-ever use of a heat pipe to extract thermal power from a fission reactor
  - First-ever use of a Stirling convertor to produce electric power with a fission heat source
  - Demonstration of nuclear reactivity feedback and dynamics with representative components

- **Sept 13, 2012: Success! 24 Watts produced**
  - Completed in less than 6 months with a total cost <$1M
  - Proof that a nuclear reactor ground test can be conducted quickly and affordably



Possible Applications

- **Government Missions:**
  - Human Mars surface missions
  - Lunar surface operations
  - Planetary orbiters and landers: Europa, Titan, Enceladus, Neptune, Pluto, etc.
  - Planetary nuclear electric propulsion (EP): Small Bodies, Ocean Worlds, Interstellar, etc.

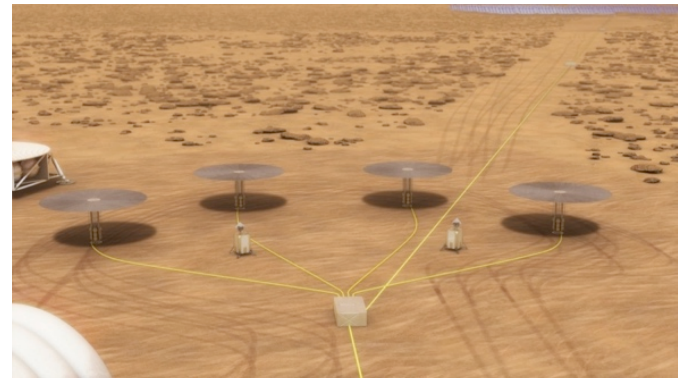
- **Commercial Missions:**
  - Space mining
  - Lunar/Mars settlements
  - High-rate communications

Planetary Surface Mining Operation Concept

(Credit: NASA)

- **Power uses:** drilling, melting, heating, refrigeration, sample collection, material processing, manufacturing, video, radar, EP, telecomm, rover recharging

Current Thrust: Mars Surface



- **No off-the-shelf options exist to power long-term human surface missions on Mars**
  - Power systems used on previous robotic missions (e.g. Mars Science Lab, Phoenix) will not suffice
- **Stationary power needs:**
  - Up to 40 kilowatts day/night continuous power
  - Power for ISRU propellant production (pre-crew arrival)
  - Power for landers, habitats, life support, rover recharging (during crew operations)
  - Technology options: Nuclear Fission, or Photovoltaics with Energy Storage
  - Need compact stowage, robotic deployment, survivable for multiple crew campaigns (>10 yrs), long distance power distribution (1-2 km), and contingency options for dust storms
  - Potential mid/late 2020s Mars Entry/Descent/Landing-ISRU-Power Technology Demonstration Lander Mission (5 to 10 kW)
- **Primary Target is Mars, but extensibility to Moon is desired**
  - Mars environment challenges include: $3/8^{th}$ gravity, $1/3^{rd}$ solar flux, 12.5 hour night, CO_2 atmosphere, dust storms, wind loads, 170 to 270K temperature cycles
  - Moon: $1/6^{th}$ gravity, 354 hour night, vacuum, dust, 100 to 370K temperature cycles

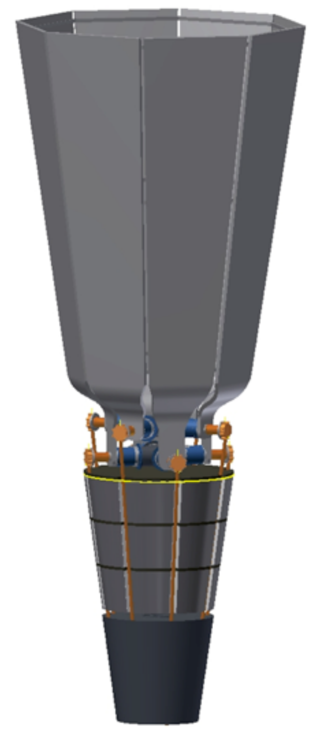
STMD Kilopower Project

Current Project under Game Changing Development Program to design, build, and test a 1 kW$_e$ reactor with technology that is relevant for systems up to 10 kW$_e$

- **Innovation:**
  - A compact, low cost, scalable fission power system for science and exploration
  - Novel integration of available uranium fuel form, passive sodium heat pipes, and flight-ready Stirling convertors
- **Impact:**
  - Provides modular option for human exploration mars surface missions
  - Bridges the gap between Radioisotope Power Systems (RPS) and large-scale fission power technology studied in past
  - Enables Decadal Survey science missions
- **Goals:**
  - Nuclear-heated system-level test of prototype U235 reactor core coupled to flight-like Stirling convertors
  - Design concepts that verify scalability to 10 kW for Mars

1 to 10 kilowatt Kilopower Technology

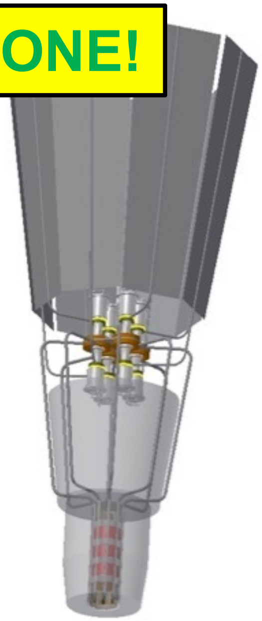
Full-scale nuclear test of reactor core, sodium heat pipes, and Stirling convertors at prototypic operating conditions



- **10 times the power of current Radioisotope Power Systems**
- **Available component technologies**
- **Testing in existing facilities**

Kilowatt Reactor Using Stirling TechnologY (KRUSTY)

DONE!



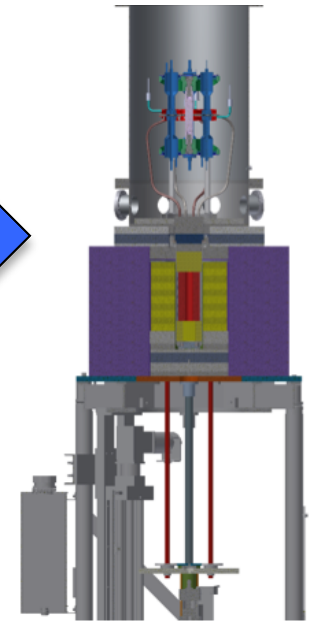
Notional 1 kW_e Flight System Concept

DONE!

Thermal Prototype & Materials Testing (Phase 1)

DONE!

Thermal-Vac System Test with Depleted Uranium (DU) Core at GRC (Phase 2)



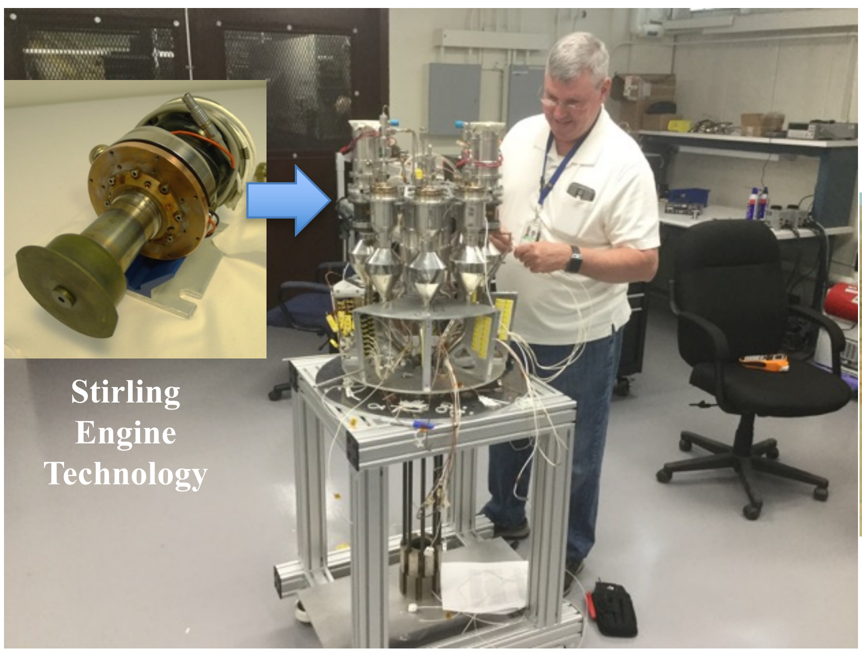
Reactor Prototype Test with Highly-Enriched Uranium Core at NNSS (Phase 3)

- Verify system-level performance of flight-like U-Mo reactor core, sodium heat pipes, and Stirling power conversion at prototypic operating conditions (temperature, heat flux, power) in vacuum
- Establish technical foundation for 1 to 10 kW_e-class fission power systems

Kilopower Hardware Status

3 Highly Enriched
Core Sections Casted…

…and Ready for
Machining (1 of 3 DU
core sections shown)



GRC-Built Demonstration Assembly

Shipped to Nevada
This Summer for
Experiment
Assembly

Comet Experiment Platform at the Nevada
National Security Site (NNSS)
Device Assembly Facility

Summary

- Kilopower Technology Development on-going under STMD/Game Changing Development Program
- Scalable fission technology from 1-10 kW_e for science and exploration missions
- New paradigm for space reactors with design based on affordability rather than performance
- Smaller and simpler than Constellation-era Fission Surface Power system concepts
- Leverages available materials and components; sized for existing ground test facilities
- Proposed follow-on: high-fidelity Engineering Development Unit in simulated Mars environment
- Potential for flight test in less than 10 years