Kilopower: Small & Affordable Fission Power Systems for Space

Bryan Smith
Director, Space Flight Systems

Lee Mason
Don Palac
Marc Gibson

NASA Glenn Research Center
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

• **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: 3/8th gravity, 1/3rd solar flux, 12.5 hour night, CO₂ atmosphere, dust storms, wind loads, 170 to 270K temperature cycles
  - Moon: 1/6th gravity, 354 hour night, vacuum, dust, 100 to 370K temperature cycles
Current Project under Game Changing Development Program to design, build, and test a 1 kW<sub>e</sub> reactor with technology that is relevant for systems up to 10 kW<sub>e</sub>

- **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

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
• 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 kWₑ-class fission power systems
Kilopower Hardware Status

3 Highly Enriched Core Sections Casted…

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

Stirling Engine Technology

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\textsubscript{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