

National Aeronautics and
Space Administration



Space Technology Mission Directorate Game Changing Development Program

Nuclear Systems Kilopower Overview

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Kilopower Technology Demonstration – Overall Objectives & Elements



- **Innovation:**

- A compact, low cost, scalable fission power system for science and exploration
- Novel integration of available U235 fuel form, passive sodium heat pipes, and flight-ready Stirling convertors

- **Impact:**

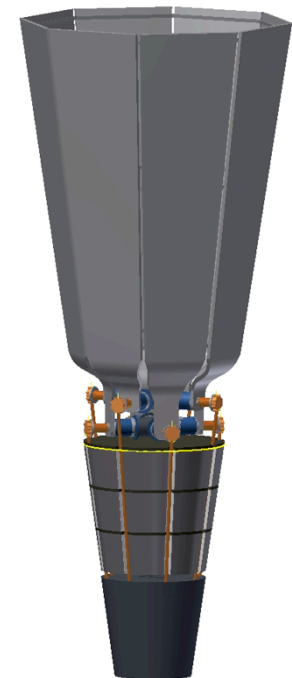
- Provides Modular Option for HEOMD Mars Surface Missions
- **Bridges the gap between Radioisotope Power Systems (RPS) and 40 kW_e class fission power technology**
- Enables SMD Decadal Survey Missions
- Reduces NASA dependence on Pu238

- **Goals:**

- **Nuclear-heated system-level test of prototype U235 reactor core coupled to flight-like Stirling convertors**
- Detailed design concept that verifies scalability to 10 kW_e for Mars

1 to 10 kW_e Kilopower Technology

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



- **10X the power of current RPS**
- **Available component technologies**
- **Tested in existing facilities**



Why Kilopower?



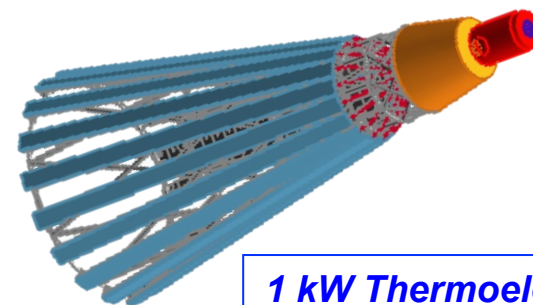
- **The Kilopower technology demonstration is the practical and affordable first step to getting a reactor power system in space**
 - Executing nuclear testing in existing DOE facilities is crucial to affordable technology development and demonstration
 - Small physical size of hardware and low power level allows use of existing facility within current regulatory authority
 - The reactor core can be fabricated and shipped with existing assets
 - The same equipment used to test pre-nuclear prototypes can be transported to the DOE facility and used in the nuclear test
 - *Keeping it small means keeping it affordable*
- **Kilopower enables larger power systems and nuclear propulsion**
 - The path from technology maturation to flight qualification of a larger power system will not be trivial; smaller and simpler is better
 - Qualification and programmatic risks will be substantially retired so that larger reactor systems requiring more fuel and engineering complexity can be developed



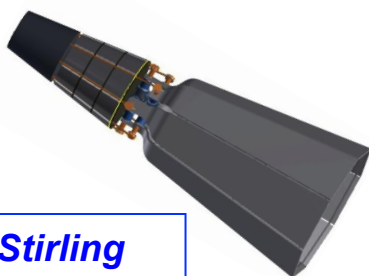
Kilopower-Enabled Concepts Family



- **Common Design Features include:**
 - 0.5 to 10 kWe; >10 year design life
 - Utilize available UMo reactor fuel from DOE
 - Minimize thermal power to simplify reactor design and control
 - Incorporate passive Na heat pipes for reactor heat transport
 - Leverage power conversion technologies from RPS Program (TE, Stirling)
 - Design system so that it can be tested in existing DOE nuclear facilities

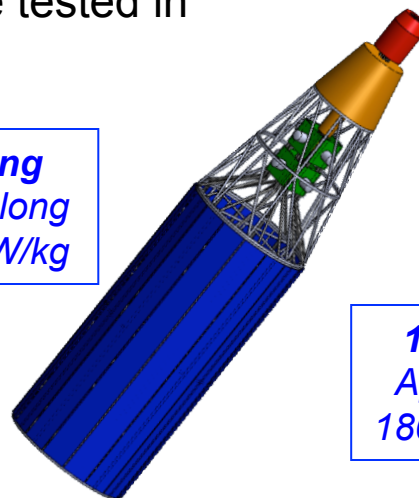


1 kW Thermoelectric
Approx. 4 m long
600 kg or 1.7 W/kg

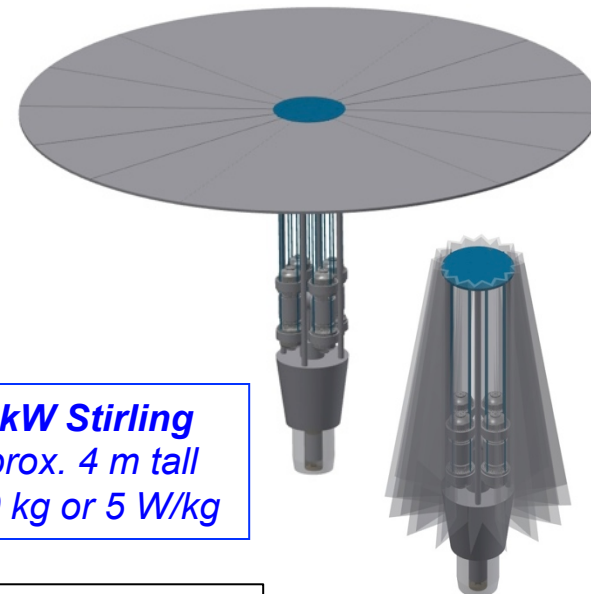


800 W Stirling
Approx. 2.5 m long
400 kg or 2 W/kg

3 kW Stirling
Approx. 5 m long
750 kg or 4 W/kg



10 kW Stirling
Approx. 4 m tall
1800 kg or 5 W/kg



1 kWe-class Technology Demonstration establishes foundation for range of systems and capabilities



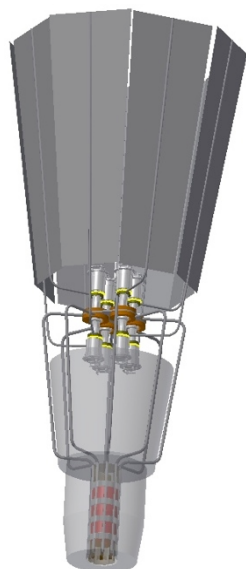
Approved Kilopower Project Plan by Element



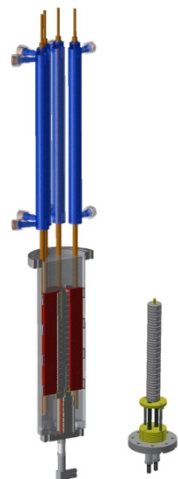
Task	FY15	FY16	FY17	FY18
Kilopower Prototype Test	Finalize system design and assemble components	Perform non-nuclear system verification test at GRC	Install reactor core and perform nuclear test at Nevada Nuclear Security Site	Initiate modifications for Mars surface power 10 kW _e technology demo
Mars Kilopower System Concept and Scalability from Prototype	Develop 10 kW _e -class power system concept for Mars surface missions	Mars Kilopower detailed conceptual design	Demonstrate in-core heat pipe heat transfer, determine power conversion adaptation scope, and deliver system technology demonstration plan	



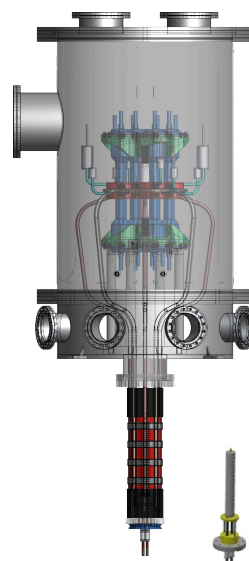
Kilowatt Reactor Using Stirling Technology (KRUSTy)



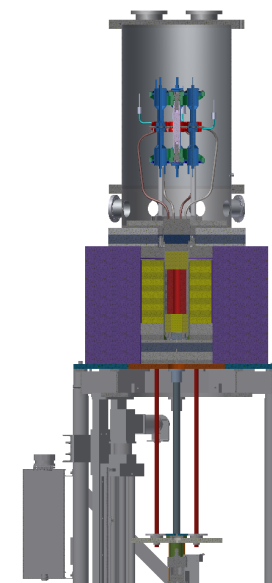
**Notional Flight
System Concept**



**Thermal Prototype &
Materials Testing
(Year 1)**



**Thermal-Vac System Test
with Depleted Uranium
Core at GRC (Year 2)**



**Reactor Prototype Test
with Highly-Enriched Uranium
Core at NNSS (Year 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 kWe-class fission power systems**

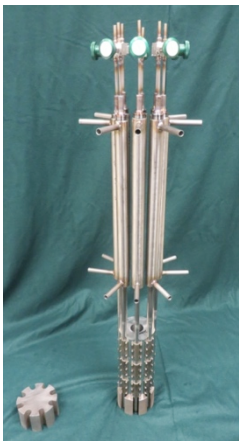




Kilopower Thermal Prototype



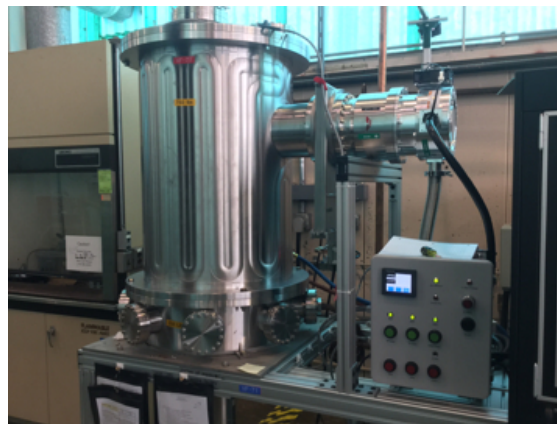
- **Kilopower Thermal Prototype is first of three steps to a nuclear ground demonstration**
 - Non-nuclear functional prototype with steel simulated reactor core
 - Non-nuclear prototype with depleted uranium simulated core
 - Nuclear demonstration with uranium reactor core
- **Thermal prototype validates core geometry and heat pipe attachment method prior to build of depleted uranium simulated core**
 - Steel core thermal properties are close enough to uranium to validate heat pipe attachment method under thermal load, and segmentation of core
 - First of two electrically heated trials of heat pipe attachment methods tested at temperature in vacuum



**Stainless Steel
Thermal Prototype**



Vacuum Tank Integration



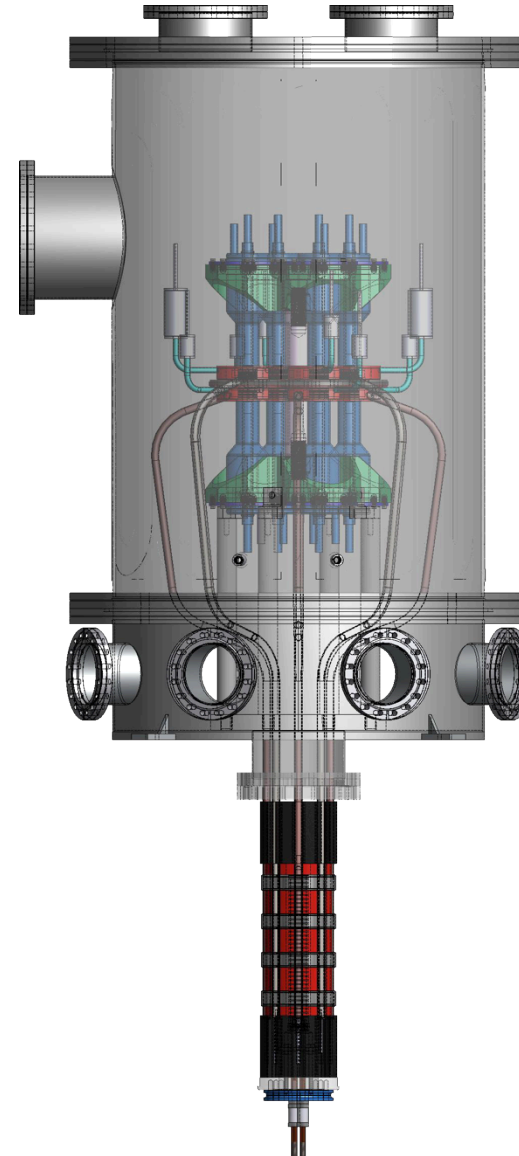
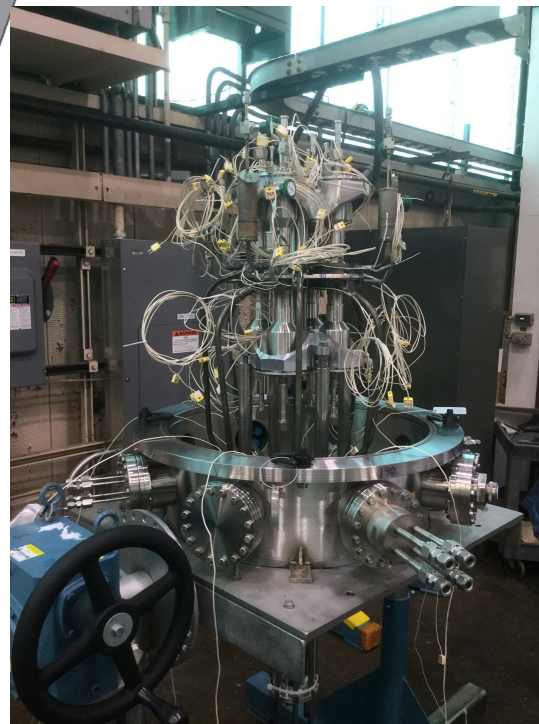
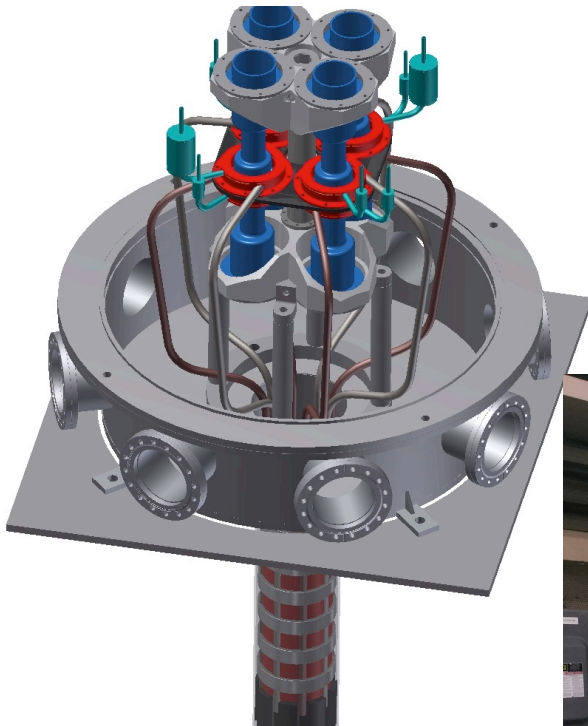
Integrated Assembly



Test



Latest Configuration of 1 kW_e Krusty Nuclear Demonstration

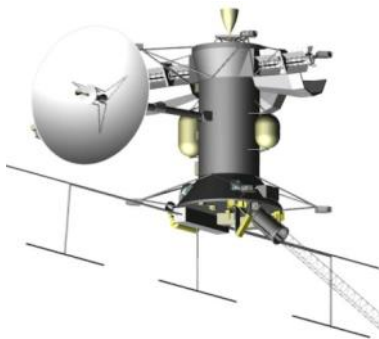




SMD Mission Pull for Small Fission



- **Small fission technology enables expanded science and new Decadal Survey missions (examples below)**
- **Potential benefits to SMD include:**
 - Orbiters instead of flybys, landers instead of orbiters, multiple targets
 - More instruments, bigger instruments, increased duty cycles
 - High rate communications, real time tele-operations, in-situ data analysis
 - Electric propulsion, lower launch mass, greater mission flexibility

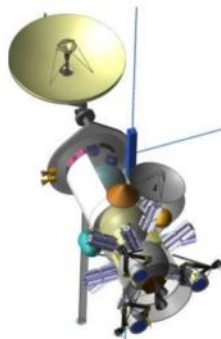


**Jupiter Europa
Orbiter ~600 We**

6 MMRTGs

4 ASRGs

1 Small Fission System

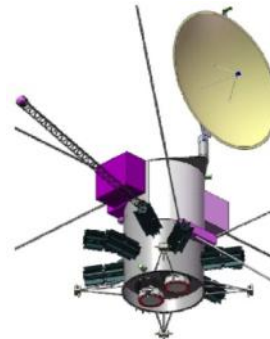


**Neptune Systems
Explorer ~3 kWe**

28 MMRTGs

6 Large SRGs

1 Small Fission System

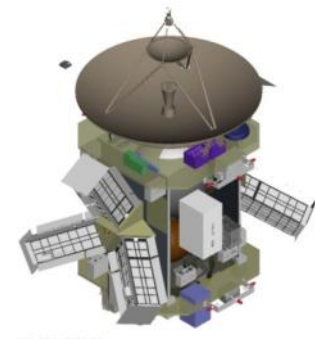


**Kuiper Belt Object
Orbiter ~4 kWe**

36 MMRTGs

8 Large SRGs

1 Small Fission System



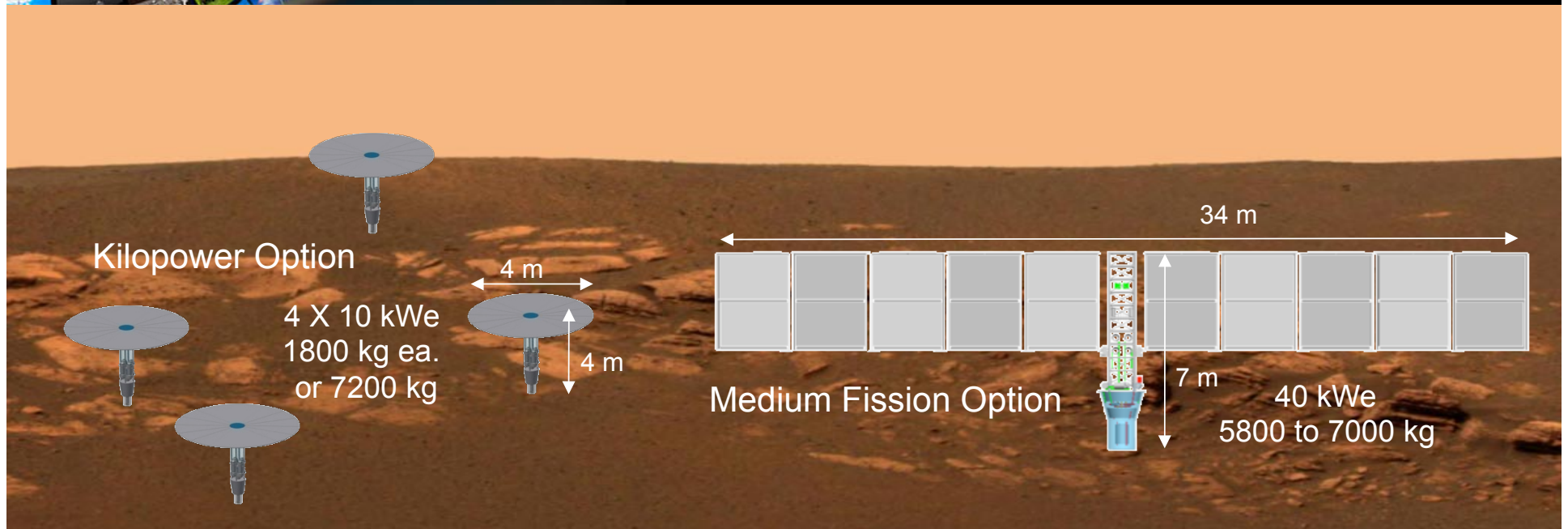
**Trojan Tour
~800 W**

8 MMRTGs

6 ASRGs

1 Small Fission System

HEOMD Mission Pull for Small Fission



- **The Evolvable Mars Campaign has found that Kilopower systems can be used in multiples to address human surface missions as an alternative to a large single power plant**
 - Smaller unit size and mass permits easier packaging in surface landers
 - Multiple units provide a greater level of redundancy and fault tolerance
 - Units can be deployed as needed in timeline for flexibility in buildup approach
 - Human missions can benefit from first user's establishment of nuclear infrastructure (material handling, testing, safeguards) and launch approval process

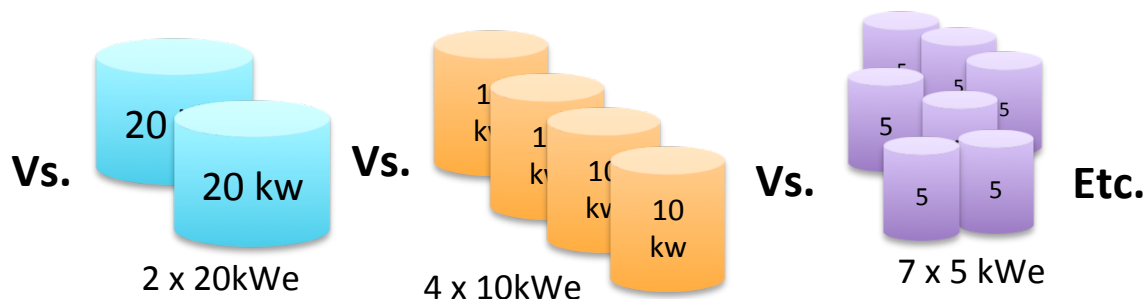
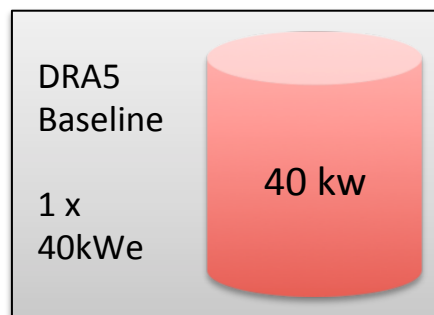


HAT Study: Fission Surface Power 40 kW_e System vs. Kilopower

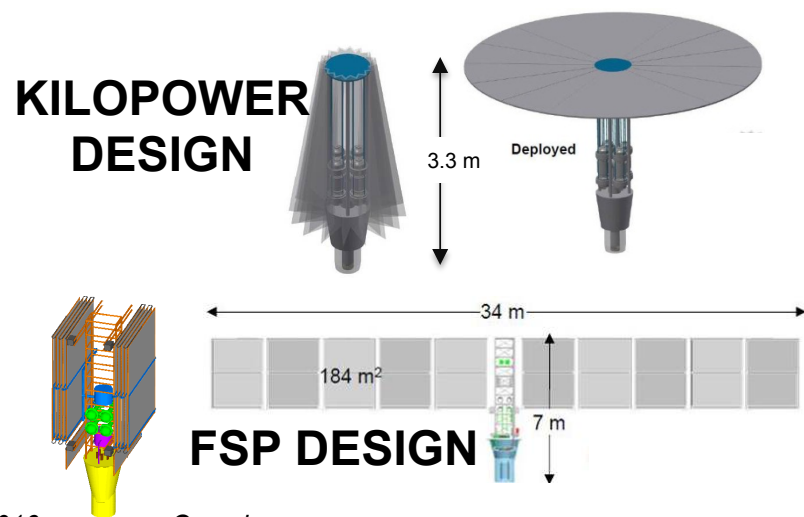


Mars surface mission needs ~40 kW of surface power

...but it doesn't necessarily have to be in a single package



“Kilopower” design is similar to the FSP, but with lower mass, less volume, easier logistics, and fewer moving parts



Type	Power (kWe)	Mass (kg)	Dimensions (m)		Radiators
			Dia	Height	
KP	3	751	1.2	2.2	9.6 m²
	5	1,011	1.3	2.7	13.5 m²
	7	1,246	1.4	3.0	17.1 m²
	10	1,544	1.5	3.3	20 m²
FSP	10	3,300	1.0	7 m tall	37 m²
	40	7,000	2.7	7 m tall	184 m²



Partner Organizations Investing in Kilopower



- **DOE/National Nuclear Security Administration**
 - Nevada Nuclear Security Site Device Assembly Facility is being provided without cost to NASA
 - NNSA will own, keep, and dispose of Kilopower demonstration reactor core
 - *NNSA is a funding partner in FY16 & 17 to Kilopower*
- **HEOMD**
 - Kilopower is the assumed surface power technology for Evolvable Mars Campaign architecture trades
 - Providing time of Human Spaceflight Architecture Team (HAT) members for Mars Kilopower Concept Development
 - Possible Kilopower use on 2024-26 Mars In Situ Resource Utilization Surface Demo
- **Other Government Agencies: ARPA-E**
 - Contracts awarded for 1 kWe residential power: GENerators for Small Electrical and Thermal Systems (GENSETS)
 - Two Stirling technology contracts could have direct benefit to Kilopower (Infinia, Sunpower)



Extensive Project Leveraging



- Existing NNSA nuclear test facilities operated within current safety constraints
- Available high-enrichment U235 fuel and other nuclear materials from Y-12
- Existing, benchmarked LANL reactor design codes
- Four SBIRs producing plug-in ready test hardware
 - Phase II contracts for Na heat pipes, radiators, and alternate (Brayton) power conversion
 - Phase IIE in negotiation for Na heat pipes to be used in nuclear test at NNSS
- Existing Advanced Stirling Convertors and design expertise from RPS Program
- Stirling cold-end heat pipes from Flight Opportunities Program & RPS
- Extensive MSFC experience-base in reactor thermal simulators and custom electric resistance heaters



Device Assembly Facility (DAF)
Nevada Nuclear Security Site (NNSS)



Advanced Stirling Convertor (ASC)
From ASRG Project

**Existing facilities, expertise, and equipment
provide a uniquely timed level of affordability**



Cross-cutting Experience Gained Through 1 kW_e Test



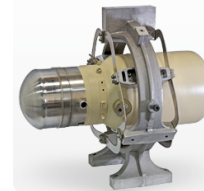
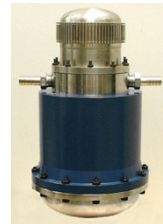
- **Experience gained and infrastructure established during the 1 kW_e test will reduce risk of any future reactor development**
 - Common nuclear fuel form that is scalable to 10 kW_e
 - Fabrication of reactor core to NASA specifications
 - Shipping and handling of reactor core in specialized cask
 - NNSS familiarization with NASA test practices
 - NASA familiarization with NNSS nuclear safety & contingencies
 - Reactor assembly with combination of NNSS and NASA personnel
 - Reliable instrumentation, data acquisition, and data storage
 - Reactor operator experience for startup, steady-state, transient, & shutdown
 - Reactor cool down, disassembly, and core disposal



These capabilities translate across a wide range of space nuclear applications and power levels



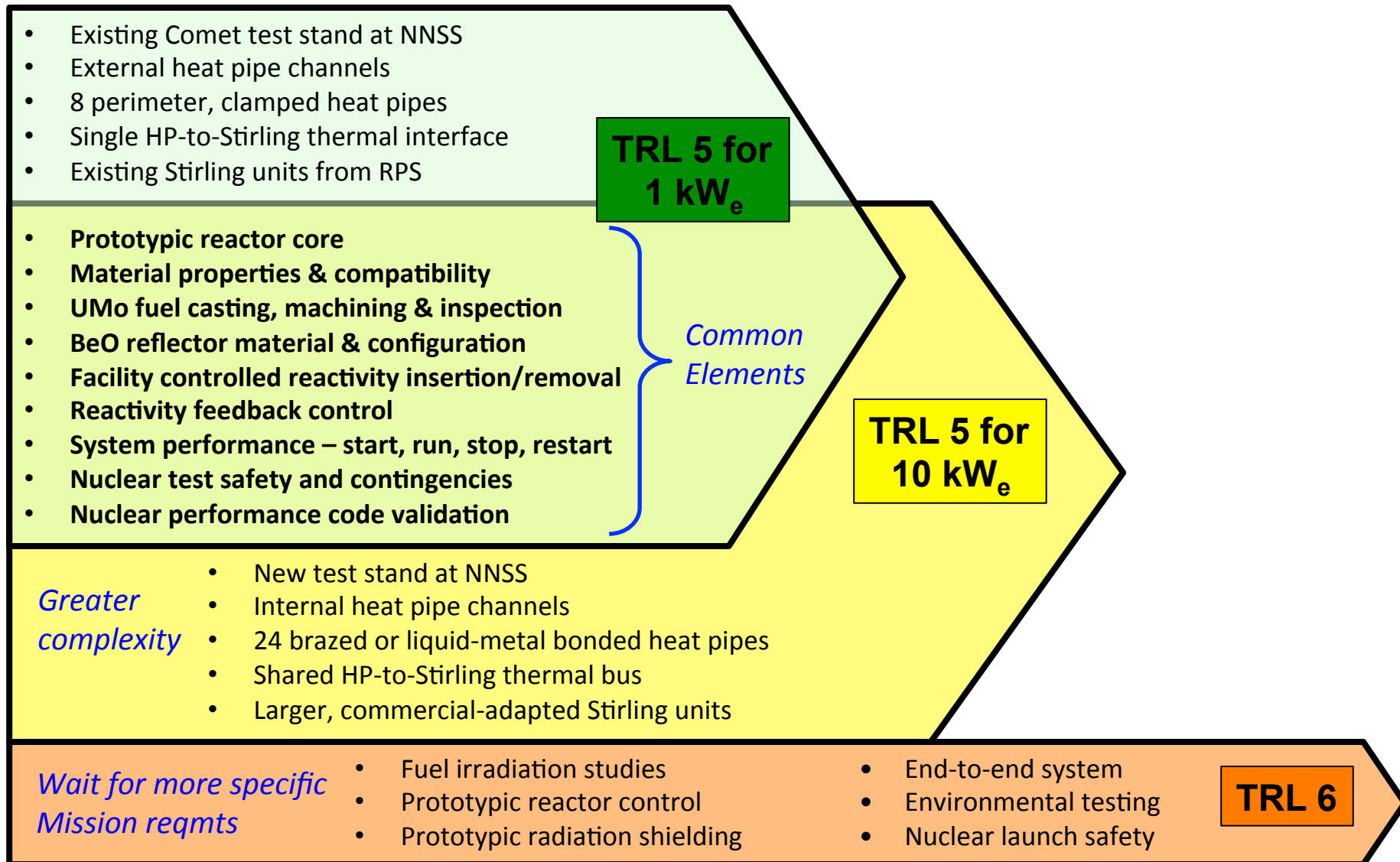
Stirling Industry Base Supports Full Range of Kilopower Systems



	Sunpower EE-35	Infinia TDC	Sunpower ASC	Sunpower P2A	Qnergy QB-3500	Sunpower PCU	Qnergy QB-7500
Nominal	35 W	55 W	80 W	1 kW	3.5 kW	6 kW	7.5 kW
Range	20 - 42 W	50 - 60 W	60 - 90 W	0.5 - 1.4 kW		4.5 - 7.2 kW	
Thot	650 °C	650 °C	760 °C	550 °C	Qnergy I.P.	575 °C	Qnergy I.P.
Tcold	80 °C	120 °C	90 °C	50 °C		100 °C	
Frequency	105 hz	80 hz	102 hz	50 hz		60 hz	
Piston Amp.	4 mm	5.6 mm	4.5 mm	10 mm		16 mm	
Approx. Mass	1.4 kg	4.5 kg	2.5 kg	35 kg	67 kg	100 kg	103 kg
Bearings	Gas	Flexure	Gas	Gas	Flexure	Gas	Flexure
Status	6 units built for GRC	16 units built, 4 remain on test at GRC	29 units built for GRC, 13 on test at GRC	>10,000 units built by Microgen for CHP	430 solar Powerdish units on field trial at Tooele	2 units built at SP for GRC TDU	>100 production units built for CHP



1 kW_e Kilopower Test Retires Many Challenges for 10 kW_e Fission Systems





Summary



- **We have the team**
- **We have available, leveraged infrastructure and experience**
- **We have mission pull from HEOMD and willingness to use the technology from SMD**
- **We have an NASA-wide directive on a role to fulfill**
- **We are making progress today with successful technology development accomplishments**

We're seizing the opportunity to demonstrate system-level technology readiness of space fission power