



# Powering the Lunar Frontier Nuclear Energy for the Artemis Era

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**Phase 1:**

Secure reliable access to the surface and experiment

**Starts now**

**Phase 2:**

Establish the initial Moon Base operating capability

**Starts 2029**

**Phase 3:**

Achieve semi-permanent crew presence

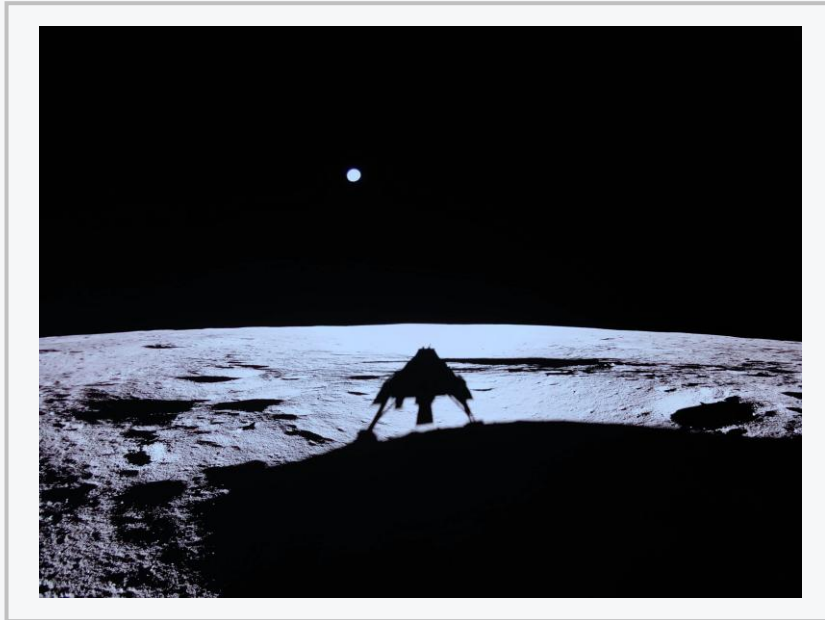
**Starts 2032**

# BUILDING THE MOON BASE

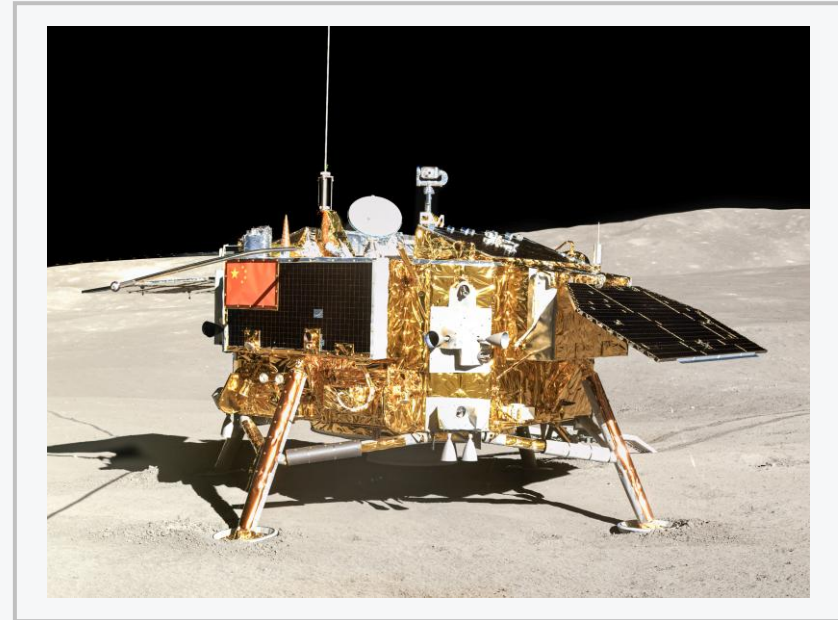


# Surviving the Lunar Night is Crucial for U.S. Leadership on the Moon

U.S. lunar spacecraft can only operate for days while China's lunar spacecraft, powered by radioisotopes, operates for years



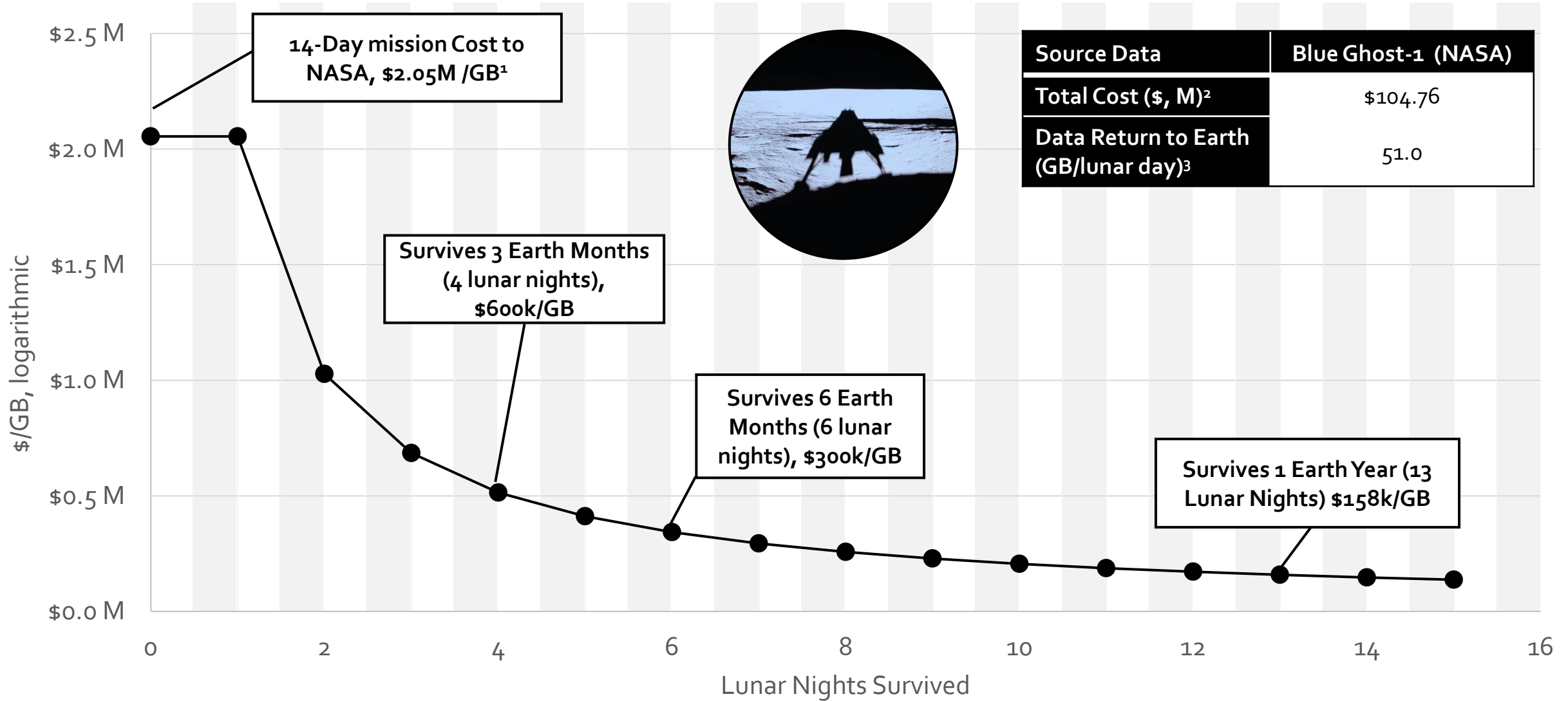
Firefly Blue Ghost Spacecraft  
Mission Duration: 14 Days  
Power Source: Solar



China Chang'4 Lander  
Mission Duration: 6+ Years  
Power Source: Solar + Radioisotopes

# Quantifying the Value of Surviving the Lunar Night Using Historical Data

Blue Ghost Mission 1: \$/GB Costs to NASA, Long Term (full analysis to be presented at ASCEND 2026)



1. Value calculated from source historical data.
2. CLPS TO and plus-up total value (\$101.5M), adjusted for inflation to 2026 USD.
3. Firefly gave NASA 51 of the 119 GBs of data they collected during Blue Ghost-1. CLPS mission data costs reflect data delivered to NASA in this analysis.

# Lunar Permanently Shadowed Regions (PSRs)

PSRs near the lunar poles are among the most scientifically compelling and operationally challenging environments in the inner solar system. PSRs contain volatile deposits that record billions of years of Solar System history.

Knowledge of these volatiles helps in understanding lunar geologic evolution and Solar System formation, and future resource prospecting campaigns.

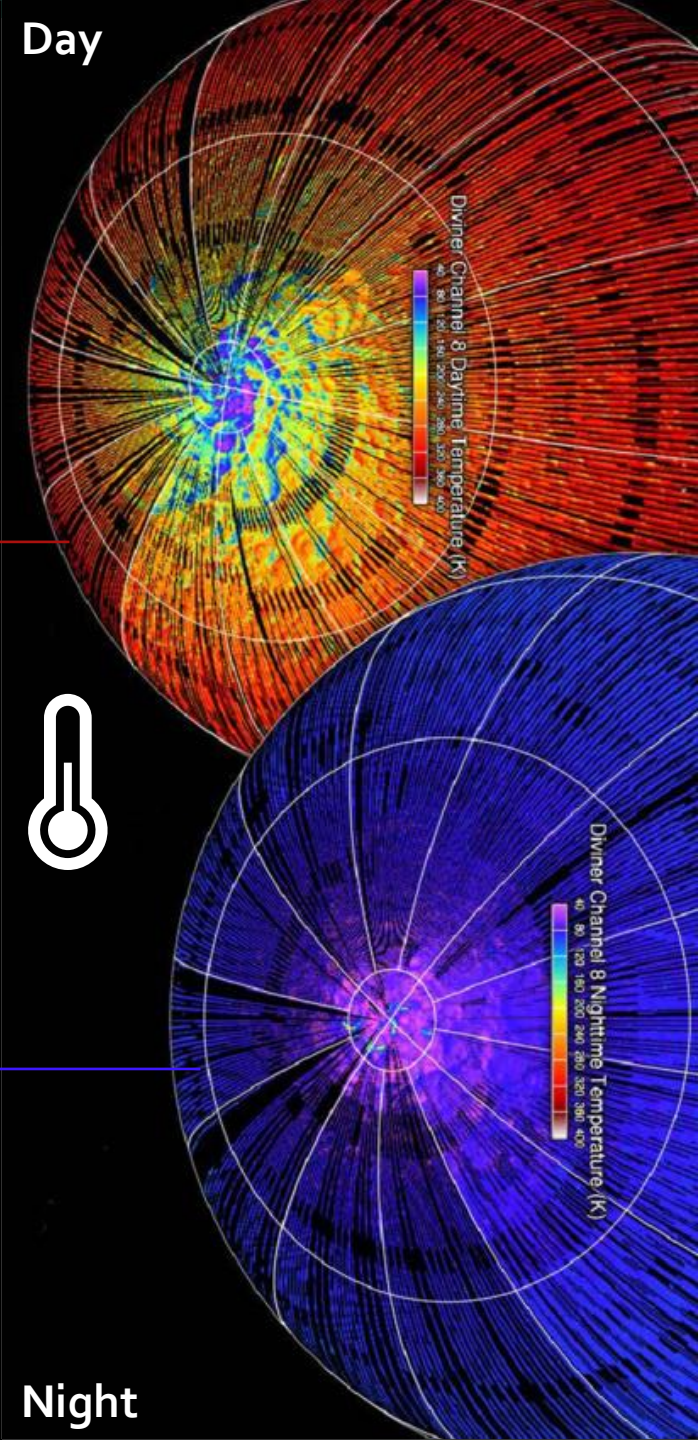
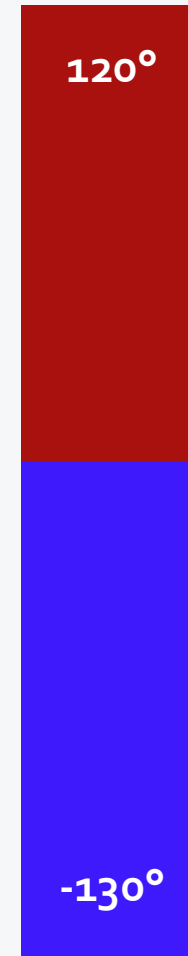
More detailed scale geomorphology of PSRs would enhance future exploration. Ground truth measurements from within PSRs can validate orbital remote sensing and reduce risks for future human landings in these high-priority regions.

Multi-temporal illumination [map](#) of the lunar south pole, Shackleton crater (19 km diameter) is in the center, the south pole is located approximately at 9 o'clock on its rim. Mapped area extends from 88°S to 90°S [NASA/GSFC/Arizona State University].

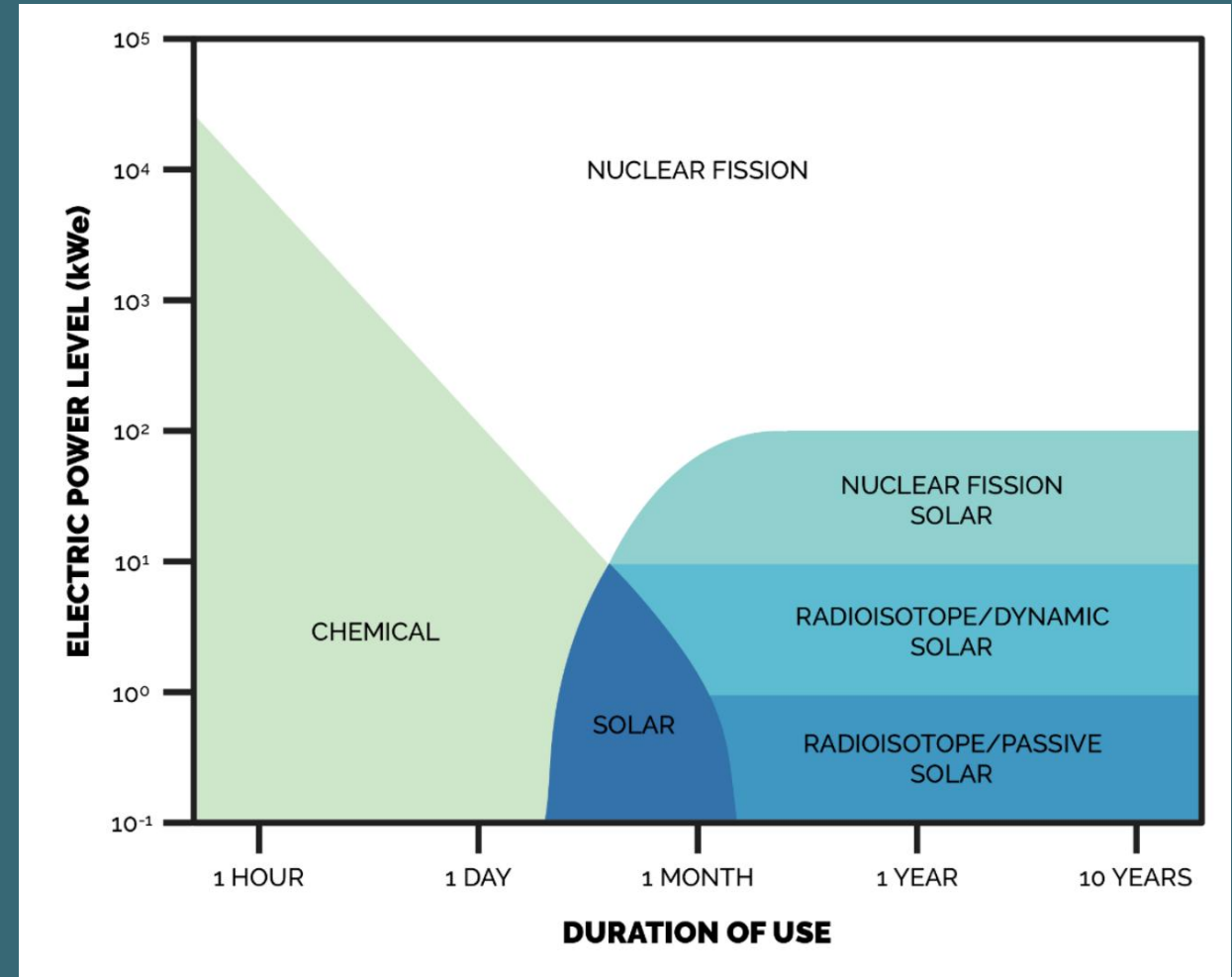
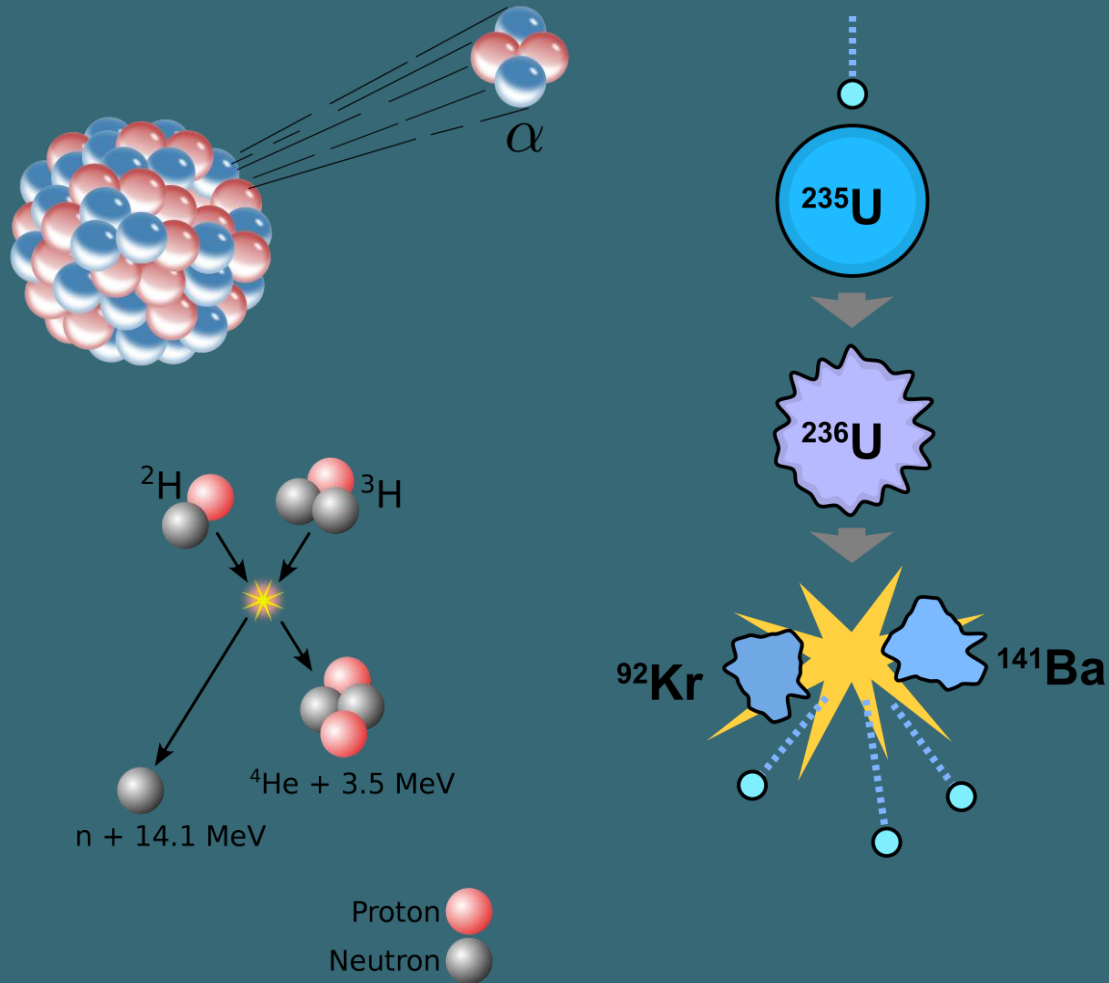
Reduced resolution (6x; 11.4 m/pixel) [mosaic](#) of Erlanger crater. [NASA/GSFC/Arizona State University].

# Surviving the Lunar Night: Challenges

- Electronics
  - Resistivity decreases at low temperatures
  - Increased chance of shorts
- Batteries
  - Lithium-ion battery liquid electrolyte solutions prone to freezing
  - Battery cases can crack open
- Material Properties
  - Extreme temperatures break circuit boards, delaminate solar panels
  - Specific heat decreases at low temperatures
  - Thermal conductivity changes



# Fundamentals of Nuclear Power for Lunar Needs



**NUCLEAR BATTERIES HAVE BEEN USED  
SINCE THE 1960s BUT HAVE BEEN  
PROHIBITIVELY EXPENSIVE OR HEAVY FOR  
BROAD USE**

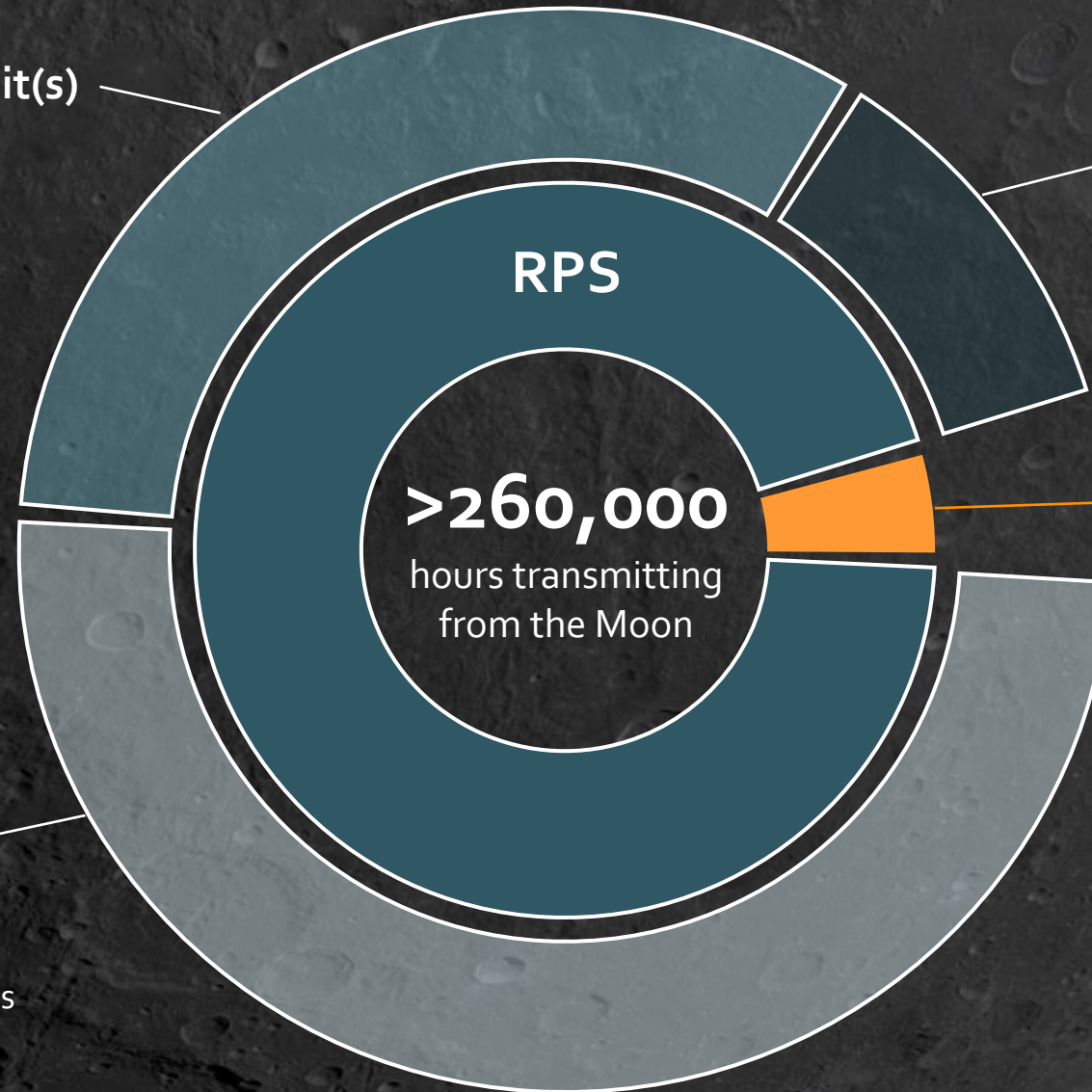
RPSs enabled >90% of all non-human operational time on the lunar surface.

### Radioisotope Heater Unit(s)

- Apollo 11 EASAP
- Lunokhod-1, -2 rovers
- Chang'e 3 lander
- Yutu-1 rover
- Yutu-2 rover

### Radioisotope Heater Unit and Radioisotope Thermoelectric Generator

- Chang'e 4 lander



### Solar, Batteries and/or Electric Heaters

- Surveyor 1
- Surveyor 5
- Surveyor 6
- Surveyor 7
- Luna 17 lander
- SLIM lander

### Radioisotope Thermoelectric Generators

- Apollo 12, 14-17 ALSEPs

# Radioisotope Power Systems (RPS)

## RHUs

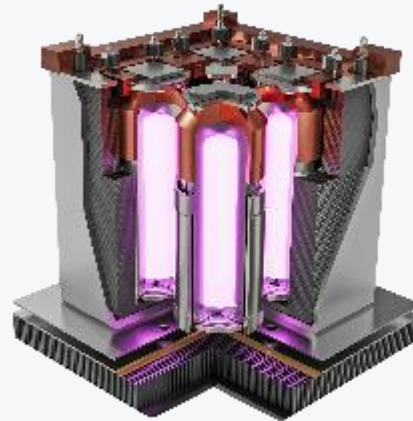
Radioisotope Heater Unit



**Size:** 1s  $W_t$  – 10s  $W_t$   
**Efficiency:** N/A

## RTGs

Radioisotope Thermoelectric Generator



**Size:** 10s  $W_e$  – 100s  $W_e$   
**Efficiency:** ~5%

## RSGs



























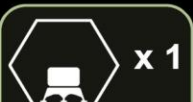

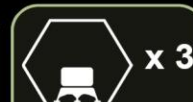







































Radioisotope Stirling Generator



**Size:** 10s  $W_e$  – 100s  $W_e$   
**Efficiency:** ~25%



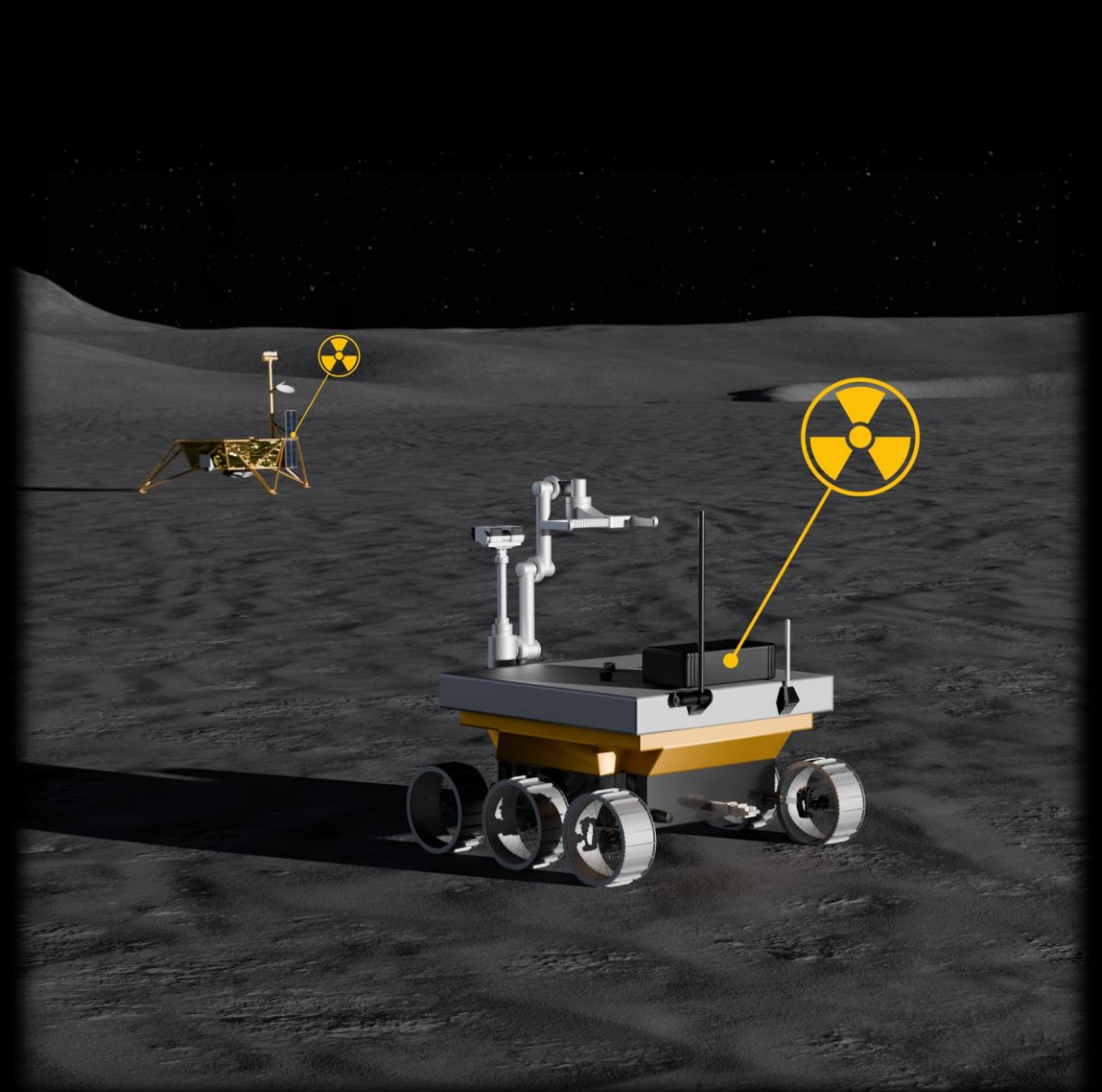
# MOON BASE

PHASE	PHASE 01			PHASE 02				PHASE 03			
YEAR	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
INVESTMENT	\$10 BILLION			\$10 BILLION				\$10 BILLION +			
SURFACE & ORBITAL ASSETS	 x 1	 x 2	 x 1	 x 1	 x 1	 x 1	 x 1	 x 1	 x 1	 x 1	 x 1
		 x 5	 x 5	 x 1	 x 4	 x 1	 x 4	 x 2	 x 1	 x 1	 x 1
			 x 4	 x 2	 x 2	 x 3					 x 1
LANDERS	 x 1	 x 8	 x 3	 x 1	 x 2	 x 3	 x 2	 x 1	 x 2	 x 2	 x 2
	 x 1	 x 1	 x 3	 x 3	 x 2	 x 1	 x 2	 x 3	 x 2	 x 2	 x 2
			 x 4	 x 1	 x 2	 x 3	 x 2	 x 2	 x 3	 x 3	 x 4
LAUNCHES	 x 2	 x 10	 x 12	 x 6	 x 7	 x 7	 x 7	 x 7	 x 7	 x 7	 x 7

# Radioisotope Demos

**Radioisotope heater units (RHUs) provide heat, allowing for survive the night capability during lunar surface operations**

- Test updated nuclear fuel sources for increased reliability and safety for commercial use
- Initial lander demonstrations will survive 120+ continuous hours of darkness and send a signal back to Earth
- Enable future lunar assets to survive 354+ hours of local darkness



# Nuclear Surface Power Capability

## Demonstrate nuclear surface power capabilities

- Demonstrate technologies, processes, and operations for future larger scale nuclear power/propulsion
- Demonstrate thermal management concepts and methods for larger scale future applications
- Used as power generation stations
- Used within assets to enable night survival and permanently shadowed region exploration
- Demonstrate reactor surface power



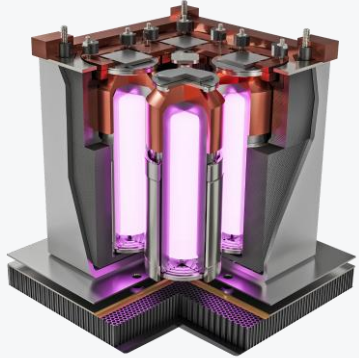


Phase 1	Phase 2	Phase 3
<p><b><i>Initial Power</i></b></p> <ul style="list-style-type: none"> <li>• Deploy assets responsible for self-supported power generation and survival</li> <li>• Demo initial hibernation points</li> <li>• Demo initial Radioisotope Heater Units (RHUs)</li> </ul>	<p><b><i>Deploying Power Infrastructure</i></b></p> <ul style="list-style-type: none"> <li>• Deploy Solar Arrays Power Stations</li> <li>• Deploy Radioisotope Thermal Generator (RTG) Power Stations</li> <li>• Assets begin routinely using RHUs &amp; RTGs to enable night survival and additional night operational capability</li> <li>• Demonstrate wireless charging for Rovers</li> <li>• Demonstrate dust tolerant electrical connectors</li> <li>• Demonstrate electrical cable deployment</li> <li>• Demonstrate reactor surface power</li> </ul>	<p><b><i>Enabling Power Distribution</i></b></p> <ul style="list-style-type: none"> <li>• Fission Surface Power</li> <li>• Power distribution deployed to support habitats and surface assets <ul style="list-style-type: none"> <li>• Wireless charging</li> <li>• Dust tolerant electrical connectors</li> <li>• Electrical cable deployment</li> </ul> </li> <li>• Permanently Shadowed Region exploration</li> </ul>

# Zeno Power: Radioisotope Power Systems (RPS)



**Zeno Power is on track to demonstrate initial commercial radioisotope power systems by 2027**



Zeno Power's RPSs enable frontier missions for government and commercial customers, from the seabed, to the Arctic, to lunar surface

**Founded:** 2018

**Locations:** Seattle, D.C.

**Team Size:** 95+

**Private Capital Raised:** \$80M

## ANCHOR CUSTOMERS



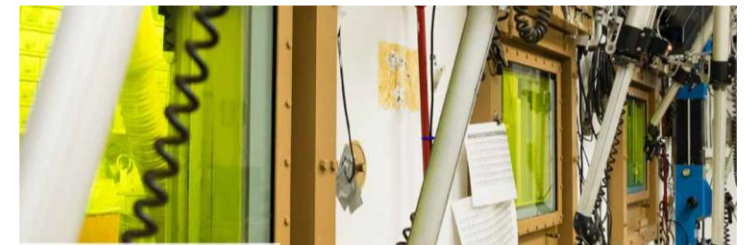
Contract Value: \$60M+  
Includes NASA STMD Tipping Point Project  
"Harmonia"

## PROVEN TECHNOLOGY



Successful Nuclear Prototype Demonstration at  
PNNL

## SECURED SUPPLY CHAIN



Nuclear Fuel Source &  
Facilities Secured to Build  
Initial 10+ RPSs

zeno

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