National Aeronautics and
Space Administration

Lunar Night Survivability Achieved by Radioisotope and Fission Power System Technology

Robert L. Cataldo | NASA Glenn Research Center | Robert.L.Cataldo@nasa.gov | (216) 977-7082

Lee Mason | NASA Glenn Research Center | lee.s.mason@nasa.gov | (216) 977-7106

ABSTRACT

The Moon's surface environment offers a significant challenge for most space systems and, particularly, for power technologies. A complete lunar day cycle is 354 hours of sunlight and 354 hours of darkness. Equatorial diurnal surface temperatures range from about 400K at lunar noon to 100K during the night. Surviving the long lunar night poses a significant challenge for photovoltaic arrays and energy storage systems. Providing the required energy for both nominal operations and for electric heaters to maintain keep-alive temperatures for electronics and other vital systems would necessitate a massive photovoltaic power supply and storage system, thereby reducing the amount of landed payload available for exploration and science investigations. Radioisotope power systems (RPS) produce power by converting the heat produced by natural isotopic decay into electricity. For example, the 110 We multi-mission radioisotope thermoelectric generator (MMRTG) has been powering the Mars Curiosity rover and is also planned for the Mars 2020 mission rover. RPS is ideally suited for lunar surface applications eliminating the need for large batteries, thus saving 100's kg of mass even for modest science missions while providing waste heat to maintain components and systems in required temperature ranges. The US uses plutonium-238 as the fuel source and it offers a high energy density along with an 88-year half-life. Eventual human habitats, crewed rovers, in-situ resource production demonstration, etc., will require significantly greater levels of power not practical for a RPS system or photovoltaic systems. For these higher power needs, nuclear fission systems would be a viable solution. Recent developments in smaller scale reactor systems called Kilopower are envisioned as an initial step in powering near term human lunar surface systems. Options for advanced RPS and Kilopower systems will be discussed and compared to alternate power system solutions.

COMPARISON OF SOLAR AND RADIOISOTOPE POWER SYSTEMS

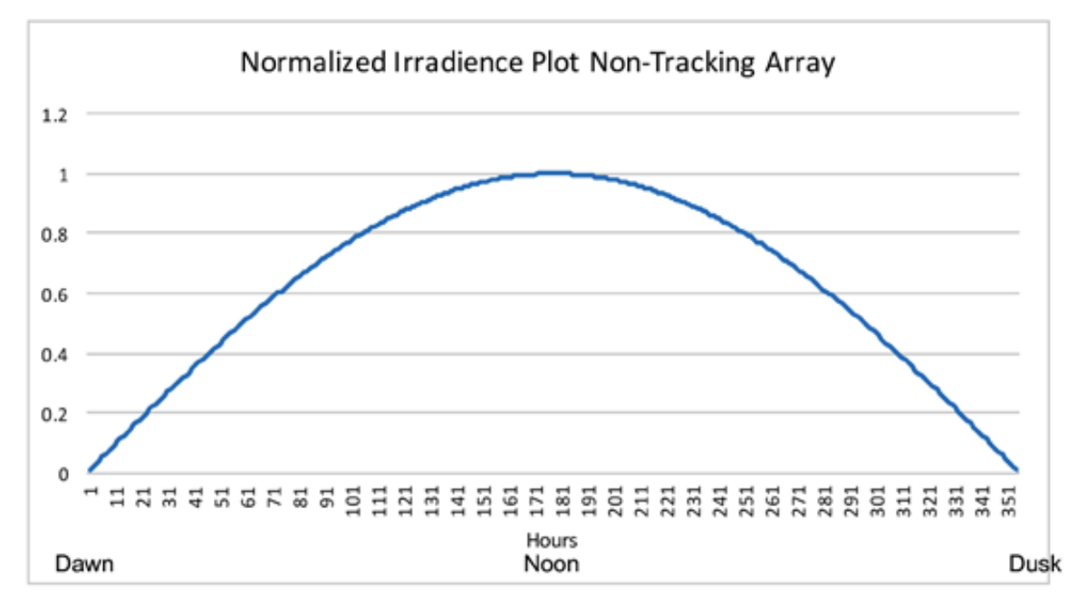
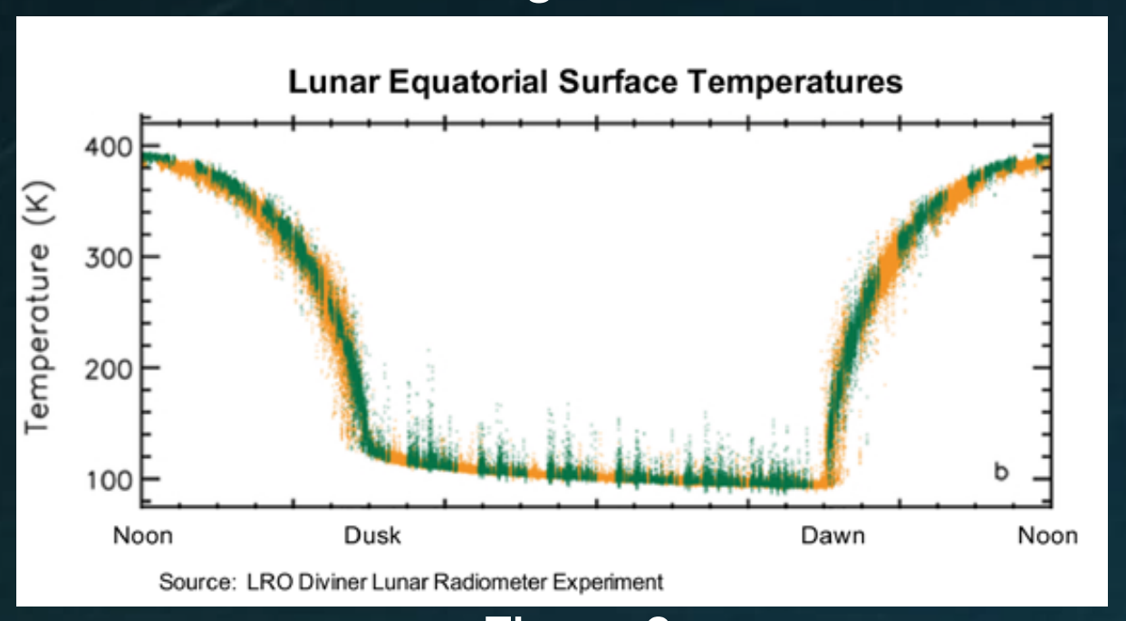


Figure 1



Source: LRO Diviner Lunar Radiometer Experiment

Figure 2

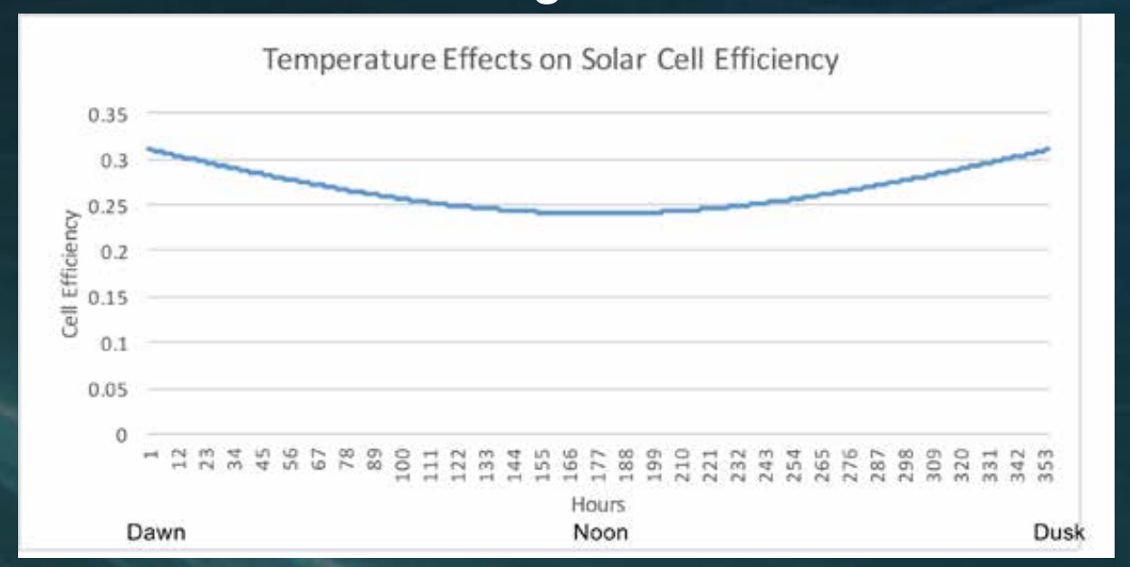


Figure 3

The most recent accepted measurements of the Earth orbit total solar irradiance value are ~1,361 W/m$_2$. Since the Moon has no appreciable atmosphere, an array can be sized using this value. It is anticipated that a science mission would likely have a flat mounted, non-tracking array due to simplicity and cost. Figure 1 shows the solar irradiance that would reach a zenith pointing fixed nontracking array at the lunar equator. The consequence of a fixed array is an increased area needed to provide the same total energy that a tracking array would provide. A trade-off can be made comparing the complexity, cost, and risks between tracking and nontracking solar array.

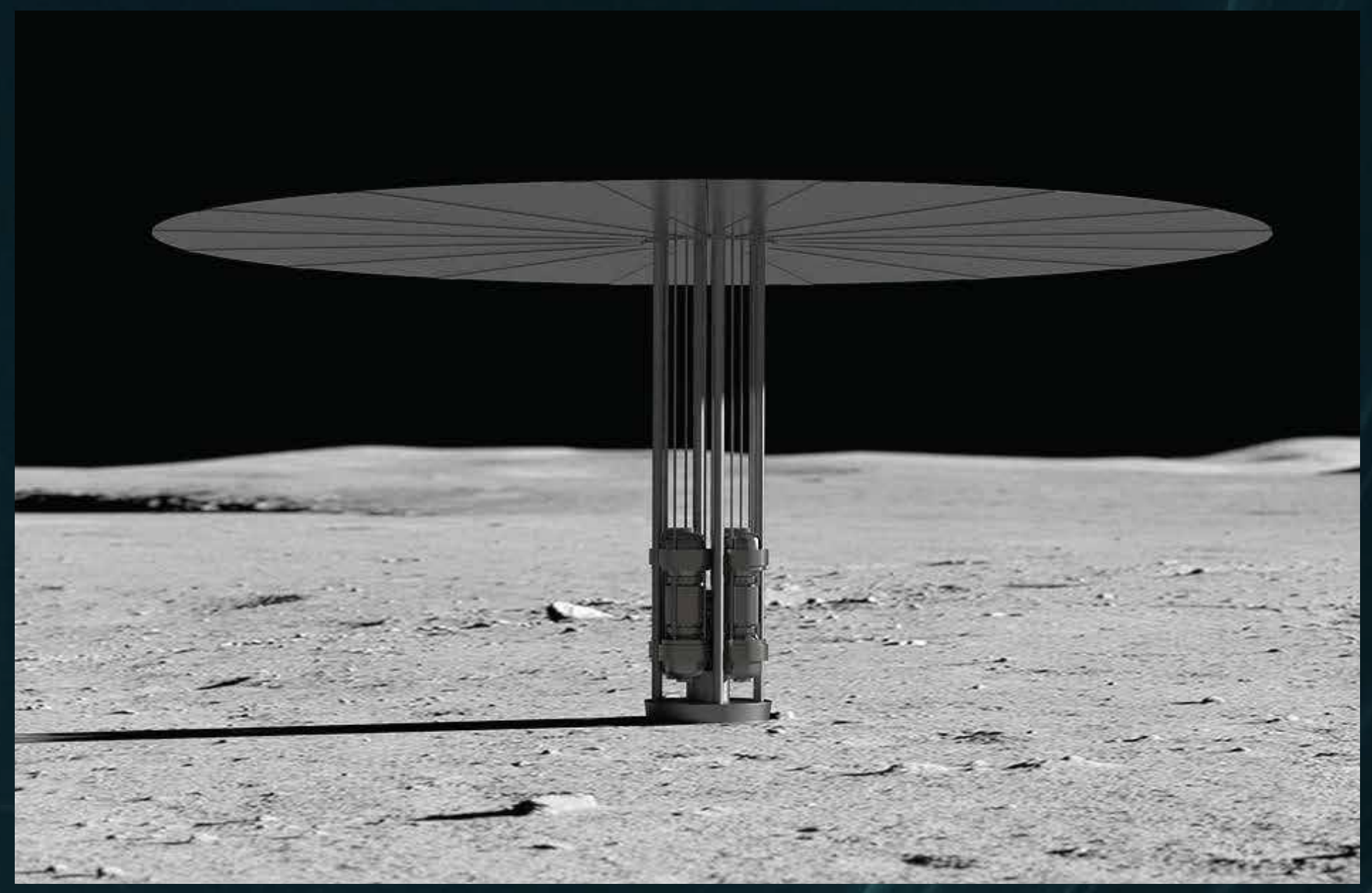
Lunar surface temperature must also be considered and factored into a power system design. Figure 2 shows the inferred lunar equatorial diurnal surface temperature data from the Diviner Lunar Radiometer Experiment on the Lunar Reconnaissance Orbiter (LRO). Peak temperatures at noon reach about 117 °C (390 K) and –173 °C (100 K) during the night.

It is expected that the array temperature will be near the same as the surrounding surface. The high temperature will reduce array efficiency from the 28 °C standard and will result in an increased array area. The power output of RPS will also be effected whereby daytime power will be lower compared to that during the night. Figure 3 shows the solar array efficiency as a function of surface temperature.

The data shown in Figure 3 is based on the triple junction GaInP$_2$/GaAs/Ge cell with a nominal efficiency of 29.4% at 28 °C (301 K) and 1 AU. The solar cell efficiency drops to ~24% during lunar noon and increases near dawn and dusk. No decrease in array performance is accounted for ultraviolet radiation degradation nor dust on the array panel.

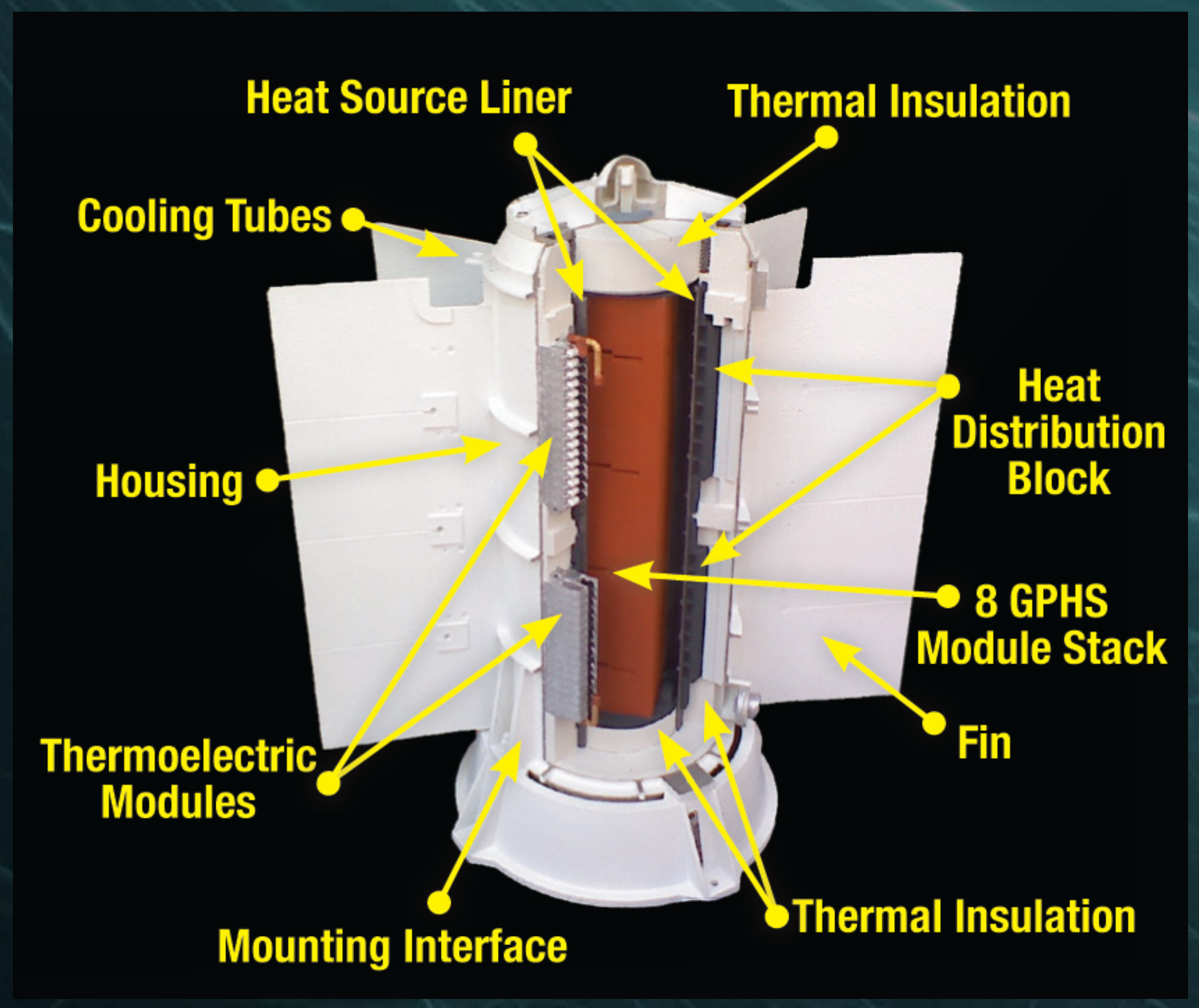
KILOPOWER

The Kilopower project is a near-term technology effort to develop preliminary concepts and technologies that could be used for an affordable fission nuclear power system to enable long-duration stays on planetary surfaces. After successful completion of the Kilopower Reactor Using Stirling Technology (KRUSTy) experiment in March 2018, the Kilopower project team is developing mission concepts and performing additional risk reduction activities to prepare for a possible future flight demonstration. Such a demonstration could pave the way for future Kilopower systems that power human outposts on the Moon and Mars, enabling mission operations in harsh environments and missions that rely on ISRU to produce propellants from local materials.

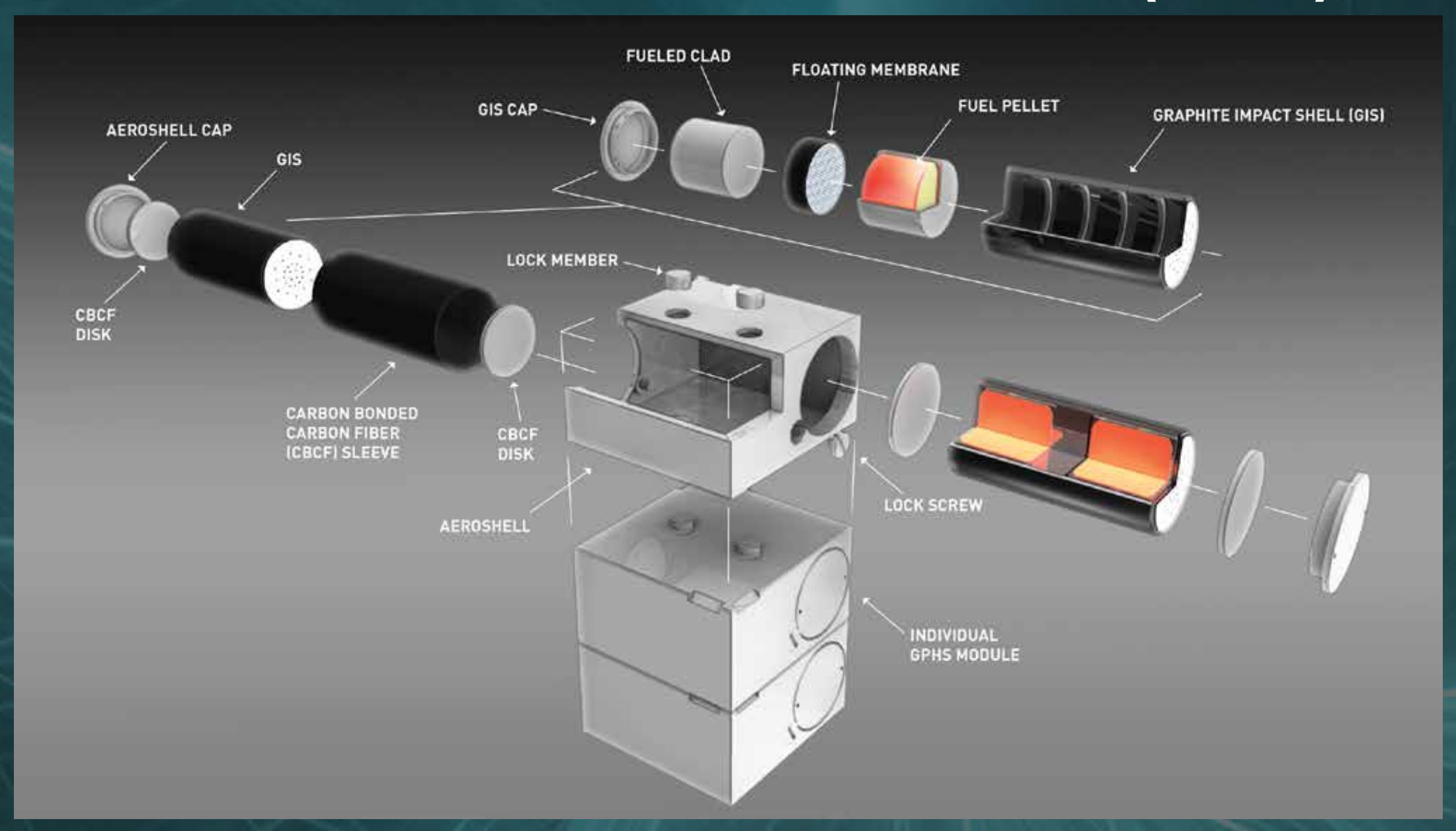


RADIOISOTOPE POWER SYSTEMS (RPS)

MMRTG



GENERAL PURPOSE HEAT SOURCE (GPHS)



DYNAMIC RADIOISOTOPE POWER SYSTEMS

Advanced RPS concepts utilizing dynamic power conversion can offer similar power of current RTG technology with about 25% of the isotope fuel or four times the power with the same amount of fuel. This increase in heat-to-electric efficiency becomes more significant for missions requiring higher powers in the multi-hundred-watt range, such as, rover prospecting for volatiles in lunar polar craters, propellant production, and for possible future human mission activities.

BRAYTON

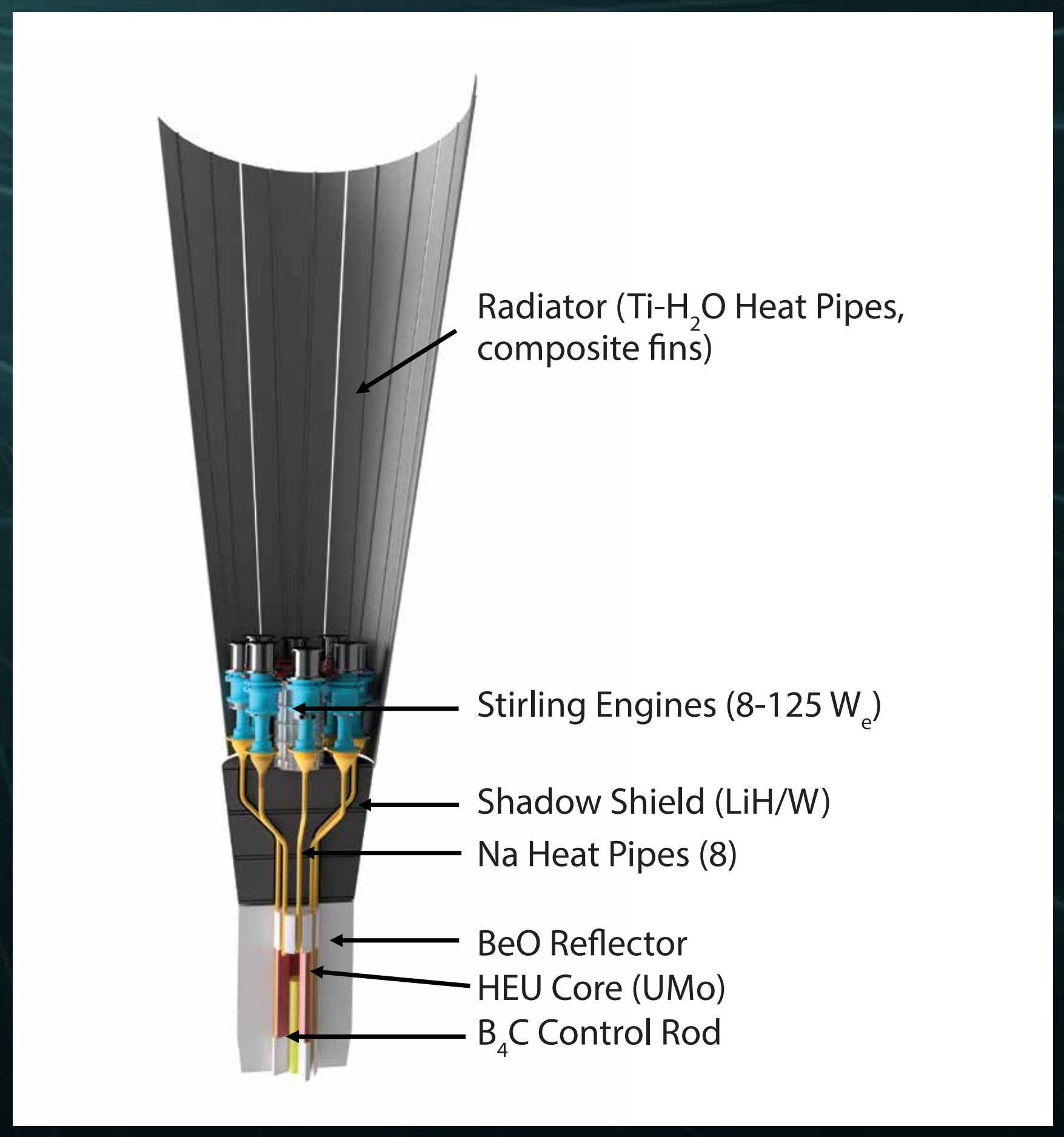
STIRLING

DYNAMIC ISOTOPE POWER SYSTEM (DIPS) CART

SMALL AND SIMPLE

The Kilopower concept leverages available components and low risk materials in a simple design to enable much greater power output than Radioisotope Power Systems (RPS) particularly for long-term missions where radioisotope power decay may become an issue.

- Well-characterized cast U-Mo alloy fuel operated within established limits
- Passive Na heat pipes for reactor heat transport
- Flight-like Stirling power conversion
- Launched cold (not operating) with minimal radiological hazards
- Single control action for reactor startup or shutdown
- Inherent thermal load following with little or no power degradation



Radiator (Ti-H$_2$O Heat Pipes, composite fins)

Stirling Engines (8-125 W$_e$)

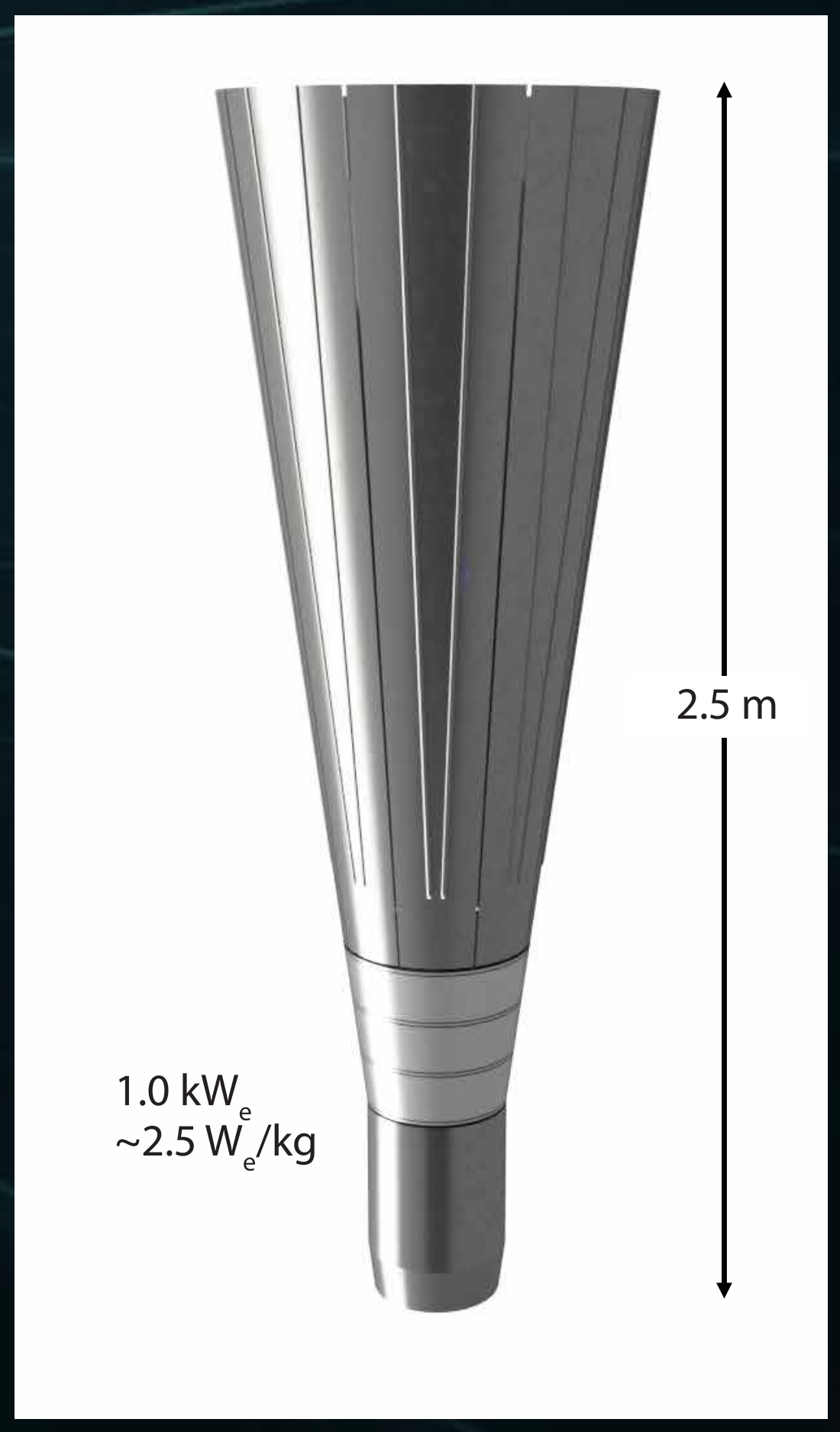
Shadow Shield (LiH/W)

Na Heat Pipes (8)

BeO Reflector

HEU Core (UMo)

B$_4$C Control Rod



1.0 kW$_e$
~2.5 W$_e$/kg