Commercially Available Radioisotope Systems for Extreme Environments, Primary Power, and Electric Propulsion

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1. Introduction

Radioisotope heater units (RHU) and their natural extensions Radioisotope Power Systems (RPS) have been used to provide thermal and electrical power respectively since the start of the space age. Traditionally these systems have relied upon the commercially prohibitive special nuclear material Plutonium. This choice of isotope provides significant performance overhead, but introduces consequential mission hurdles in cost, supply chain, schedule, and regulatory burden for both transportation and spacecraft integration. Ultra Safe Nuclear is pioneering a new approach to providing a catalog of these vital energy dense tools to the space community by leveraging the medical radioisotope production pathway and in doing so significantly reducing the cost as well as the production timeline.

The modular approach utilized to produce radioisotope sources begins with a patent pending manufacturing method termed "pre-activation encapsulation" where natural precursor materials are embedded within a ceramic encapsulant to form a discrete Ember™. Using ceramic encapsulants rather than traditional metals enables the Embers to withstand very high operating temperatures, high specific energies, and aggregation into customizable power levels. An Ember can contain any of a family of radioisotopes pending the mission specific requirements for mass, power, cost, lifetime, and radiation burden. The Ember is then activated by an appropriate neutron source. The mission driven number of Ember unit cells are assembled into a containment vessel per the power levels desired as shown in Figure 1.

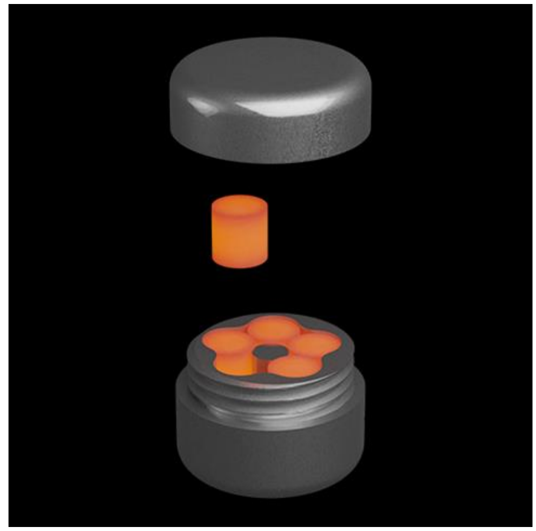

Figure 1: Ember units assembled into a containment vessel.

EmberCore™ is the RHU product name for a fully shielded containment vessel that can be radiatively or conductively coupled to a thermal management system. The fully assembled device is designed to maintain confinement of the radioisotope across a variety of accident scenarios while limiting personnel radiation exposure to publicly acceptable dosage rates. However, since the majority of an EmberCore's mass is attributed to the shielding material and shielding thickness these parameters can be tailored to balance mission requirements against the acceptable integration complexity. Due to the modular nature the output can be scaled from watts to kilowatts of thermal power while providing significant mass and volume savings compared to battery centric systems. The initial EmberCore offering utilizes thulium to provide up to $40W_{th}$ of passive thermal heating to keep chemical batteries and other temperature sensitive components warm enough to survive the lunar night or enter extreme environments such as permanently shadowed regions of the lunar surface.

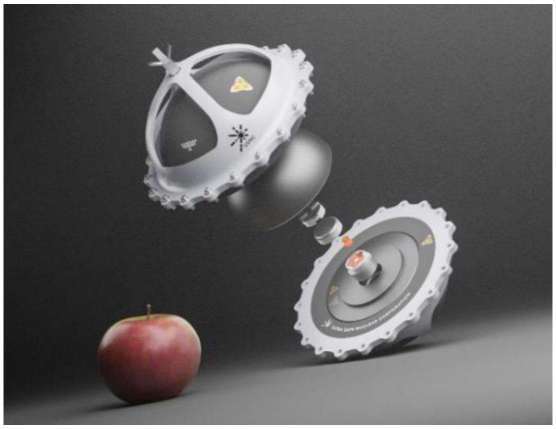

Figure 2: Expanded EmberCore assembly with radiation shield and aeroshell.

EmberPower™ is the RPS product name for an electrical power system that converts the thermal power produced from an assembly of Embers with high technology readiness level (TRL) thermoelectrics, high efficiency thermionics, or a dynamic Stirling engine. The $1kW_e$ electric power system currently under development is designed to maintain confinement of the radioisotope across a variety of accident scenarios. The radiation shadow shield seen in between EmberPower and the radiators of Figure 3 comprises the majority of system mass. The shielding material and thickness can be modified per the payload radiation tolerance pending mission requirements and the acceptable integration complexity. Due to the modular nature used the output can be scaled from watts to kilowatts of power while providing significant mass and volume savings compared to solar centric systems.

Currently EmberCore has reached a TRL 4, with a demonstration roadmap targeting a TRL 6 system prototype ground demonstration in 2023. This is to be followed by a first of its kind commercial space launch and TRL 7 system prototype flight demonstration by the end of 2024. The initial EmberCore product offering is expected to be commercially available for interested parties in 2025 with an expected price of a few million dollars making it suitable for all mission classes.

EmberPower is presently at TRL 3, with a pathway to a TRL 6 system prototype demonstration in 2025. This is to be followed by a system flight demonstration by the end of 2027 to reach TRL 9. The $1kW_e$ EmberPower product offering is expected to be commercially available for interested parties in 2028 and suitable for Flagship or Discovery missions.

The technology and product development process are supported by awards from NASA Innovative Advanced Concepts and the Defense Innovation Unit.

Figure 3: DIU concept spacecraft utilizing $1kW_e$ EmberPower for power system and electric propulsion.

2. Mission capability alignment

The central benefit enabled by EmberCore is sun independent thermal power to support extreme access and survival in extreme environments. For missions that will operate robotic vehicles autonomously or remotely the exploration and objective focus can be achieved without selective path finding along sun illuminated routes. In addition to improving the mission concept of operations, EmberCore offers to significantly extend the utility of deployed equipment through survival of the lunar night and safeguarding critical systems from the temperature swings experienced when exploring permanently shadowed regions.

EmberPower builds upon the functionality of EmberCore with affordable sun independent electrical and thermal power to support spacecraft power and electric propulsion. Many of the missions listed already call out radioisotope power sources as central to their ability to achieve core objectives. However, the constrained nature of the current plutonium RTG strategic supply chain and the associated costs are identified as high-risk factors for many of the proposed missions seeking several NG-RTGs with overlapping schedules. A significant point of differentiation with the technological approach utilized by Ultra Safe Nuclear is that the EmberPower radioisotope can be selected to match mission durations and mass budgets.

	Power [W]	Half-life [Years]	Radiation Shielding
EmberCore	Up to 40	129 days	Light
EmberPower	Up to 1,000	13.5	Heavy
Alternative EP		5.7	Heavy
Other	Per customer inquiry other radioisotopes are accessible for development.		

Table 1: Radioisotopes in development

Additional advantages offered by radioisotope systems versus solar powered battery driven systems is operation in dust laden environments. This key point of risk mitigation aligns with Mars forward development and the exploration of other celestial bodies where sun independence gains further prominence in system design.

A selection of relevant EmberCore missions that would benefit from the advantages offered include:

Lunar Exploration Assessment Group (LEAG)

- ASTROLAB: A South Pole-Aitken Basin Sample Return Mission Using Commercial Rovers and Landers
- Endurance: Lunar South Pole-Aitken Basin Traverse and Sample Return Rover

Mars Exploration Program Assessment Group (MEPAG)

- Collecting In Situ Observations of Meteorological and Aeolian Processes on Mars (and maybe other bodies)

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Mars Exploration Program Assessment Group (MEPAG)

- Collecting In Situ Observations of Meteorological and Aeolian Processes on Mars (and maybe other bodies)
- The Icebreaker Life Mission to Mars: a Search for Biomolecular Evidence of Recent Life

Mercury Exploration Assessment Group (MExAG)

- A Mercury Lander Mission Concept Study

Outer Planets Assessment Group (OPAG)

- New Frontiers Titan Orbiter
- Uranus Orbiter and Probe (UOP)
- Enceladus Orbilander
- Titan Orbiter + Probe
- Triton Ocean World Surveyor

Small Bodies Assessment Group (SBAG)

- Centaur Orbiter and Lander (CORAL)