# Am-241 Powered Dynamic Radioisotope Power System (DRPS) for Long Duration Lunar Rovers

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***Abstract*— For more than half a century most deep space and planetary missions have utilised Pu-238 as the isotope of choice for fuelling radioisotope thermoelectric generators and radioisotope heater units. In Europe, Am-241 based fuel has been selected and developed as part of the European Space Agency funded radioisotope power system program to provide technology solutions in the form of radioisotope thermoelectric generators and radioisotope heater units. A concurrent design study, in collaboration with NASA Glenn Research Centre, has been undertaken to design and develop a dynamic radioisotope power conversion concept that uses the European Large Heat Source. This is a 200 $W_{th}$ Am-241 based heat source being developed for ESA and is an essential building block for the University of Leicester led radioisotope thermoelectric generator programme. This study aims to expand on the applications of the Am-241 based heat source within and outside Europe. The advancement in Am-241 power technologies could give rise to a suitable and sustainable addition to current Pu-238 based technologies, making the solar system and beyond more accessible for science and exploration mission.**

***Keywords*— *Dynamic Radioisotope Power System, Americium, Lunar Rover, Permanently Shadowed Region.***

## I. Introduction

The Lunar permanently shadowed regions (PSRs) and transient shadowed regions (TSRs) are expected to contain large volumes of cold trapped volatile materials in the form ice. These environments receive little to no sunlight during the lunar day and none at all through the lunar night. Temperatures in these environments are estimated to reach <110 K [1] which gives rise thermal and power engineering challenges that are required in order to explore these regions. The ice contained within these regions present a high priority for the development of science and exploration of the Moon and beyond. The abundance of data from mission such as the Lyman Alpha Mapping Project (LAMP), the Lunar Orbiter Laser Altimeter (LOLA), and the Lunar Crater Observation and Sensing Satellite (LCROSS) have been able to peer into and pick out some of the previously unknown properties of these surface formations. Although the findings from these missions have been invaluable for science and exploration, they are limited to their instruments signal-to-noise ratio (SNR) and are only able to provide significant data of PSRs that are on the order of kilometre and sub-kilometre scales [2]. The ability to study and characterise micro and small PSRs has of yet not been possible. V. T. Bickel et al., describe a developed post-processing technique of Lunar Reconnaissance Orbiter (LRO) images and have uncovered previously unknown geomorphological features in PSR regions. However, Bickel et al., states that validation of their findings depend on surface observation and ground truth, indicating the need for robotic science missions to explore these regions [2].

Within the next 10 years NASA plans to execute its Artemis programme, with astronauts present on the surface by the year 2025, with future endeavours of creating artificial environments, such as settlements or “Base Camps” for a long-term sustainable human presence [3]. This shall be achieved through the collaboration of international space agencies, such as ESA, and commercial partners such as Astrobotic. ESA plans to explore the lunar surface and permanently shadowed regions (PSRs) such as cave systems and deep craters found on the surface. Current mission objectives are to send rovers and probes into the craters and cave systems. The approach to overcome the lack of sunlight is to deploy the probes via a crane attached to a rover that is equipped with solar panels, the rover may then supply electrical power to the probes via a charging head attached to the end of the crane. The mission is planned to last over a lunar day (14 Earth days) [4]. NASA is currently preparing to launch its Volatiles Investigating Polar Explorer (VIPER) mission, equipped with scientific instruments and a 1 m drill with a peak power of 450 $W_e$ to sample various lunar soil samples, and aims to collect around 100 days of data that will contribute to the first water resource map of the Moon [5]. Moreover, the Lunar Surface Innovation Consortium (LSIC) are seeking and presenting novel ideas for powering exploration on the moon. Findings presented by the John Hopkins Applied Physics Laboratory (APL) describe the estimated power requirements to perform and maintain lunar surface activities [6].

A Pu-238 powered VIPER rover was conceptualised by the Compass Team at NASA Glenn Research Center (GRC) in 2021 [7]. The study aimed to investigate the benefits of integrating a Pu-based dynamic radioisotope power system (DRPS) into a future iteration of the VIPER mission. This work revealed that the addition of an RPS would allow the enhanced rover to operate continuously in PSR, rather than be limited to six-hour excursions by the energy storage system. The resulting design implemented a 'pickup truck bed' approach, which both simplified the installation of the DRPS and established a thermal barrier to prevent surface heating from the power source in front of the rover. The thermal barrier was added to ensure the science areas were not contaminated by the waste heat. The Stirling DRPS used in this study produced ~330 Watts electrical (We) using six general purpose heat source (GPHS) bricks and eight Stirling convertors.

This study was setup to compare a concept for a DRPS using Am-241 as opposed to a Pu-238 DRPS on a representative lunar rover mission such as VIPER. The concept would demonstrate the impacts of the lower heat density Am-241 on the Stirling design as well as evaluate its feasibility. Comparing its implementation for a lunar rover operating in a PSR would show the performance and integration differences of the two isotopes.

## II. Heat Source Design

The European Large Heat Source (ELHS) is a Am-241 based heat source design proposed by the University of Leicester. Like historic radioisotope heat source designs, it also implements a multi-layer containment approach for safety requirements. The radioisotope fuel is encased within a system of physical barriers to remain undamaged during the nominal environments of launch, and to minimize the risk of dispersal under extreme accident conditions. This safety design philosophy is referred as 'confinement and containment'; it has proven to be successful in two aborted NASA missions involving Radioisotope Power Systems (RPS) [8], and during the accidental re-entry of the Russian Mars-96 spacecraft [8].

The current heat source design has a 6-side polygonal shape, with a distributed 12-fuel pellet architecture; this allows it to maximise specific thermal power while minimising the total volume, since Am-based fuels have a lower thermal power density than Pu-based fuels. This has been the approach since the design evolved from an on-axis single fuel pellet architecture for an 80 $W_{th}$ heat source to the current 200 $W_{th}$ design [9].

**Fig. 1.** The European Large Heat Source.

## III. Radioisotope Power System Design

In 2022 the Compass Team investigated using an americium-based DRPS (Am-DRPS) to support spacecraft operations. The Am-DRPS design incorporated multi-layer insulation (MLI), an aluminum housing, four ELHS, and 6 Stirling engines each with a dedicated balancer. The Am-DRPS concept design can be seen in figure 2.

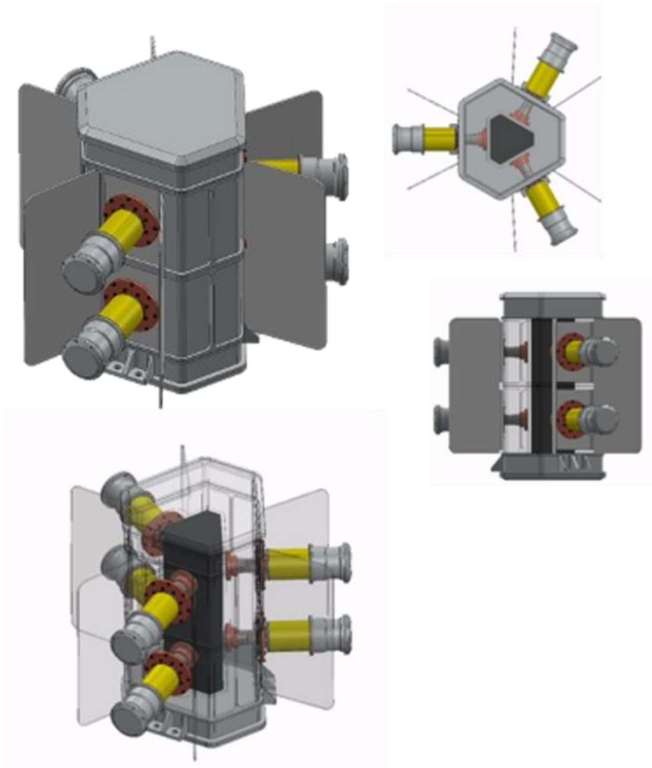

**Fig. 2.** The americium-based dynamic radioisotope power system concept design and layout.

The total mass of the RPS tallied 110 kg and is predicted to deliver around 213 $W_e$ of power. This concept study assumed that the Am-DRPS must support an 18-month exploration of PSRs on the south pole of the moon, just like the Pu-based version.

## IV. Lunar Rover Design

The RPS-enabled, VIPER-based rover was used as a representative mission to investigate how an ELHS-based RPS could support spacecraft operations. This concept study assumed that the ELHS RPS must support an 18-month exploration of PSRs on the south pole of the moon, just like the Pu-based version. Whereas the Pu-based DRPS used in the original concept study can produce around 330 We, the similar massed ELHS DRPS only produced 216 We when in ideal operating conditions and 213 when placed next to the thermal barrier required to protect the surface for science investigations.

Using the Pu-based VIPER rover as a baseline, the following subsystems required modification to realize an Am-DRPS solution: RPS, Electrical Power, and Structures and Mechanisms. The mass differences due to these changes mean the Am-DRPS rover is approximately 28 kgs more than the Pu-DRPS rover.

The change to an Am-DRPS required modification to the concept of operations (ConOps). Whereas the Pu-based rover required a recharge time of 6 hours, following 8 hours of driving and 1 hour of drilling, the Am-based rover required 14.25 hours to recharge. This modification flows from the lower power level of the Am-DRPS, which means more battery energy is required to supplement high power operations and subsequently less power is available to recharge the larger battery during the recharge mode. Despite this modification, the Am-DRPS lunar rover is expected to be able to traverse more than 100 km in the 18-month base mission. Additionally, these ConOps closely mirror a 24-hour clock, perhaps providing benefits for the operations team on Earth.

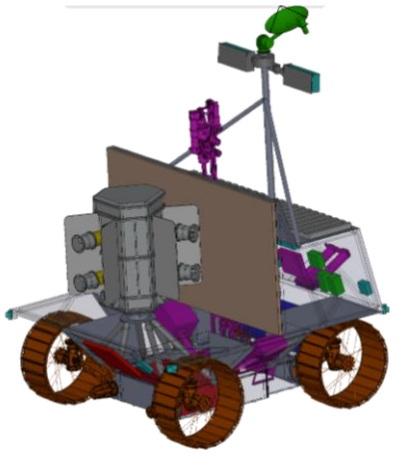

**Fig. 3.** Isometric view of a representative model of the Am-DRPS VIPER class lunar rover.

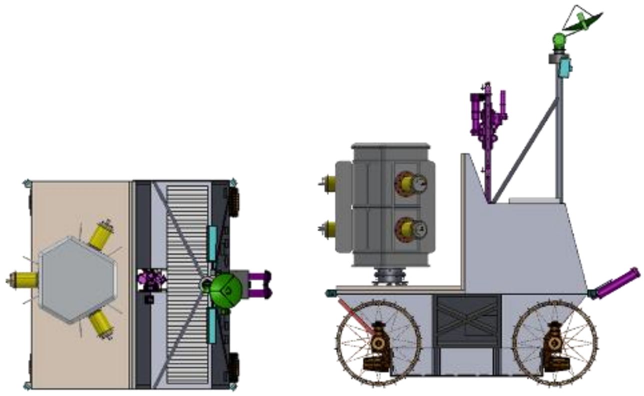

**Fig. 4.** Top and side view of a representative model of the Am-DRPS VIPER class lunar rover.

## V. Conclusions

As anticipated, the Am-DRPS provides less electrical power output (about 2/3) when compared to a Pu-238 powered DRPS for roughly the same system mass. The Am-241 system was also larger volumetrically (by about 1/3) than the Pu-238 system but could be accommodated in the original lunar rover design. Finally, since Am-241 has a half-life of ~430 years, it would be beneficial to investigate reuse options for the Am-DRPS, such as being used by other lunar missions to provide power or heat. This study reveals that despite the lower thermal specific power of an Am-241 heat source, practical power systems can be realised for long duration lunar science missions.

## Acknowledgment

The authors gratefully acknowledge the assistance provided by NASA and ESA.

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