Power System Overview for the Small RPS Centaur Flyby and the Mars Polar Hard Lander NASA COMPASS Studies

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Introduction: The NASA Glenn Research Center (GRC) Radioisotope Power System Program Office (RPSPO) sponsored two studies lead by their mission analysis team. The studies were performed by NASA GRC's Collaborative Modeling for Parametric Assessment of Space Systems (COMPASS) team. Typically a complete top-level design reference mission (DRM) is performed assessing conceptual spacecraft design, launch mass, trajectory, science strategy and sub-system design such as, power, propulsion, structure and thermal.

Study Scope: The premise of the first design reference mission study was to assess what type of smaller, lower cost mission (Discovery cost or less), requiring lower power, could be enabled by a RPS using a single general purpose heat source (GPHS) module. Two RPS concepts were evaluated; a small Stirling radioisotope generator (sSRG, single convertor, actively balanced) and a small radioisotope thermoelectric generator (sRTG) with advanced thermoelectric conversion. Both these designs were based on the Advanced Stirling Radioisotope Generator (ASRG) and the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), respectively.

The mission ultimately selected for this study was a Deep Space Centaur Scout to flyby Chiron, and other potential targets, employing up to four identical MicroSat class spacecraft. However, once the science instruments and operating plan was determined, the power required was higher than a single GPHS module RTG could provide and thus the study continued with a 3-GPHS module unit, thus producing similar power to the sSRG, ~ 60 We.

The second study, to evaluate very-small RPS missions, looked at utilizing the ~1.0 Wth radioisotope heater unit (RHU) as the power system heat source. A past design, developed by Hi-Z Inc. capable of shock loads greater than 1000 "g" and producing ~40 milliwatts, was baselined for this study. A dynamic heat-to-electric conversion option such as the Stirling was not evaluated because of poor scaling at such low thermal levels of the RHU.

The selected design reference mission study (MASER - Meteorology and Seismology Enabled by Radioisotopes) evaluated a network of four small Mars landers targeted for high northern latitudes where sunlight would not be present during Mars' winter such as experienced by the Phoenix Mission. The science plan proposed is a one-year minimum, however a multi-Mars year mission lifetime would be expected, and making full use of the long-life RPS technology. The instrument suite, operating plan and energy storage recharge periods required about a 210 mWe base. Higher power for communication data return was supplemented with ultracapacitors.

Deep Space Centaur Scout DRM: The four MicroSats were packaged within an Atlas 431 incorporating a Star 48B kick stage as shown in Fig. 1. The mission design baselined a Jupiter Gravity Assist after which each individual MicroSat could be propulsively maneuvered and targeted to Chiron and other potential bodies.

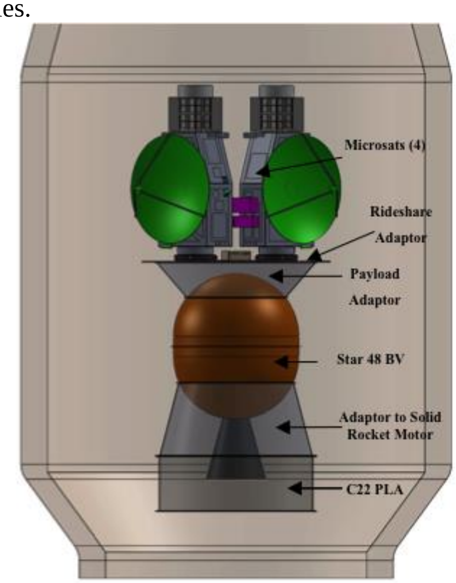

Figure 1. Payload Stack Configuration

The RPSs are mounted on top of each MicroSat for several reasons; first to give a clear "thermal" view to space for efficient heat rejection and second; to allow a more direct installation of the RPS at the Atlas Vertical Integration Facility via special access fairing doors (not shown) as with past RPS missions.

Table 1 shows the sSRG and sRTG characteristics assumed for this study. While the beginning of mission (BOM) power is similar, the end of mission power (EOM) is lower

Table 1. RPS Characteristics

Parameter	Small SRG	Small RTG
BOM Power	65 W	64 W
EOM Power (12 year mission)	57 W	48 W
Mass	18 kg	20 kg
Dimensions	49 x 39 x 38 cm	64 cm diameter (inc fins) 17 cm height
Cold-side Temp (BOM, 4K sink)	38 C	50 C
Voltage	28 +/- 6 V	28 +/- 8 V
Degradation	1.16 %/ year	2.5 %/year
Efficiency (BOM)	26%	8.5%
# GPHS Modules	1	3

for the sRTG than the sSRG, resulting in ~2 We and ~10 We above the housekeeping power, respectively. This excess power is used to charge the batteries and transmit the stored data taken during the flyby once per day. Because the sSRG system has greater excess power, a data return of 4 hours is possible rather than 1 hour per day as with the sRTG, resulting in an increase from 7 months to 27 months to return all the science data collected during encounter.

MASER DRM: A suite of low power instruments was selected for primarily measuring seismic activity and meteorology (pressure sensor), optical monitor and anemometer. The continuously operated seismometer is a heritage "geophone" with an allocation of 50 mWe. The other instruments with be cycled on\off but synced between the four landers still providing simultaneous measurements. Each lander is identical employing an aeroshell, parachute and crushable structure designed to provide a maximum 600g landing load within the design limits of the instruments and RHURPS units.

Table 2 shows the power for science operations resulted in an average base load of approximately 160 mWe plus an additional 50 mWe for recharging the energy storage ultracapacitor that was needed to provide additional power for the data system to uplink to a Mars orbiter(s) and subsequent downlink to Earth. Therefore six 40 mWe RHU-RPS and four untracapacitors comprise the power system.

Table 2. MASER Power Requirements

Load	Basic Power (mW)	Power With Margin (mW)	Duty Cycle	Total Energy Spent (mW-hrs)
Continuous Power for Electronics	50	65	100%	1,560
Pressure/Temp	2	2.6	100%	62
Seismometer	50	65	100%	1,560
Wind Sensor	250	325	8%	650
Optical Monitor	20	26	8%	52
Transmitter	2,500	3,250	1%	1,083
Self Discharge of Capacitor	15	15	100%	360

Figure 2 shows the RHURPS design baselined for the study[1]. Higher power multi-RHU systems were considered, however having six units helped with the thermal design in distributing the 6 Wth.

Multi-RHU systems could be attractive for missions in the 1-3 We range, thus reducing the number of units to integrate on the spacecraft and potentially save mass.

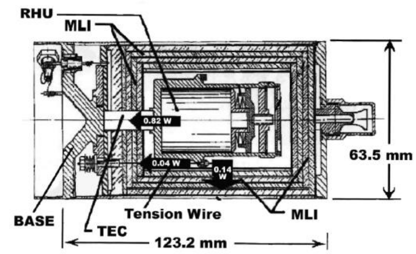

Figure 2. RHURPS Diagram

A desire for a passive thermal system required an Aerogel insulation package to surround the internal electronics and also the RHURPS to maintain temperatures during Mars winter between -40C to 50C.

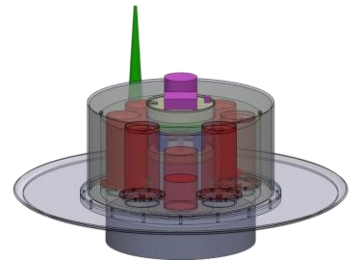

Figure 3. MASER Lander

The enclosed RHURPS creates a situation of a unique assembly process where the power system is not exposed allowing typical last minute RPS installation. In addition, the lander network will land in potentially ice-bearing "special region" requiring sterilization as employed for Viking or the Phoenix lander robotic arm. After RPS installation, dry heat microbial reduction (DHMR) is employed on the landers, except for the ultracapacitor energy storage units, whose electrolyte will not tolerate the high temperatures for DHMR. These are sterilized separately by vapor hydrogen peroxide (VHP) and then integrated into the landers before final encapsulation. A baseline ConOps plan was developed for the more complex installation of the RHURPS inside the insulation dome and in conjunction with the DHMR and VHP sterilization processes.

Summary: Both studies identified viable science mission concepts using smaller spacecraft. Future development of low-power RPS systems, either using 1-3 GPHS modules or RHU or multi-RHU based heat sources, show promise in benefiting these types of missions with a real potential for reducing the costs of future science missions.

References:

1. Allen, D. T., et al, Hi-Z Inc., Fabrication and Testing of Thermoelectric Modules and Milliwatt Power Supplies, STAIF 2004.