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# Development of a propulsion system and component test facility for advanced radioisotope powered Mars Hopper platforms

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**Abstract.** Verification and validation of design and modeling activities for radioisotope powered Mars Hopper platforms undertaken at the Center for Space Nuclear Research is essential for proof of concept. Previous research at the center has driven the selection of advanced material combinations; some of which require specialized handling capabilities. The development of a closed and contained test facility to forward this research is discussed within this paper.

**Keywords:** Radioisotope, Power, Mars, Hopper, Nuclear, RTG, Test, Facility.

## INTRODUCTION

A radioisotope-powered hopper concept has previously been identified at the Center for Space Nuclear Research (CSNR) as an advanced technology for the collection of ground-truth data over a significant portion of the Martian surface [1, 2]. The hopper platform concept utilizes CO<sub>2</sub> from the Martian atmosphere as a propellant that is heated by a thermally capacitive mass of materials such as beryllium used to accumulate and store energy released from the nuclear decay of a <sup>238</sup>PuO<sub>2</sub>-W cermet heat source [3, 4]. During heat up of the thermal capacitor, the platform would simultaneously facilitate the collection of scientific data while compressing CO<sub>2</sub>. When a storage tank is filled with compressed CO<sub>2</sub> and sufficient science data is collected, the CO<sub>2</sub> would be released through channels in the beryllium matrix and expelled through a nozzle to provide impulsive thrust. The thrust produced by this Radioisotope Thermal Rocket (RTR) would be used to provide a controlled vertical ascent and descent of the platform to another location. This process would be repeated numerous times, thus allowing the hopper to travel across the Martian surface over a period of months or years.

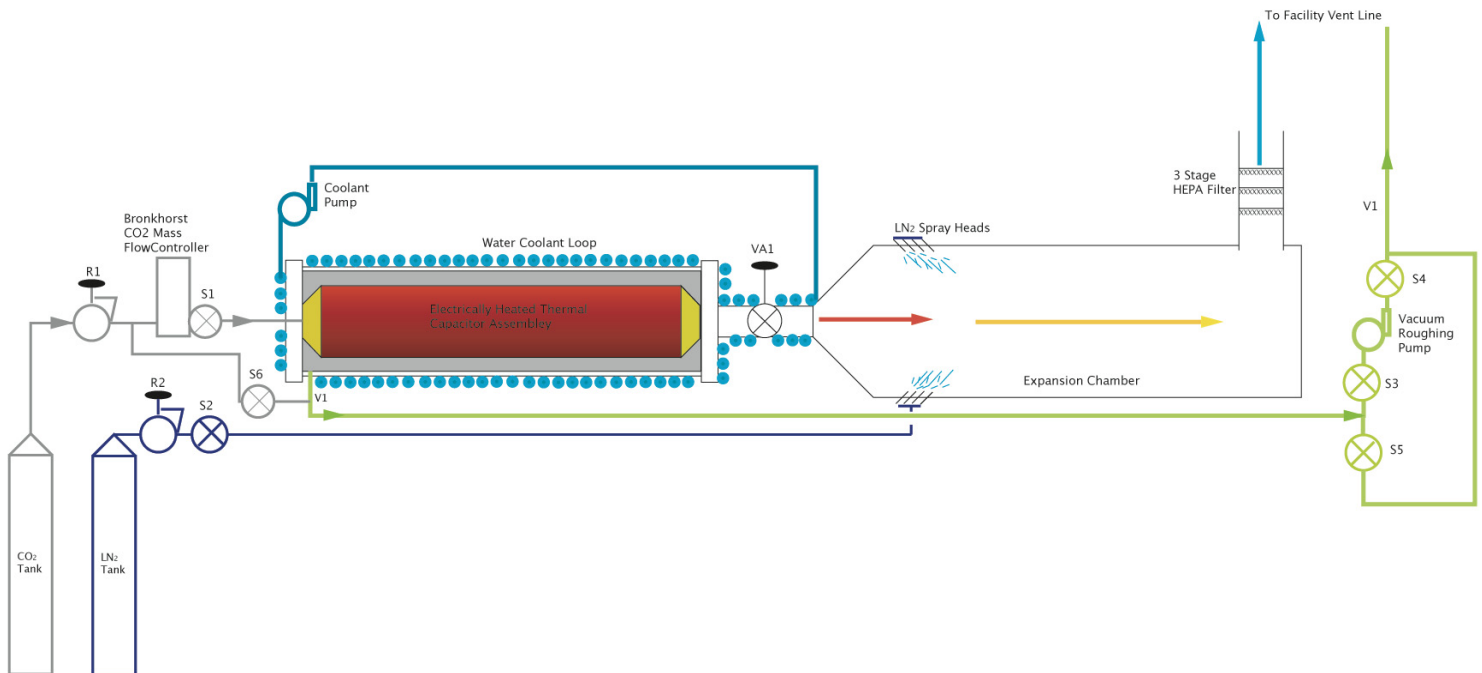


FIGURE 1. (Left) 3D render of a concept RTR engine (Right) Artist's impression of a Mars hopper in flight.

Detailed thermal analyses performed at the Center for Space Nuclear research have indicated the feasibility and performance of RTR systems via the use of commercial computational fluid dynamics (CFD) codes. The validation of CFD modeling of RTR systems is essential for the development of a flight RTR system. In order to validate the modeling results, a Hopper System Test Facility (HSTF) is being constructed at the CSNR that will be capable of testing materials, components and system thermal designs under transient heating, steady state and propellant blowdown / propulsive modes of operation.

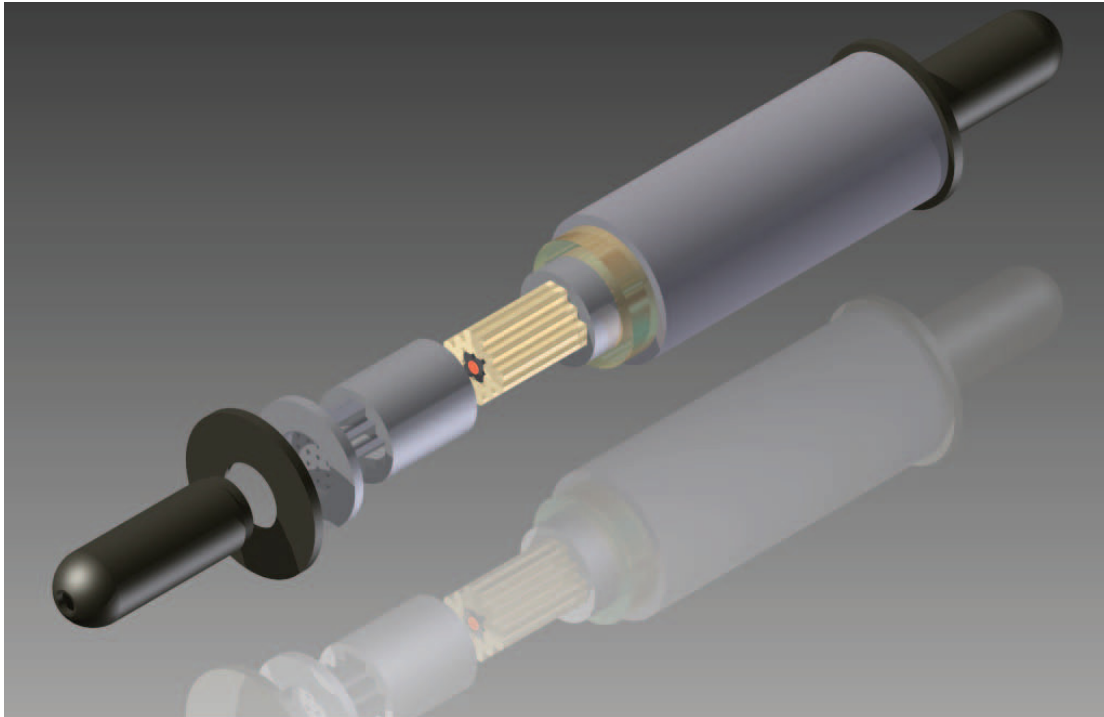
## Hopper System Test Facility (HSTF) Design Overview

Since the development of the RTR thermal capacitor is in its infancy, it is appreciable that several prototypic designs and configurations will be tested. The production of an electrically heated high temperature experimental gas flow loop for steady state and blow down analysis of beryllium core components has been initiated at the CSNR. Heating of the core components will be provided by an electrically simulated radioisotope cermet heater element (RCHE) developed in collaboration with NASA Marshall Space Flight Center. Automated control and measurement instrumentation will be used for the analysis of system behavior and overall component performance.



The beryllium (or alternative) thermal capacitor components will be thermally isolated from the external environment via the use of an insulation scheme and associated test section housed within a 316 stainless steel thermal vacuum chamber held at rough vacuum. It will also be possible to back fill the chamber with CO<sub>2</sub> under Martian atmospheric conditions so as to simulate operation on Mars. A water coolant loop will be provided to the thermal vacuum chamber so as to maintain the chamber at a specified temperature.

Within the test section of the experiment loop, the insulation scheme applied may be varied in between experiments so as to assess differing performances. As such, the suitability of insulating materials, specifically Aerogels and Microtherm® insulation may be empirically demonstrated. Test sections for prototype elements will be assembled using an initial insulation scheme that will accommodate either Aerogel or Microtherm insulation. In this design, the Be elements are confined radially by several shaped spacers with matched thermal expansion characteristics and an end thermal insulation ring. The element assembly is in turn surrounded by insulation and a Titanium outer support shroud. Inlet and outlet plena are compressed onto the assembly via tie rods allowing for a gasket to be face sealed onto the insulation ring. Based upon computational modeling and experimental results, it will be possible to optimize and test future test section assemblies.



**FIGURE 4.** Breakdown of a cylindrical prototype element test section using the same insulation scheme as described for hexagonal element test section.

Liquid or gaseous  $\text{CO}_2$  will be fed to the test section from a pressurized tank via an internal dip tube through a mass flow controller into a gas feed (fore) plenum upstream of an RTR prototype assembly. Upon passing through a heated RTR assembly, the hot gas will be fed through an aft plenum into a diffuser where it is cooled via adiabatic expansion and mixing with a spray of liquid nitrogen. Gas discharge from the experiment will be screened for particulates via a 3 stage HEPA filter located in a vertical pipe routed to the facility process extraction line. At the entrance to the diffuser section, an electronically actuated variable area ball valve (Figure 3, VA1) is provided to allow for the adjustment of backpressure and hence simulation of rocket nozzle throat designs and choked flow.

A data acquisition system will be used in conjunction with the National Instruments LabView™ software environment to automate and control all aspects of each experiment including gas flow, heater power supply and to record bulk temperature data of inlet and discharged gases. During the startup of a given test, the user will open the main shut off valves located on both the liquid nitrogen and carbon dioxide cylinders. At this point, the vacuum chamber water coolant loop may be activated. A rough vacuum may be achieved within the chamber through the opening of solenoid valves S3 and S4 (see Figure 3) and the activation of a connected vacuum roughing pump. Feedback of the pump down process will be provided to the user interface via a pressure transducer. Upon achieving rough vacuum, S3 and S4 (see Figure 3) will be closed. If operation of the test section in a simulated Martian atmospheric environment, solenoid valve S6 (see Figure 3) may be used to bleed  $\text{CO}_2$  into the chamber.

The heat up of the beryllium test matrix may be initiated at a user specified rate via the automated output control of a 24 volt laboratory power supply. Alternatively, a user will be able to specify an output power of the heater such that the heating profile will be respective of a system heated by a radioisotope heat source. Once again, feedback control of the heating system will be provided via an interfaced thermocouple. Upon reaching the desired matrix temperature, the user will set the  $\text{CO}_2$  pressure regulator R1 (see Figure 3) to 50 psig and the  $\text{LN}_2$  feed pressure to a value determined via prior empirical assessment of the flow form from the spray heads within the diffuser section. Once all gas feed systems are prepared, the user will define a blow down profile, either constant or variable flow rate with respect to time. The blow down profile termination point may be defined by the user as either a discrete time interval after startup or when the beryllium matrix reaches a specified bulk temperature. Blow down testing

will be initiated via the automated opening of LN<sub>2</sub> solenoid valve S2 (see Figure 3) and the activation of CO<sub>2</sub> solenoid S1 (see Figure 3). The electrical heating element may remain energized during a test at an output level equivalent to a RCHE or de-energized if demonstration of blow down independence of isotopic power is required. As the test proceeds, the mass flow rate of liquid CO<sub>2</sub> will be controlled in accordance with the user defined profile via the Bronkhorst mass flow controller. Test termination will be achieved via the automated closure of CO<sub>2</sub> solenoid valve S1 followed by LN<sub>2</sub> valve S2 (see Figure 3). Valve S5 (see Figure 3) is provided to restore the interior of the vacuum chamber to atmospheric pressure prior to opening and test section removal.

## THERMAL CAPACITOR MATRIX TEST ARTICLES

The performance of both heat capacitor matrix materials and the interfaces with shaped Radioisotope Cermet Heater Elements (RCHEs) will be tested using the HSTF. Initial testing will focus on the development of a modular beryllium matrix composed of 6.35 mm diameter rods of varying profiles. Figure 2 is a photograph of examples of the initial Be test matrix modules that will be tested.



**FIGURE 2.** Photographs of finished cylindrical Be thermal capacitor elements

## SUMMARY

Construction of the test loop is expected to be complete by mid 2011 and initial test data will be published in late 2011.

## NOMENCLATURE

HSTF = Hopper System Test Facility  
CSNR = Center for Space Nuclear Research  
RCHE = Radioisotope Cermet Heater Element

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