Two Phase Titanium Water Heat Pipe for Space Rated Stirling Power Conversion

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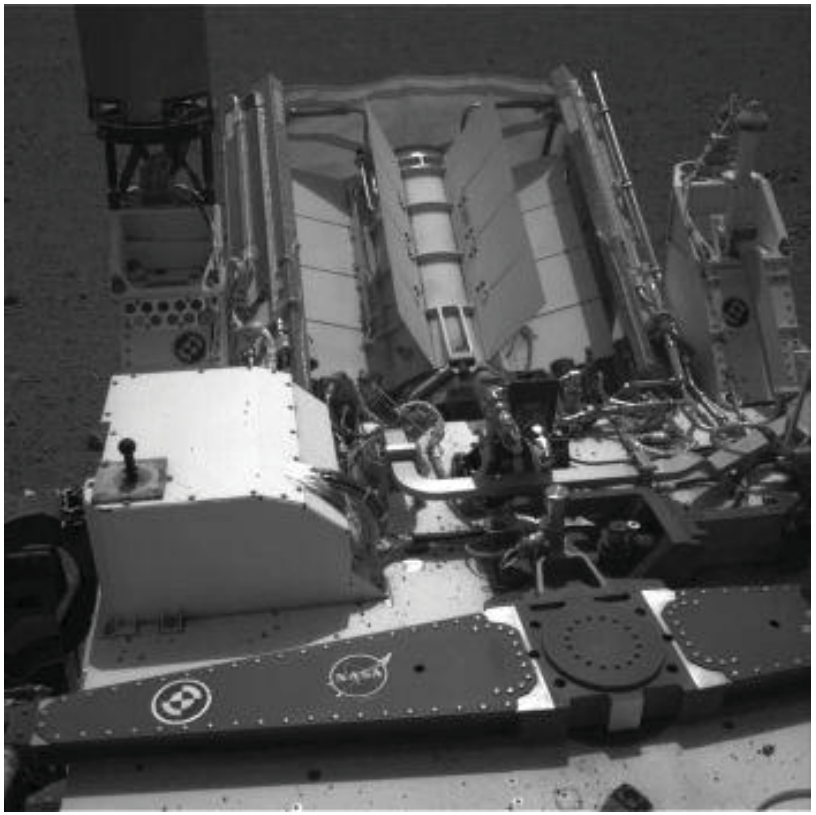
Background

- Radioisotope Power System (RPS) options that use Pu238 General Purpose Heat Sources (GPHS):
  - Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)
  - Advanced Stirling Radioisotope Generator (ASRG)

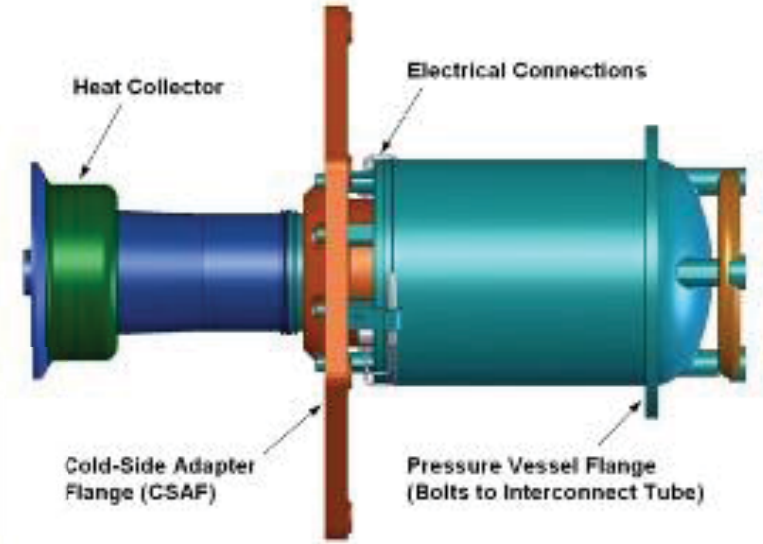


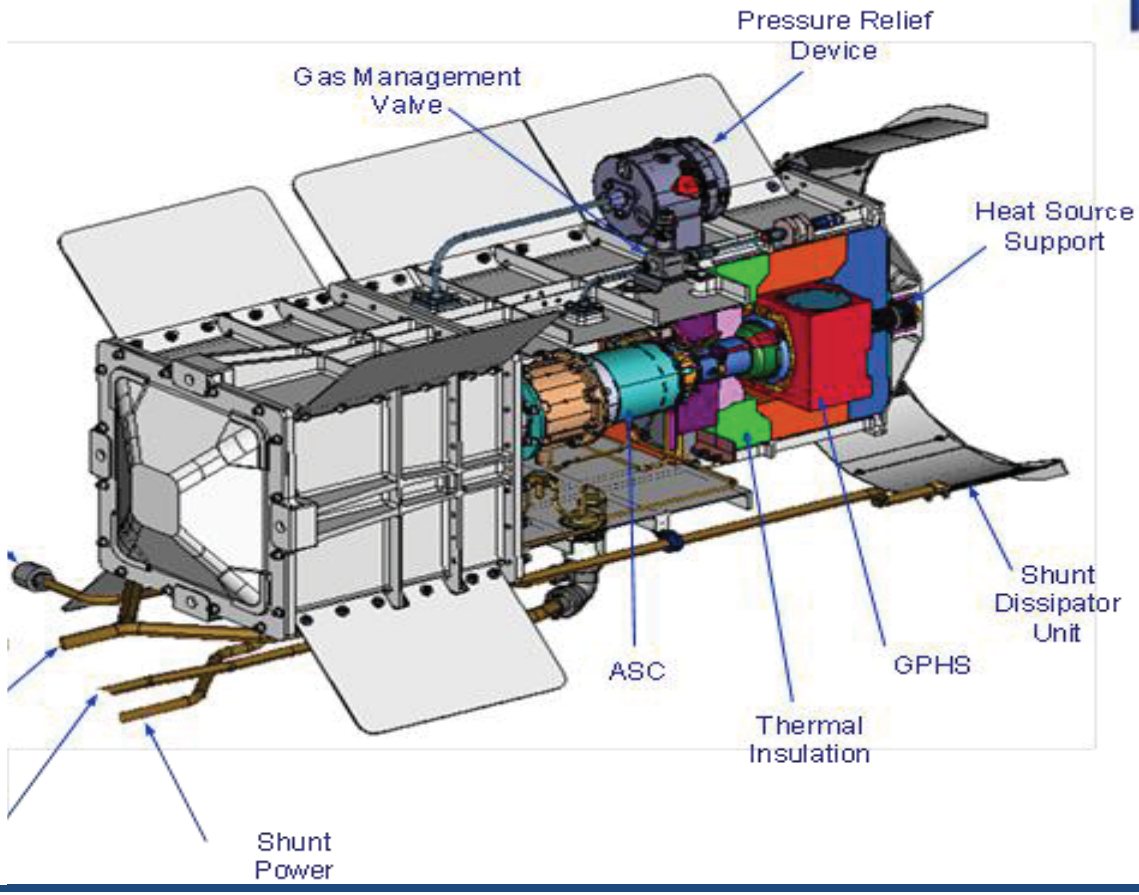
MMRTG (8 GPHS)

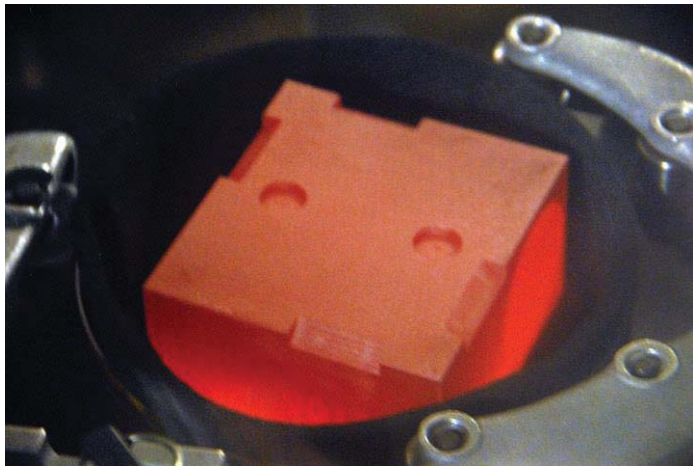
ASRTG (2 GPHS)

ASRG Thermal Control

- GPHS provides approx. 250Wt
- Convertor Accepts approx. 200Wt
- Conversion of 200Wt to 70We
- Rejects approx. 130Wt from convertor to radiator housing

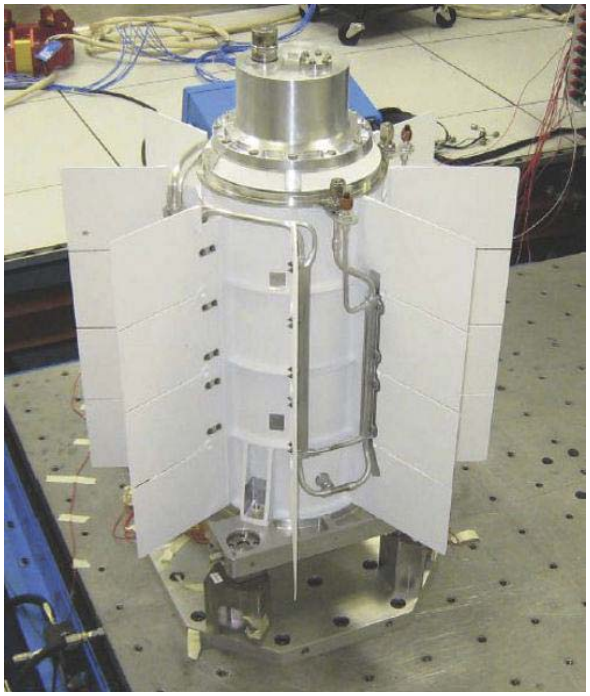






Radioisotope Power Systems

110 We Multi-Mission Radioisotope Thermalelectric Generator (MMRTG)
8 GPHS Plutonium Fuel Modules

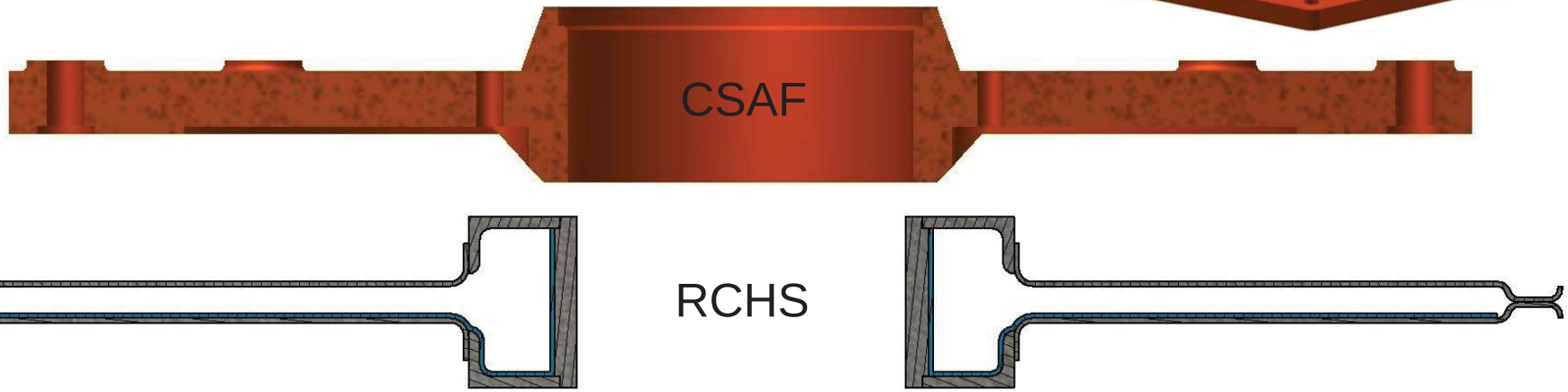


140 We Advanced Stirling Radioisotope Generator (ASRG)
2 GPHS Plutonium Fuel Modules

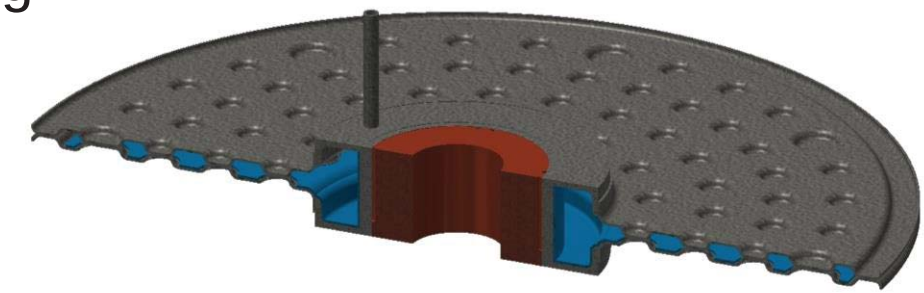
500-1000 We ASRG

Conduction vs. Two-Phase

- Conduction fins become too heavy as rejection power levels increase



- Two-phase heat pipe uses working fluid vapor to transfer heat
- Hollow design for vapor path creates much lighter design



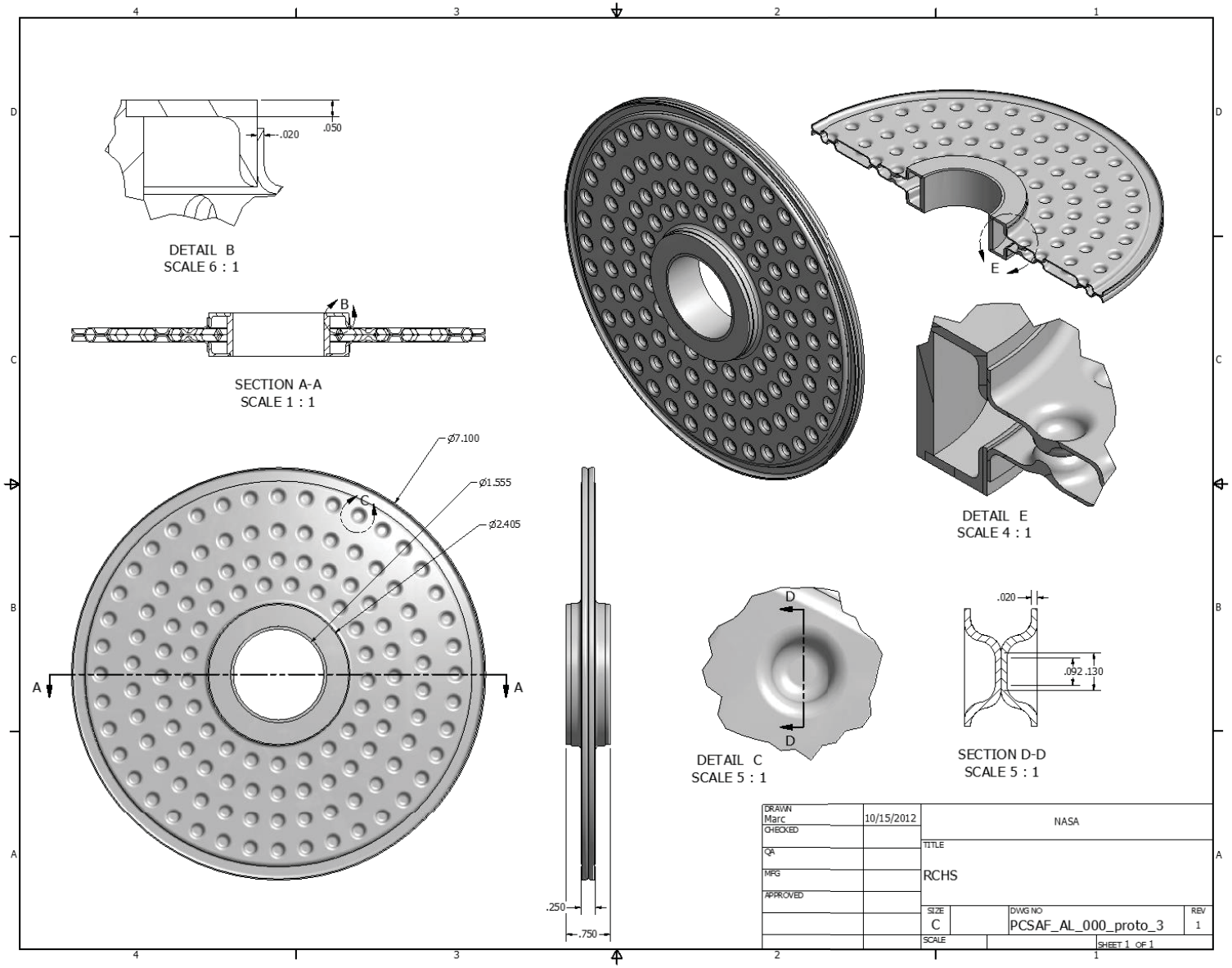
Technology Derived Design Requirements

- Thermal
  - Reject 130Wt from Stirling Convertor (RCHS ID) to generator housing (RCHS OD) DURING LAUNCH
  - Operational Temperature Range: 50-150C
  - Temperature Delta <30C
- Environment
  - Assembly Test and Launch
    - Accelerations: Specific to Launch Vehicle (Peregrine)
    - Horizontal and Vertical Orientations: Specific to Spacecraft
  - Atmospheric and Vacuum Environment
    - Atmospheric during ground, launch
    - Vacuum or Atmospheric during transit and science return depending on mission

Structural

- Survive Thermal and Environmental requirements

RCHS Design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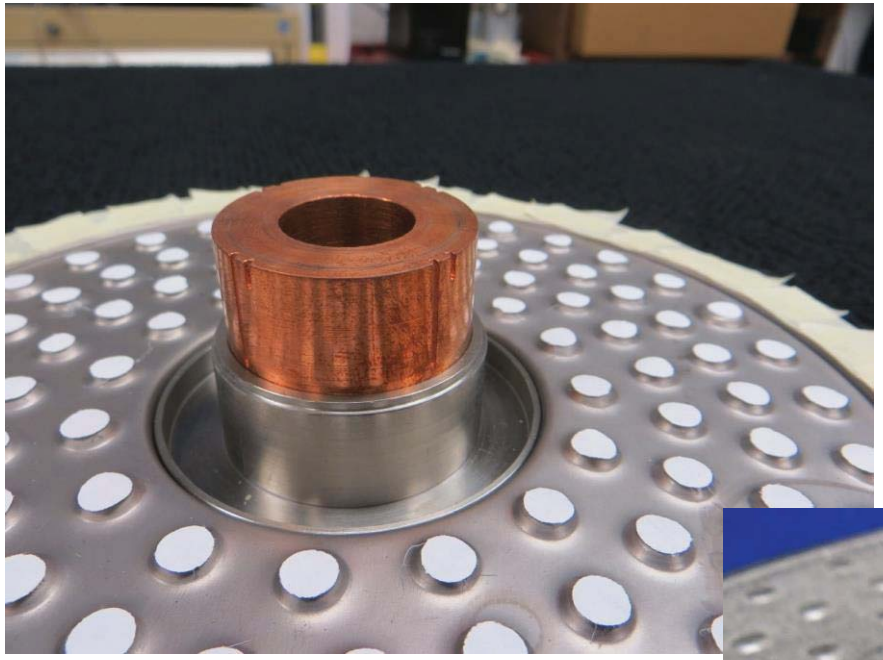
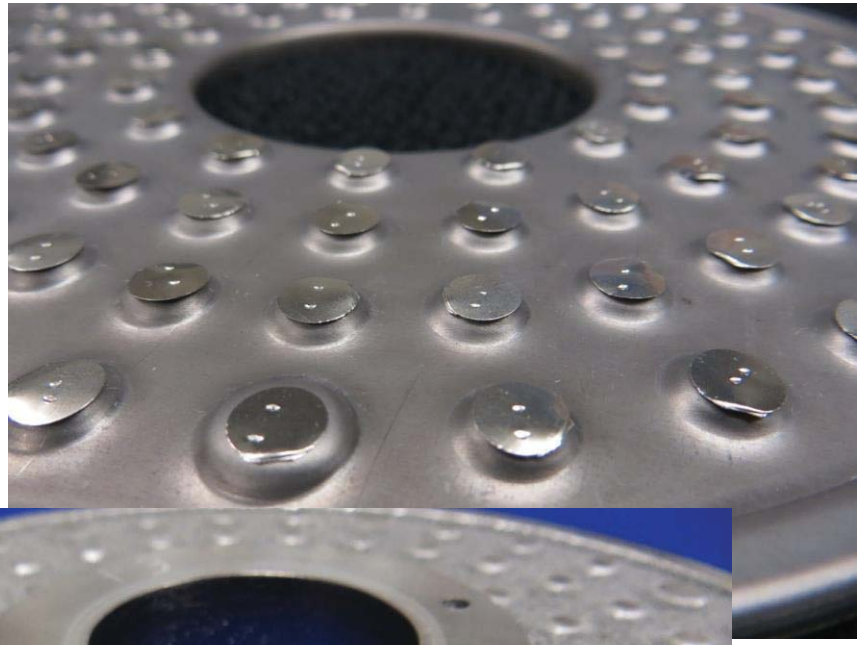
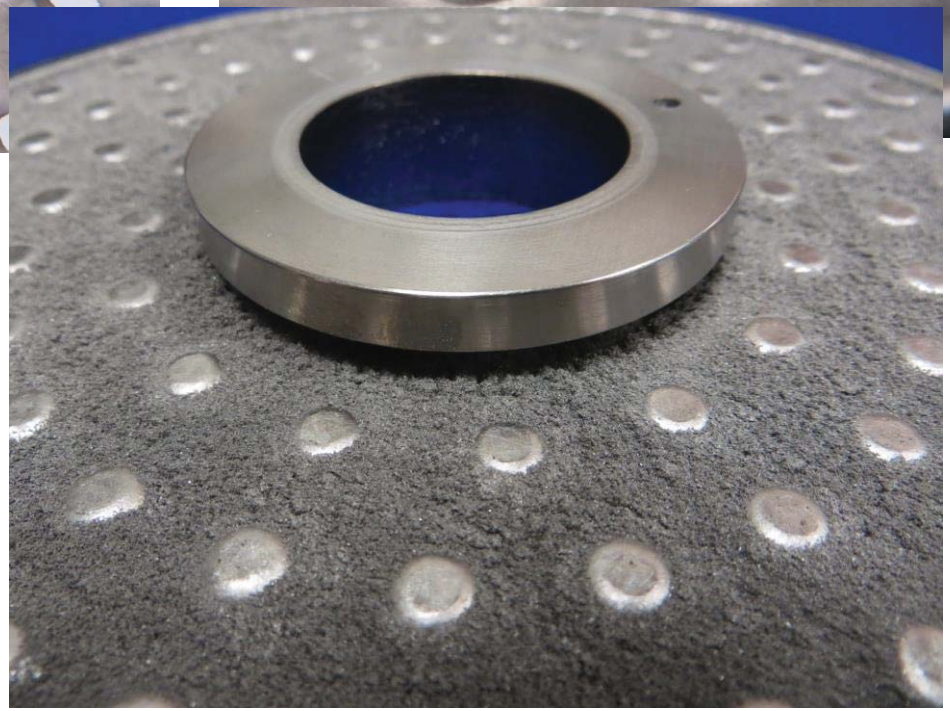
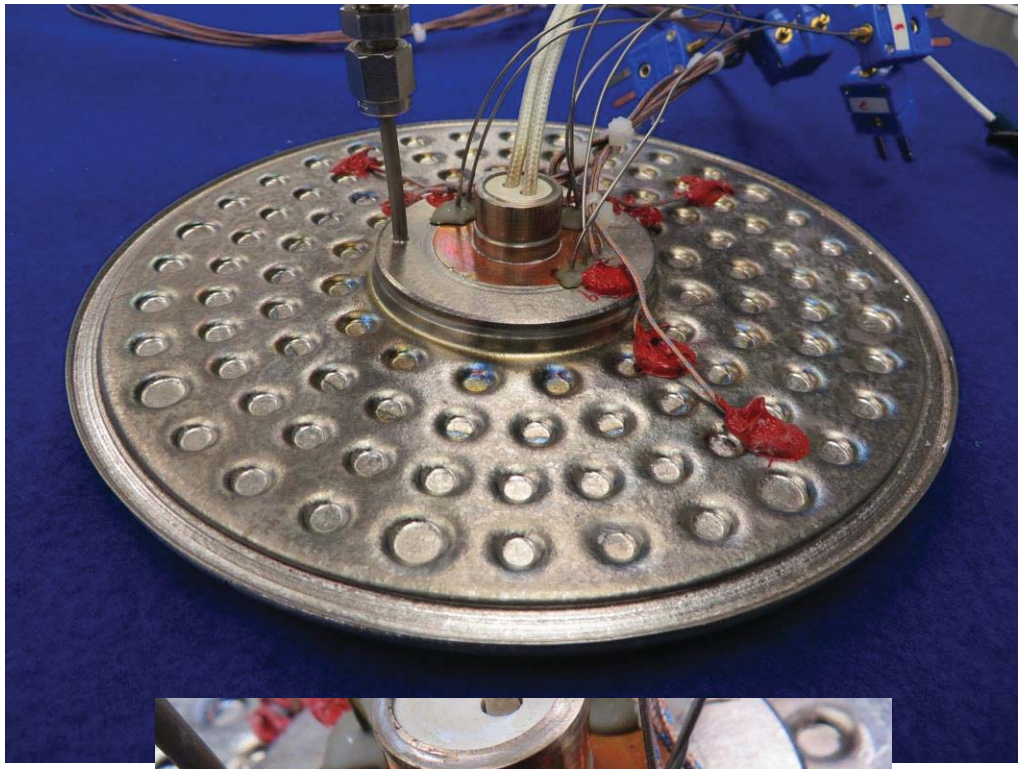
RCHS Design

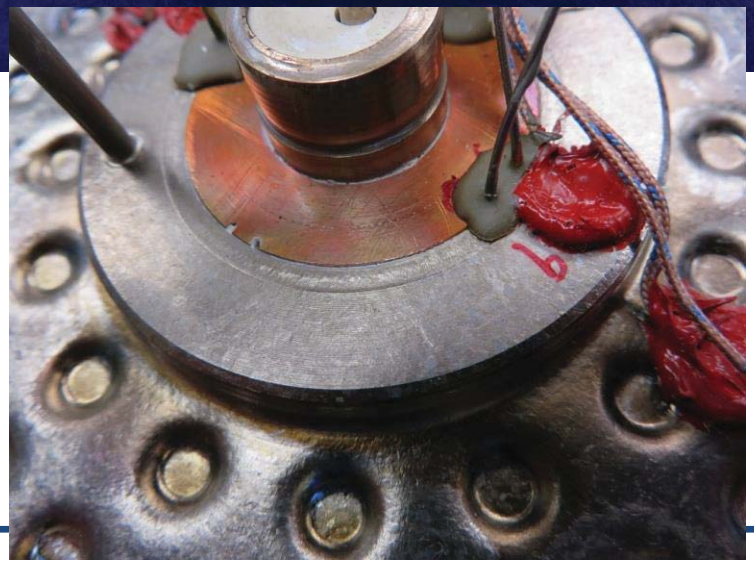






RCHS Design Continued

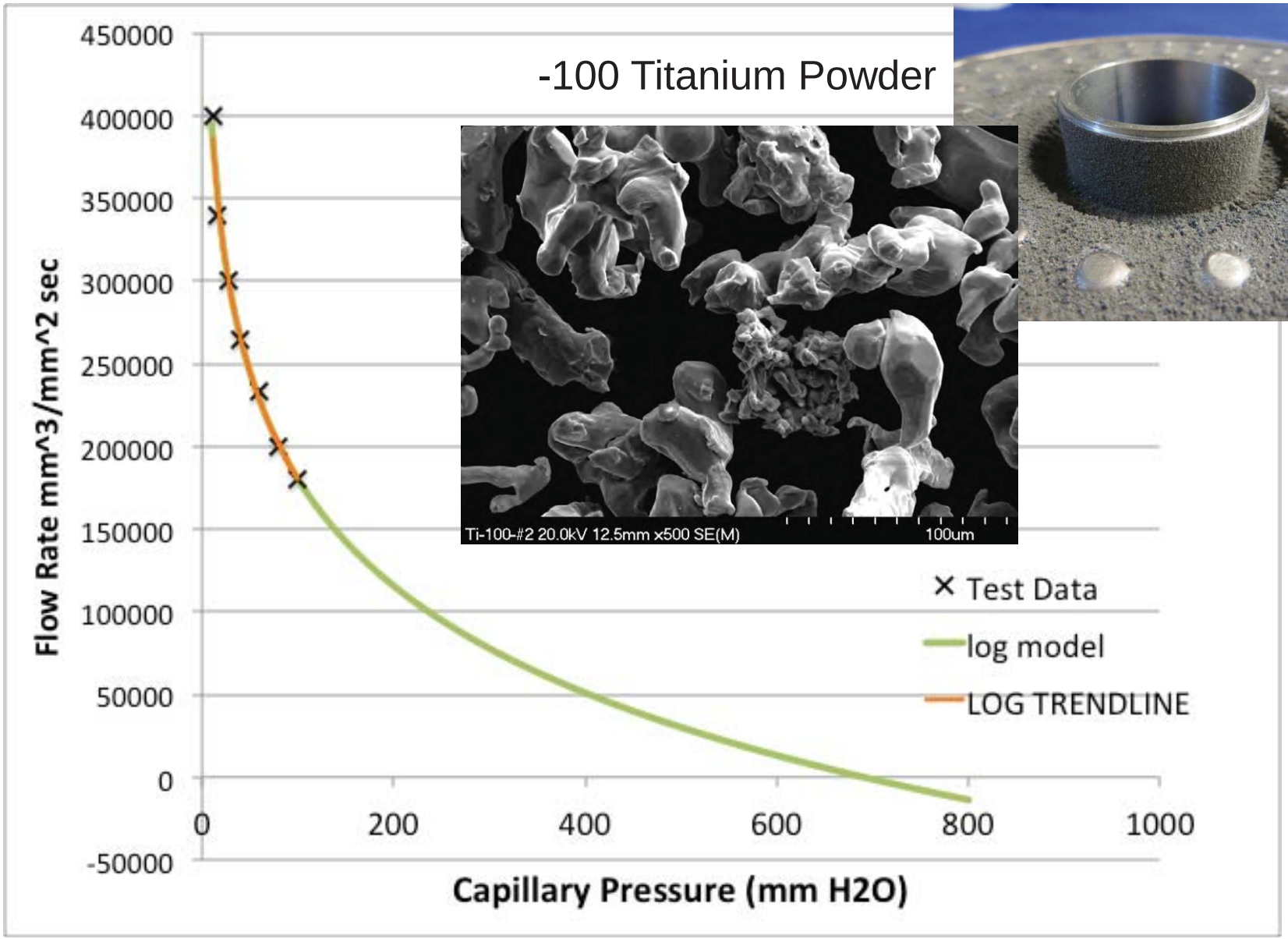




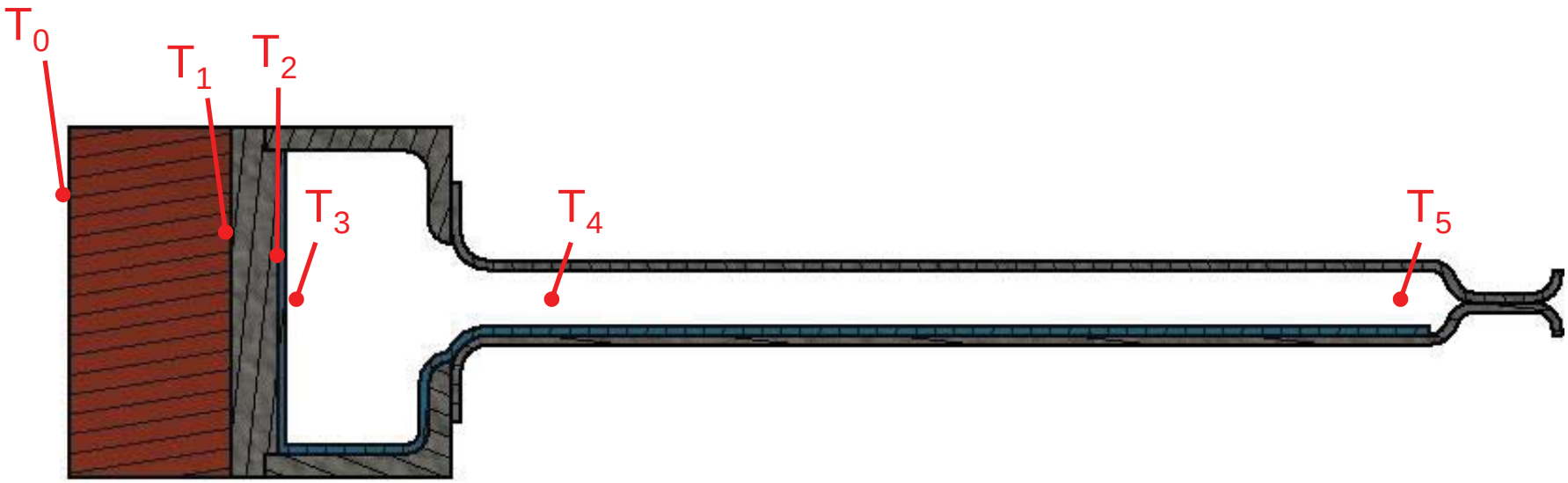
Testing

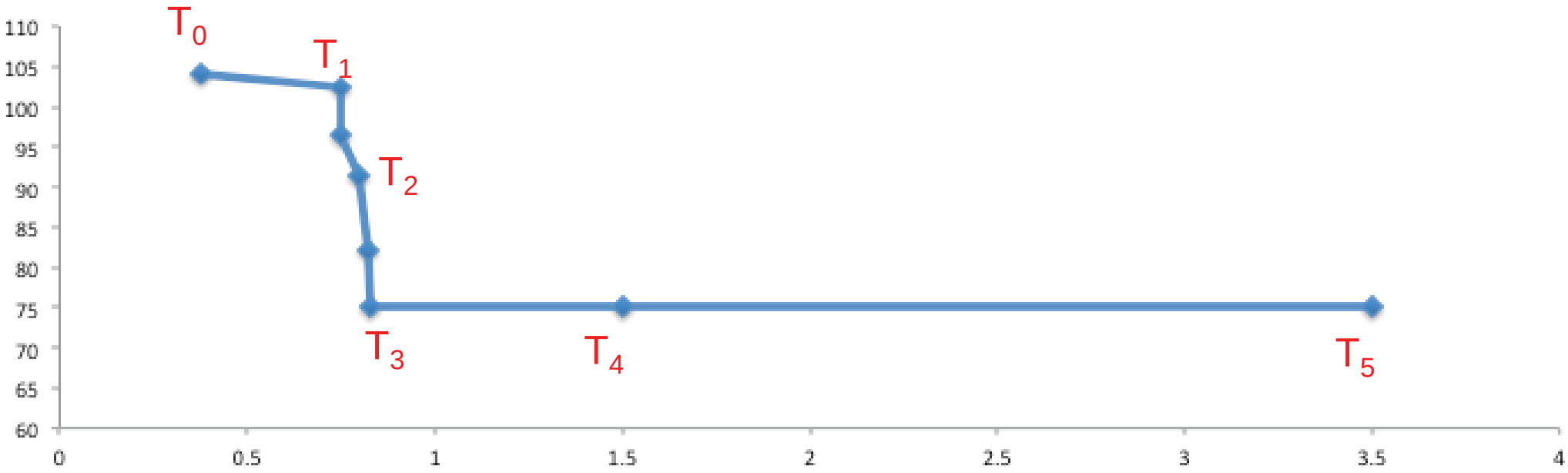
- Ground
  - 1g Environment
  - Wick Capillary Performance
  - Thermal Vacuum
  - Power Capacity
  - Vibration
- Parabolic
  - 0-2g Gravitational Performance
    - Microgravity, Lunar, and Martian Environments
- Sounding Rocket
  - Peregrine Specific Launch Accelerations
  - 6+ minutes of microgravity

Ground Testing; Wick Performance

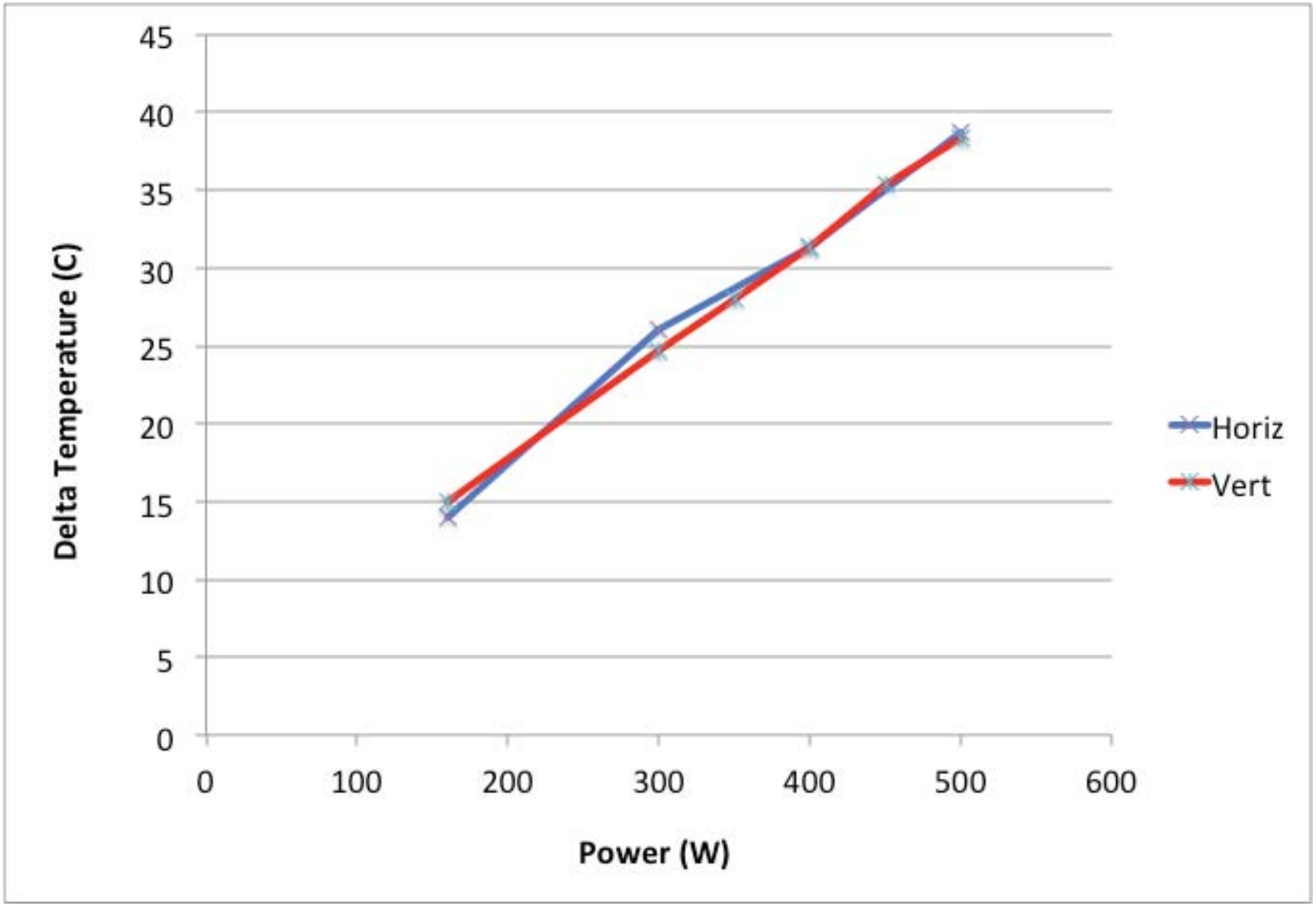


Ground Testing, Thermal Performance Cont.





Ground Testing; Thermal Performance



Parabolic Testing

- 200+parabolas 0-2g
- Multiple power levels
- Multiple Orientations

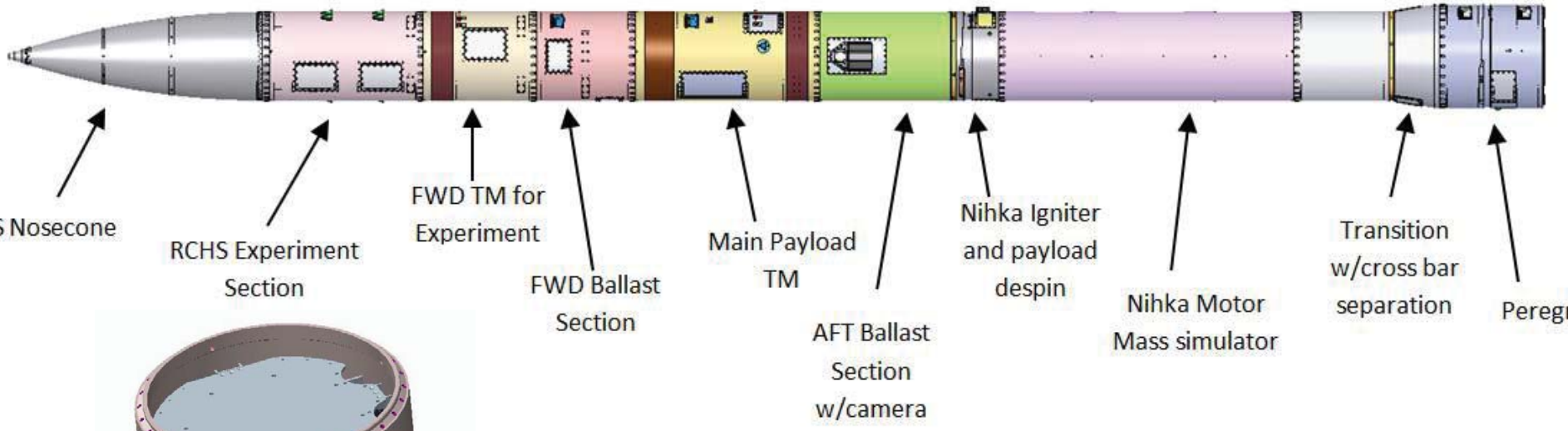
Thermal Performance was unaffected by 0-2g gravity levels!

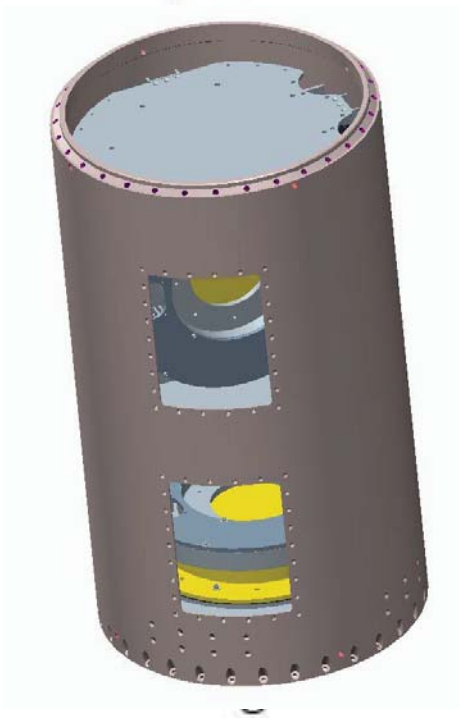
Sounding Rocket Experiment

- Radioisotope Power systems are fueled at launch pad and must perform thermal management before, during, and after launch scenarios
- RCHS must be able to:

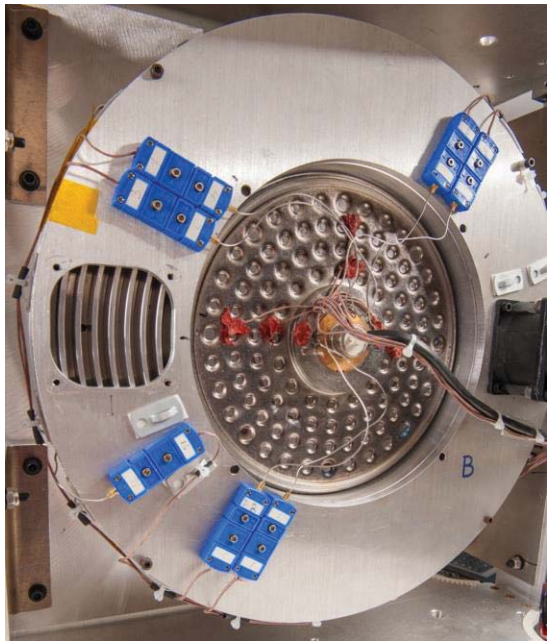
1. Reject 130Wt from the Stirling convertor to the radiator housing in any spatial configuration during 1g, hyper-gravity, negative gravity, and microgravity. *(For this experiment, the Stirling convertor has been replaced with an electrical heater and the radiator housing with an air/PCM heat exchanger)*

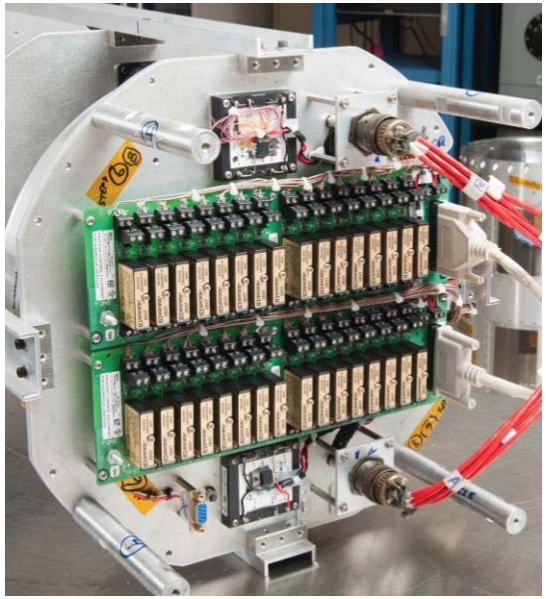
Peregrine Rocket

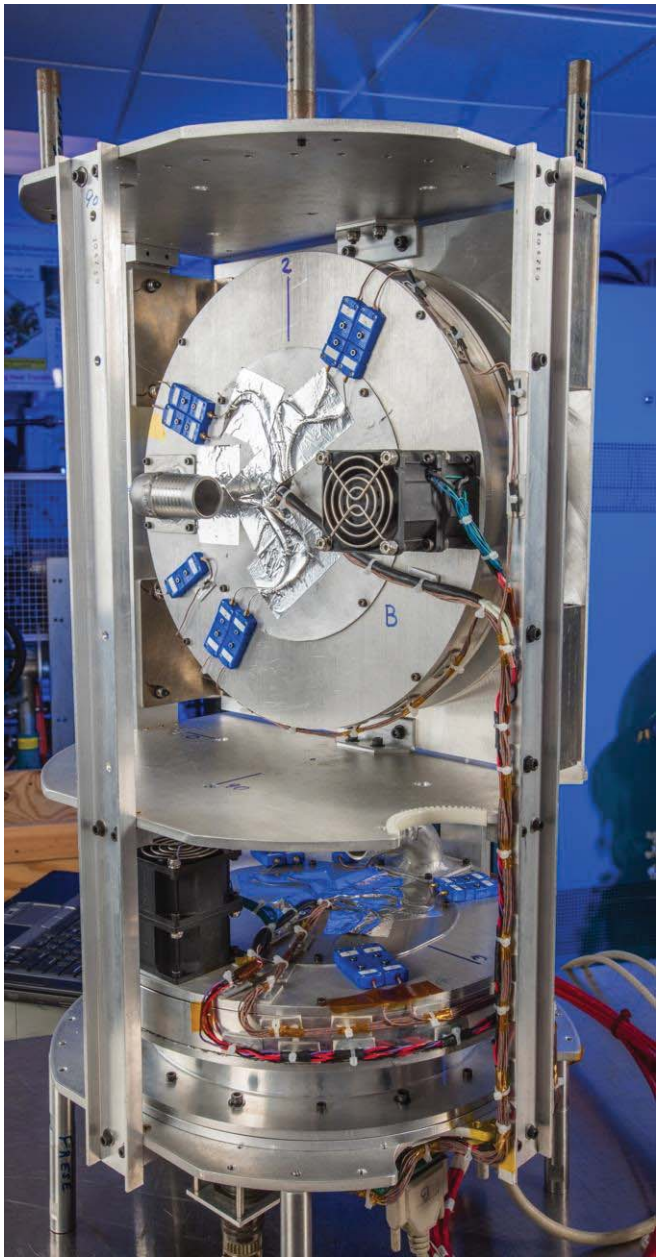




RCHS Experiment







Vibration Testing

	Vehicle Level One	Vehicle Level Two
SINE	Sweep Rate: 4 oct./min. Test Profile: 3.0 in./s 10-144 Hz 7.0 g 144-2000Hz **THRUST AXIS ONLY**	Sweep Rate: 4 oct./min. Test Profile: 3.84 in./s 5-24 Hz 1.53 g 24-110 Hz 3.50 g 110-800 Hz 10.0 g 800-2000 Hz **THRUST AXIS ONLY**
RANDOM	Duration: 20 sec./axis Thrust Axis Spectrum: 10.0 grms 0.051 g^2/Hz 20-2000 Hz Lateral Axis Spectrum: 7.60 grms 0.029 g^2/Hz 20-2000 Hz	Duration: 10 sec./axis Spectrum: 12.7 grms 0.01 g^2/Hz 20 Hz 0.10 g^2/Hz 1000 Hz (on 1.8 db/oct. slope) 0.10 g^2/Hz 1000-2000 Hz **SAME IN ALL AXES**
TEST INFO	**LEVEL 1 VEHICLES** Terrier-Orion Terrier-Malemute Single Stage Improved-Orion Terrier-Lynx	**LEVEL 2 VEHICLES** Black Brant V Black Brant VIII Black Brant IX Black Brant X Black Brant XI Black Brant XII

Table 8 Limiting Bending Moments*

Vehicle	Moment (in.-lb.)
Orion	100,000
Malemute	200,000
Black Brant	300,000
Limit Model 1830 TEAM table to a max. of 240,000 in.-lb. overturn moment.	

Input to payload during 1/2g sinusoidal vibration must be limited during first bending mode via dual control accelerometer at CG of the payload. This is done to avoid exceeding the maximum bending moment at the base of the payload.

Comparison Data

	RCHS	CSAF
Mass	175g	750g
Delta T @ 130W Heat Rejection	12	10
Max. Thermal Conductance	>1000 W/K	<20 W/K
Temperature Range	50-250C	-200 to 250C

Conclusion

- RCHS heat pipe technology provides a passive thermal control option for current and higher power Radioisotope Stirling Generators
- Current 130W heat rejection application using the RCHS provided a 4:1 decrease in mass over current state of the art with similar thermal performance
- Ground and flight testing of the RCHS has validated the thermal performance over a wide range of environments applicable to TRL5
- Peregrine sounding rocket experiment will validate the RCHS performance through launch and microgravity operations