Alkali Metal Backup Cooling for Stirling Systems – Experimental Results

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Outline

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- Concepts
- Stirling Convertor
- Variable Conductance Heat Pipe (VCHP) Design
- Modeling Results
- Experimental Configuration
- Experimental Results
  - ASRG Backup Cooling Concept
  - Venus Lander Four-Feature Concept
- Conclusions
- Acknowledgements

Summary

- ACT developed:
  - ***Backup Cooling Concept*** for ASRG (Phase II SBIR ended in December 2009 – Lanny Thieme and Jeff Schreiber)
  - ***Four-Feature Concept*** based Thermal Management System for the Long-lived Venus Lander (Phase II SBIR ended in May 2013 – Rodger Dyson)
- Both concepts were tested/demonstrated at ACT with heater head simulator and GPHS simulator
- The objective was to carry tests and demonstrate the concepts with a Stirling engine
- A Stirling engine was made available for ACT (80We, up to 850^{o}C)
- Tests were conducted at NASA GRC with Stirling convertor for:
  - ***Backup Cooling Concept for ASRG***
  - ***Four-Feature Concept for Venus Lander***

Motivation – ASRG

- **General Purpose Heat Sources (GPHSs) supply heat to the Stirling engine(s)**
  - Generate Power, Radiate Waste Heat to Space
- **Would like to be able to stop/restart Stirling Engine**
  - During installation of the GPHS
  - During some missions to minimize electromagnetic interference and vibration while taking scientific measurements
- **Must continually remove heat from the GPHS, to maintain the modules and surrounding insulation at acceptable temperatures**
  - Normally cool with Stirling Engine
  - Temperature rises when Stirling is stopped
  - Insulation will “spoil” to prevent over-temperature
  - Once insulation is spoiled, can’t restart
- **VCHP will passively allow Stirling to be stopped/started**
  - Will also save replacing the insulation after a stoppage during ground testing
- **ACT has already demonstrated the backup cooling concept with Heater Head simulator – *<u>Using a real Stirling was the next step</u>***

Motivation - Long-lived Venus Lander

- **Long Life Venus Mission**
  - Refrigeration Required
  - Cool instruments to allow operation for up to a full Venerian year
- **Baseline Design uses staged Stirling Coolers**
- **Potential Power Sources include Radioisotopes, Nuclear Reactor, and Chemical**
- **A VCHP based thermal management system would:**
  - Collect heat from the power modules with minimum ΔT
  - Focus the heat on the heater head.
  - Operate ~ 1000 to 1200° C
  - Provide multiple parallel heat paths (segments) for redundancy
  - Provide ***back-up cooling*** when convertor is OFF

Motivation - Long-lived Venus Lander

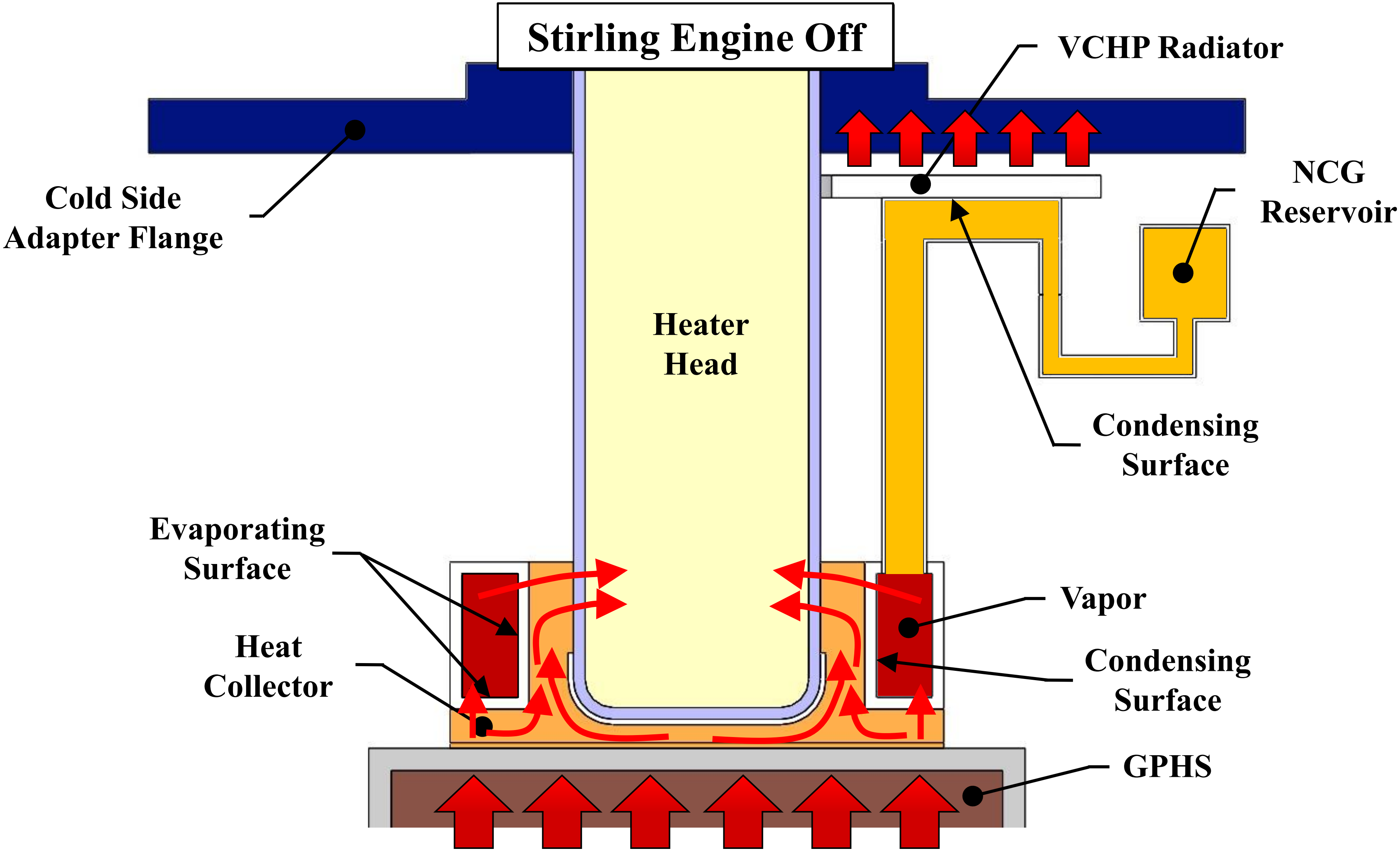
- **Backup Cooling is needed because the convertor is off for a large fraction of the mission**
  - After power modules are installed on earth
  - Launch
  - Travel to Venus
  - Re-entry
  - Short periods on Venus when low vibration and electrical noise desired, e.g., seismic measurements
- **Passive system that automatically rejects the heat when the convertor is off is desirable**
- **ACT has developed a VCHP based thermal management system that passively does these features**

Motivation - Long-lived Venus Lander

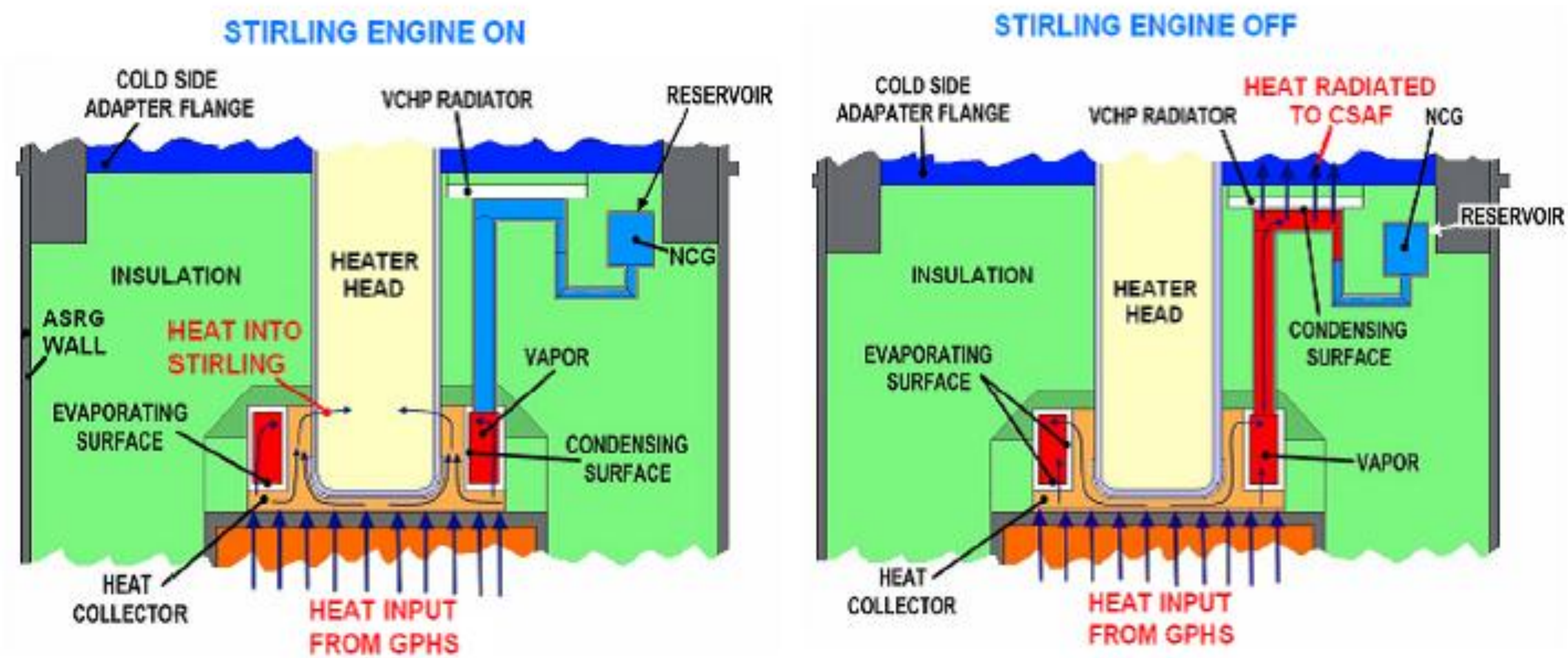
- The Four-Feature Concept consists of :
  - *Feature 1* - Stirling can be turned off during transit – Heater Head at a lower temperature than normal to save life.
    - Accomplished by operating the reservoir at a lower temperature during transit
  - *Feature 2* – Allows the convertor to pre-cool the system before entry into the Venus atmosphere.
  - *Feature 3* - Normal operation on Venus.
  - *Feature 4* - Briefly stop Stirling during normal operation on Venus to allow scientific measurements – vapor temperature increase is small.

- The Four-Feature Concept was demonstrated both theoretically and experimentally at ACT with Heater Head simulator. ***Using a real Stirling was the next step***

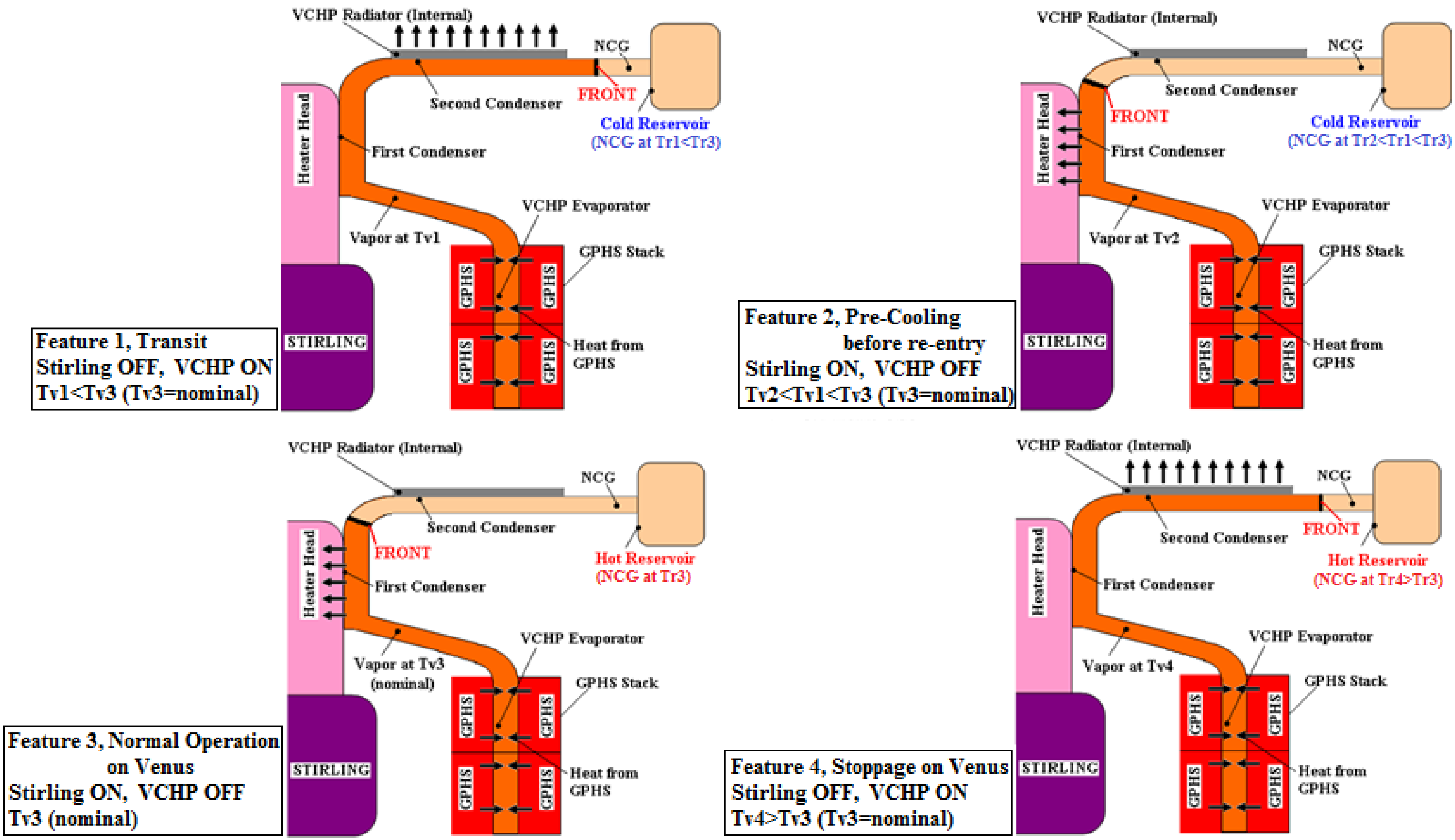
ASRG Backup Cooling Concept



ASRG Backup Cooling Concept

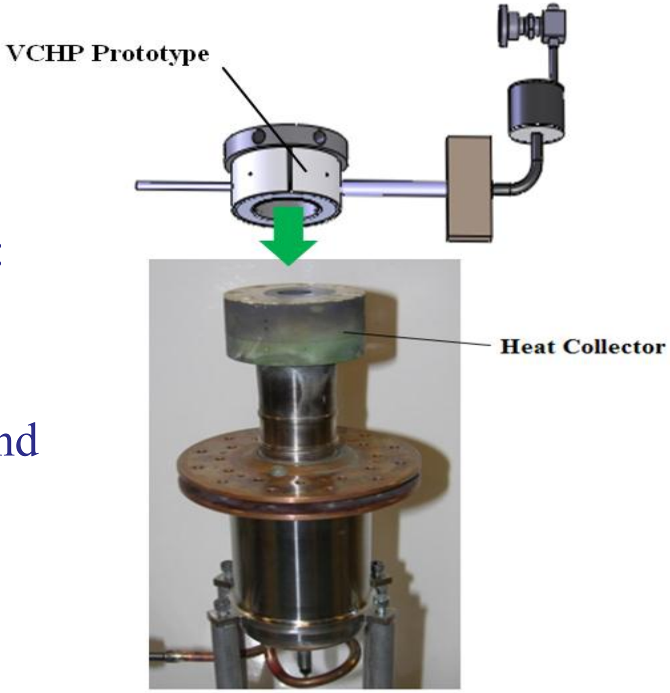


Long-lived Venus Lander - Four-Feature Concept



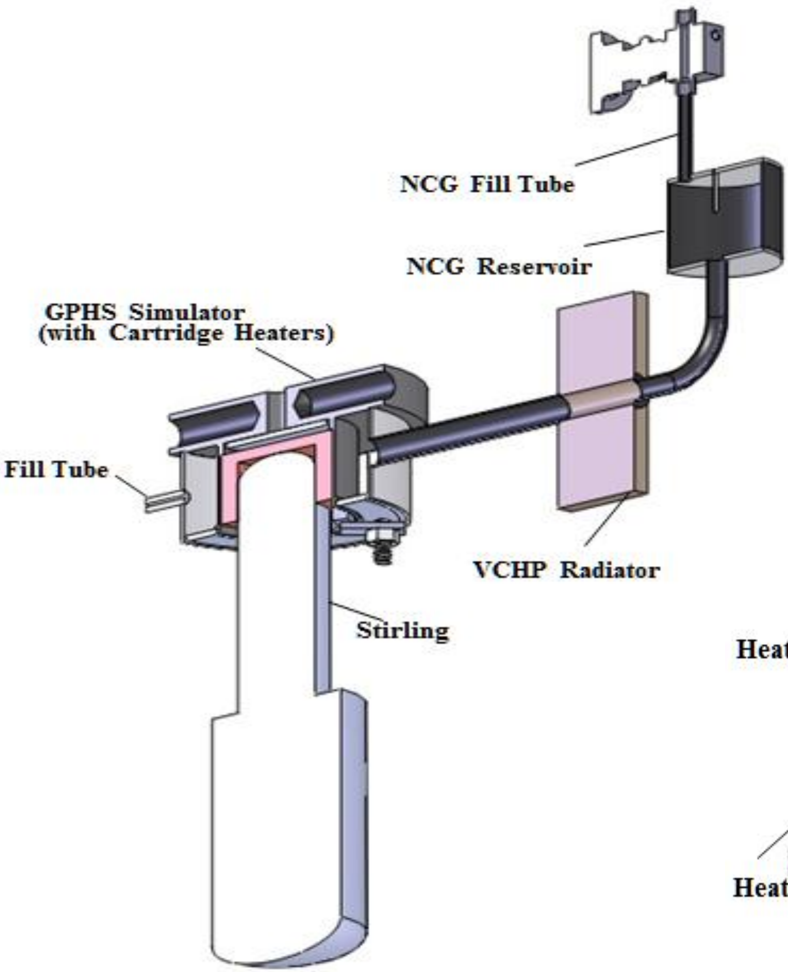
Stirling Convertor

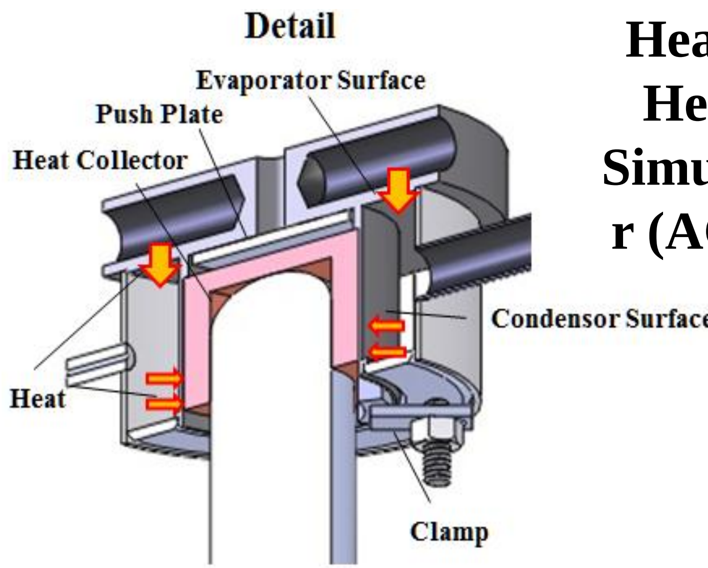
- VCHP-Stirling tests were conducted at GRC in December 2012
- NASA GRC made available a Stirling convertor:
  - 80W_e class ASC - 1HS, developed by Sunpower, Inc.
  - Maximum temperature …850 ° C
  - The convertor had already a heat collector brazed on the heater head
  - The annular evaporator/condenser of the VCHP wrapped around the existing heat collector.

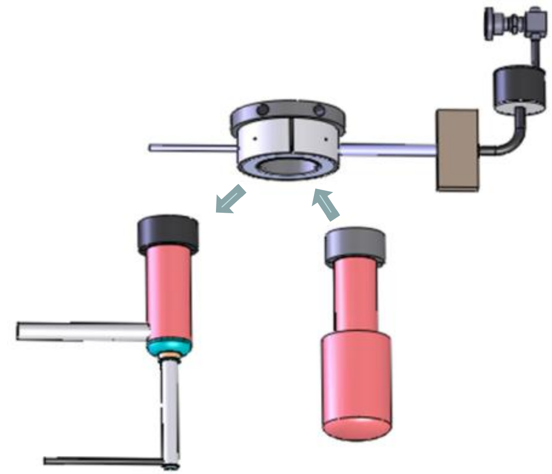


- Large temperature difference at the interface because of:
  - Existing heat collector
  - Gap
- Ideally, the annular evaporator/condenser wrapped around heater head replacing the heat collector

VCHP Prototype Design





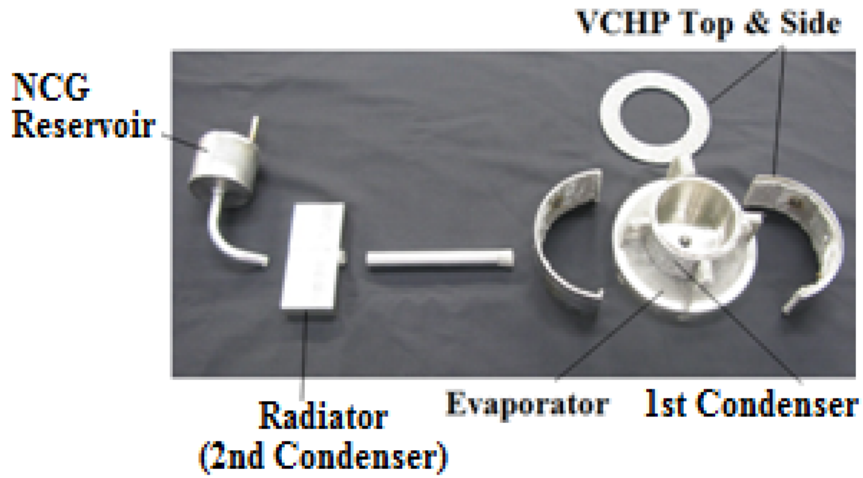


Heater Head Simulator (ACT)

ASC - 1HS (GRC)

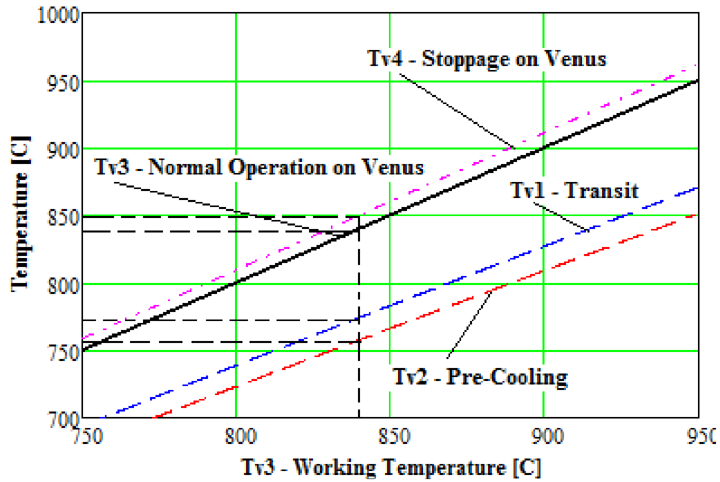
VCHP Prototype Fabrication

- Power 225 W
- Temperatures up to 850°C
- Sodium / Argon
- Stainless Steel
- Nickel Radiator
- Reservoir temperatures
  - 105°C (cold)
  - 460°C (hot)
- It is designed to handle both concepts

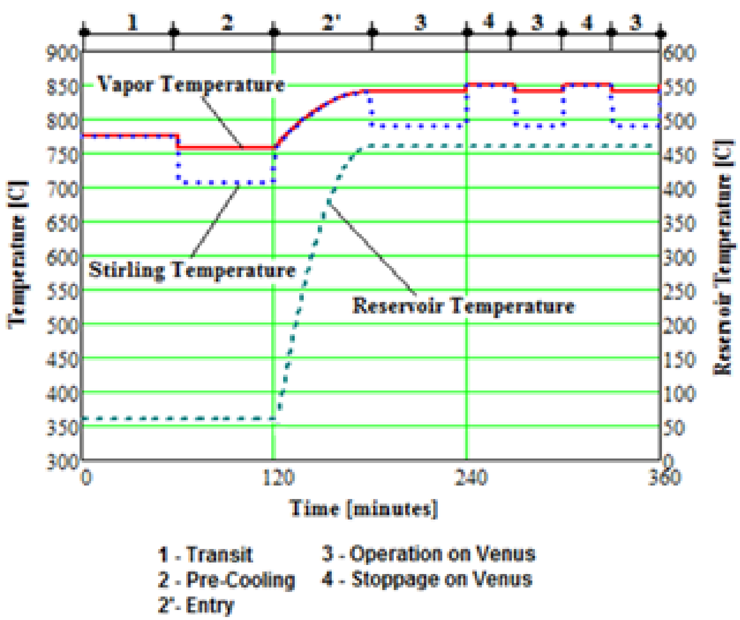


Modeling Results

- Flat front theory was used to model the VCHP
- The Four-Feature VCHP model was used for both concepts:



Power to be conducted the VCHP	1000 W
VCHP material	SS304
Heat collector material	Ni201
Radiator material	Ni201
Screen material	SS304 (100x100)
Vapor temperature during normal operation on Venus, Tv3	850°C (1123 K)
Vapor temperature during transit, Tv1	788°C (1061 K)
Vapor temperature after pre-cooling before re-entry, Tv2	765°C (1038 K)
Vapor temperature during stoppage on Venus, Tv4	855.5°C (1128.5 K)
Reservoir minimum temperature (after pre-cooling), Tr2	27°C (300 K)
Reservoir maximum temperature (during stoppage), Tr4	465°C
Reservoir temperature during transit, Tr1	100°C

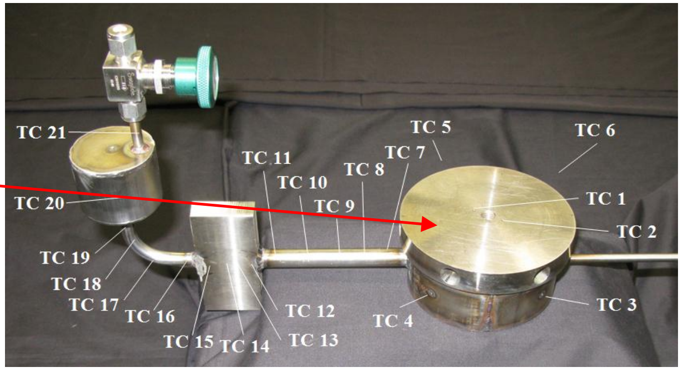


Experimental Configuration

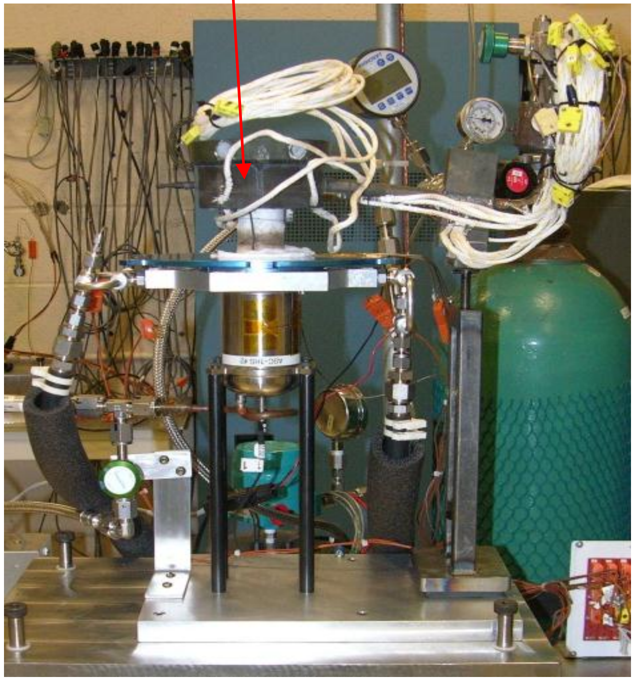
- Testing at GRC

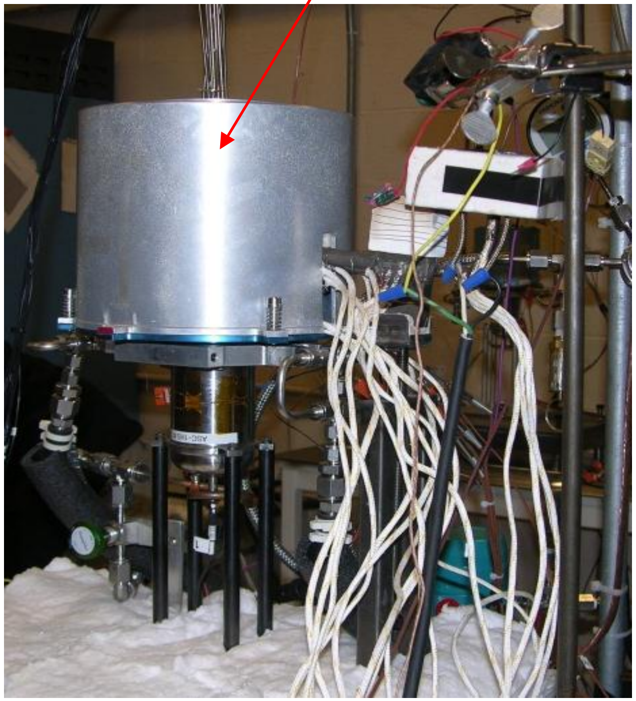
VCHP in working position

VCHP installed on the convertor



Insulation can installed

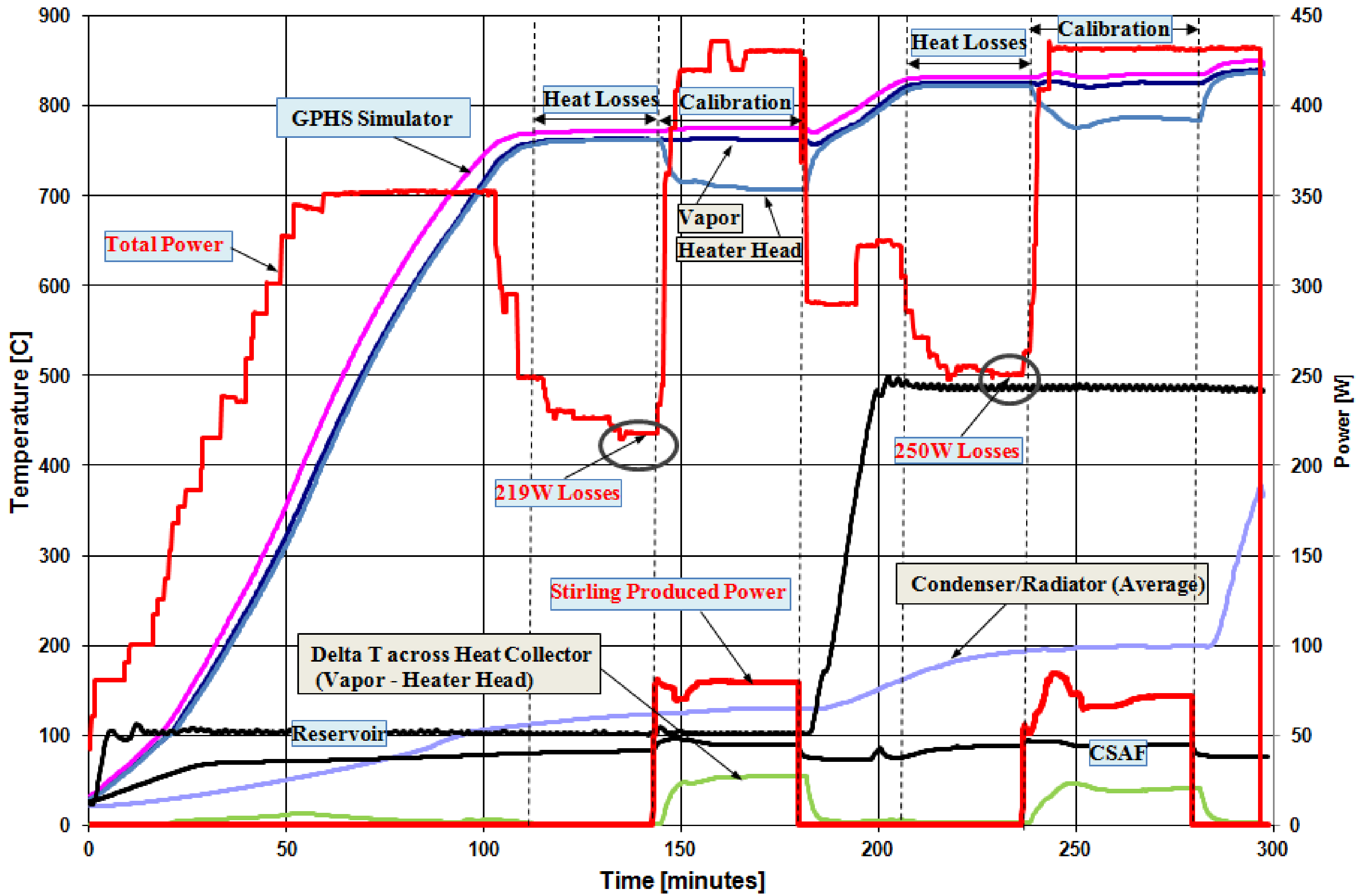




Experimental Results

- Three sets of experimental results were obtained:
  - Heat Losses Determination and Stirling Convertor Calibration
  - ASRG Backup Cooling Concept
  - Venus Lander Four-Feature Concept

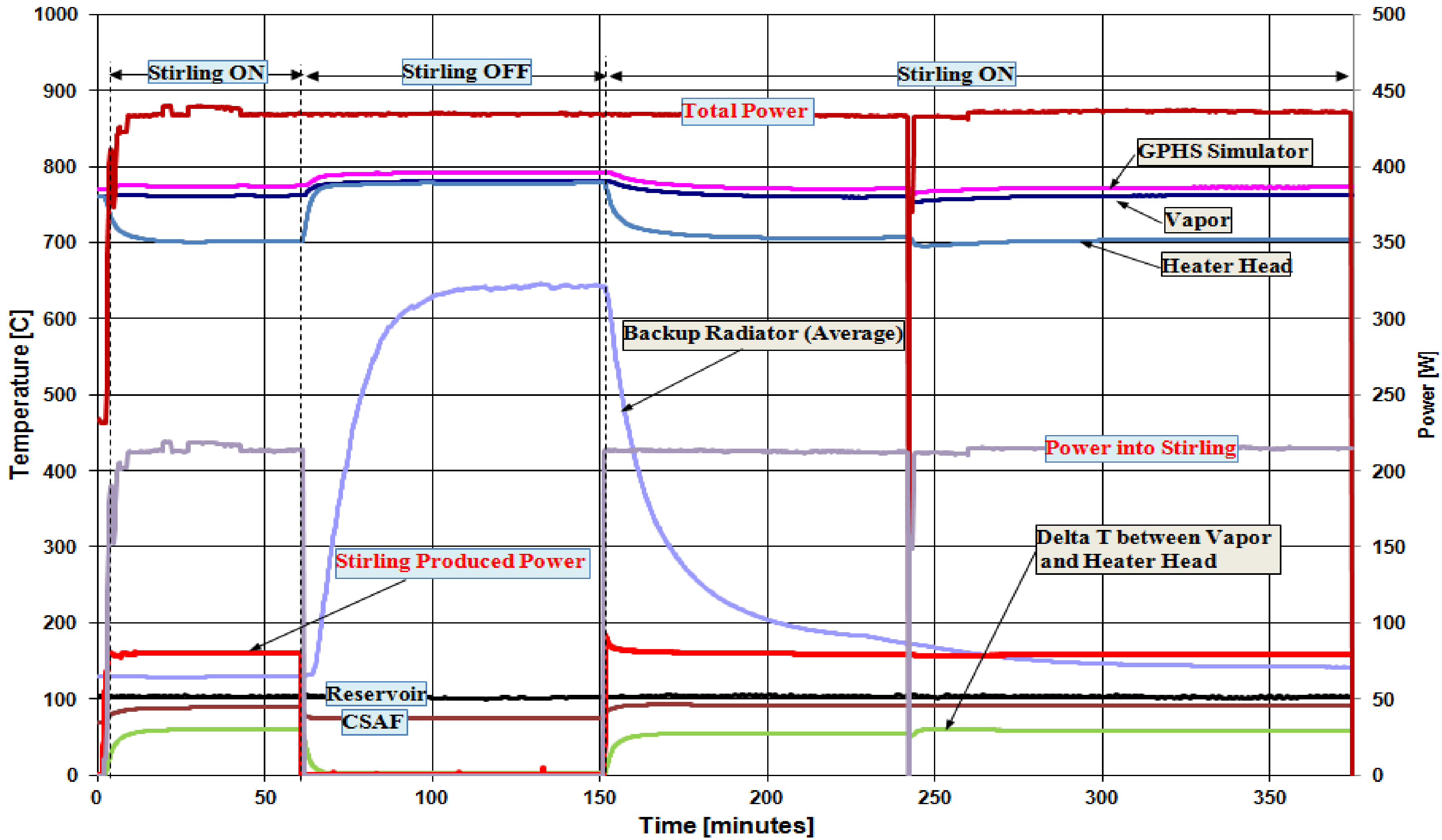
Experimental Results: Heat Losses and Stirling Convertor Calibration



Experimental Results: Heat Losses and Stirling Convertor Calibration

- **ASRG and Feature 2 (pre-cooling) of the Venus Lander Four-Feature Concept**
  - Set point: VCHP (vapor): 761° C Stirling convertor 702° C
  - Reservoir temperature: 101° C
  - VCHP radiator temperature: 130° C
  - Total Power: 433W
  - Heat losses: 219W
  - Heat transferred into Stirling: 214W
  - Electrical power produced: 80W

- **Feature 3 (normal operation) of the Venus Lander Four-Feature Concept**
  - Set point: VCHP (vapor): 814° C Stirling convertor 756° C
  - Reservoir temperature: 465° C
  - VCHP radiator temperature: 197° C
  - Total Power: 433W
  - Heat losses: 250W
  - Heat transferred into Stirling: 183W
  - Electrical power produced: 71W


Stirling ON
Stirling OFF
Stirling ON
Total Power
GPHS Simulator
Vapor
Heater Head
Backup Radiator (Average)
Power into Stirling
Delta T between Vapor and Heater Head
Stirling Produced Power
Reservoir
CSAF
Temperature [C]
Power [W]
Time [minutes]
1000
900
800
700
600
500
400
300
200
100
0
500
450
400
350
300
250
200
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100
50
0
0
50
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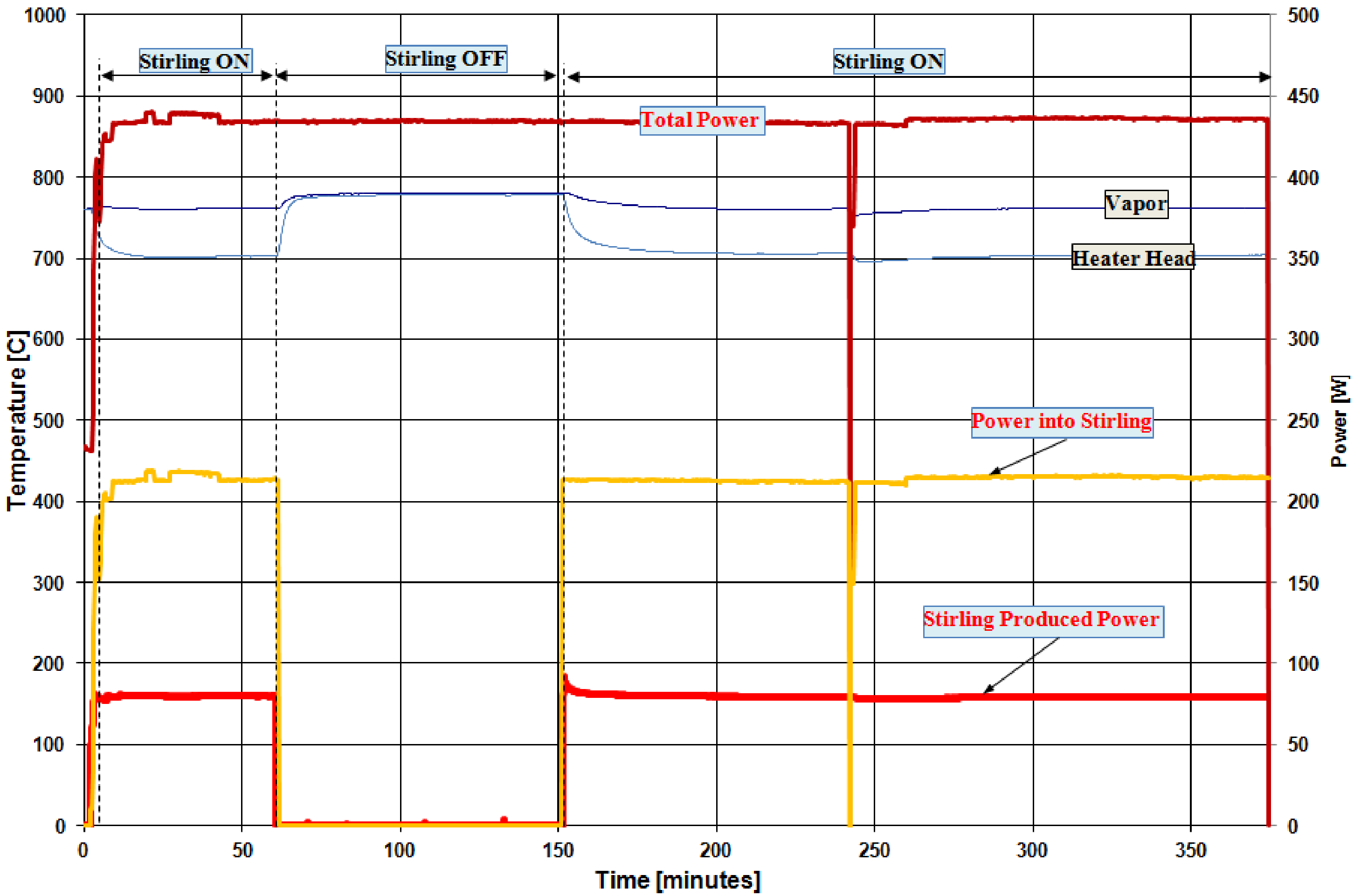
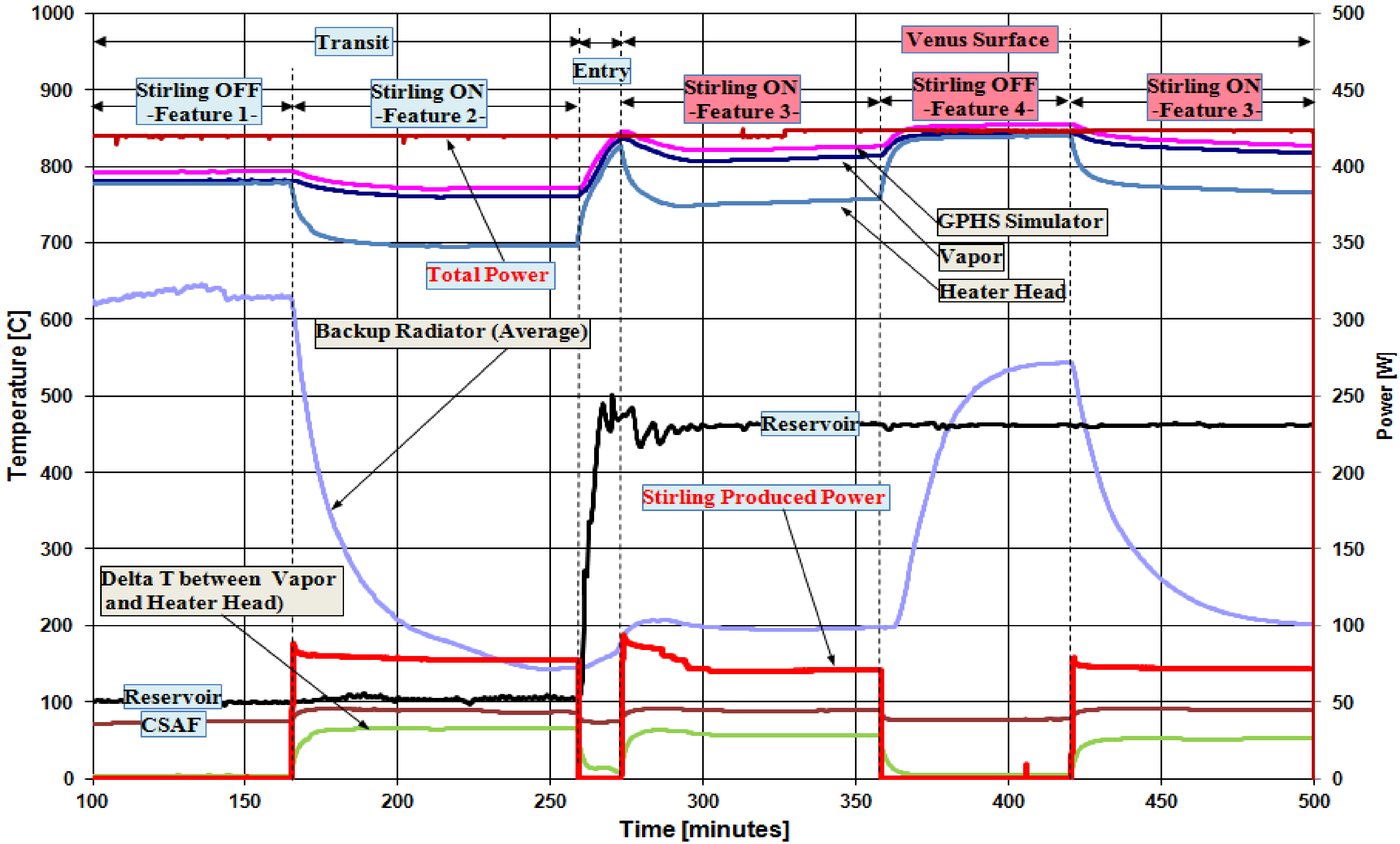
250
300
350

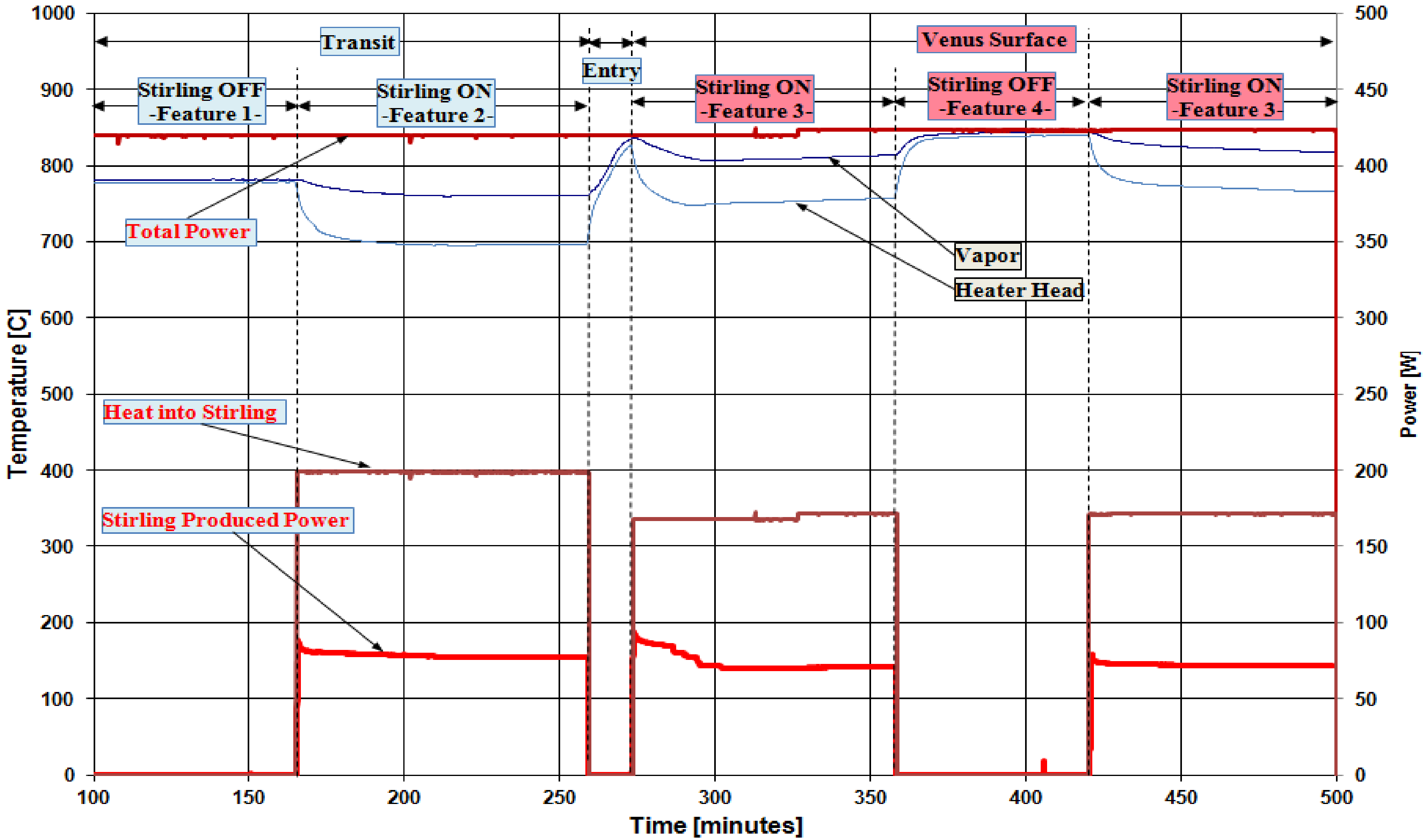
- Heat losses due to the presence of the VCHP ~ 4W



Experimental Results: Venus Lander Four-Feature Concept – Temperature Profiles



Experimental Results: Venus Lander Four-Feature Concept – Power Profiles



Conclusions

- All objectives were successfully achieved demonstrating the VCHP operating with a Stirling convertor.
- The VCHP was able to successfully demonstrate both: ASRG Backup Cooling concept and Venus Lander Four-Feature concept with a Stirling convertor .
- In the ASRG Backup Cooling concept the VCHP allowed the Stirling to be shut off with a minimum rise in the VCHP vapor temperature (approximately 16ºC) and be restarted to resume normal operation.
- The Venus Lander four-feature concept testing illustrated the ability of the VCHP to passively operate as predicted for each feature.
- Good agreement was found between the model and the experimental results with only small discrepancies.
- The feasibility of using an alkali metal VCHP as the backup or primary cooling system for a Stirling convertor has been proven experimentally.

Acknowledgements

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- Tim Wagner of ACT was the technician on the program.

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