Environmental Loss Characterization of an Advanced Stirling Convertor (ASC-E2) Insulation Package using a Mock Heater

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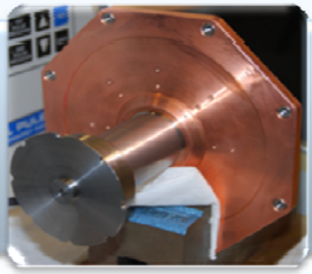
Net Heat Input Session Presentations

Overview of Heat Addition and Efficiency Predictions for an Advanced Stirling Convertor (ASC)

- Effort improved accuracy of net heat input predictions for ASCs tested at GRC
- Author: Scott Wilson

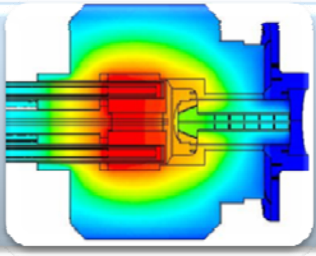
Environmental Loss Characterization of an ASC Insulation Package using a **Mock Heater Head**

- Test hardware used as pathfinder for Thermal Standard test materials and methods
- Author: Nick Schifer



Evaluation of Advanced Stirling Convertor Net Heat Input Correlation Methods using a **Thermal Standard**

- Test hardware used to validate net heat prediction models
- Author: Max Briggs, presented by Nick Schifer



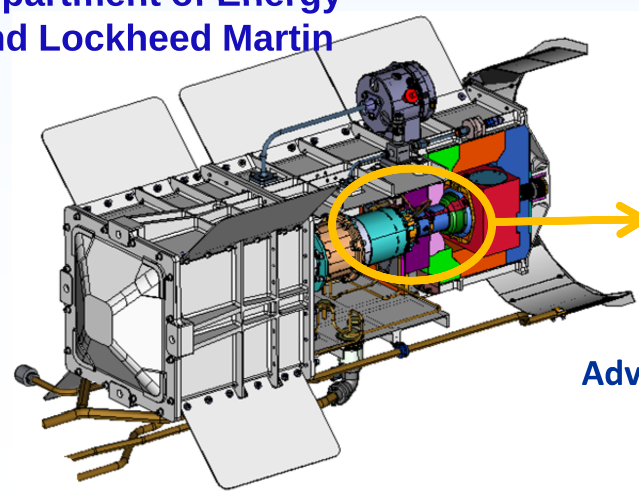
A **Computational Methodology** for Simulating Thermal Loss Testing of the Advanced Stirling Convertor

- Numerical models validated using test data
- Author: Terry Reid

Why is Net Heat Input Needed?

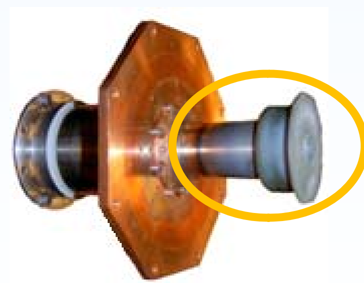
- Problem: Net Heat Input cannot be measured directly during operation
- Net heat input is a key parameter needed in prediction of efficiency for convertor performance
- Efficiency = Electrical Power Output (**Measured**) divided by Net Heat Input (**Calculated**)
- Efficiency is used to compare convertor designs and trade technology advantages for mission planning

ASRG developed by Department of Energy and Lockheed Martin

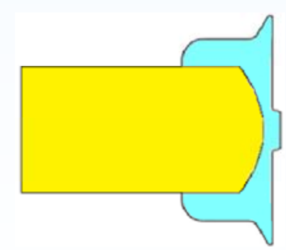


Advanced Stirling Radioisotope Generator (ASRG)

ASC developed by Sunpower, Inc. & NASA Glenn Research Center



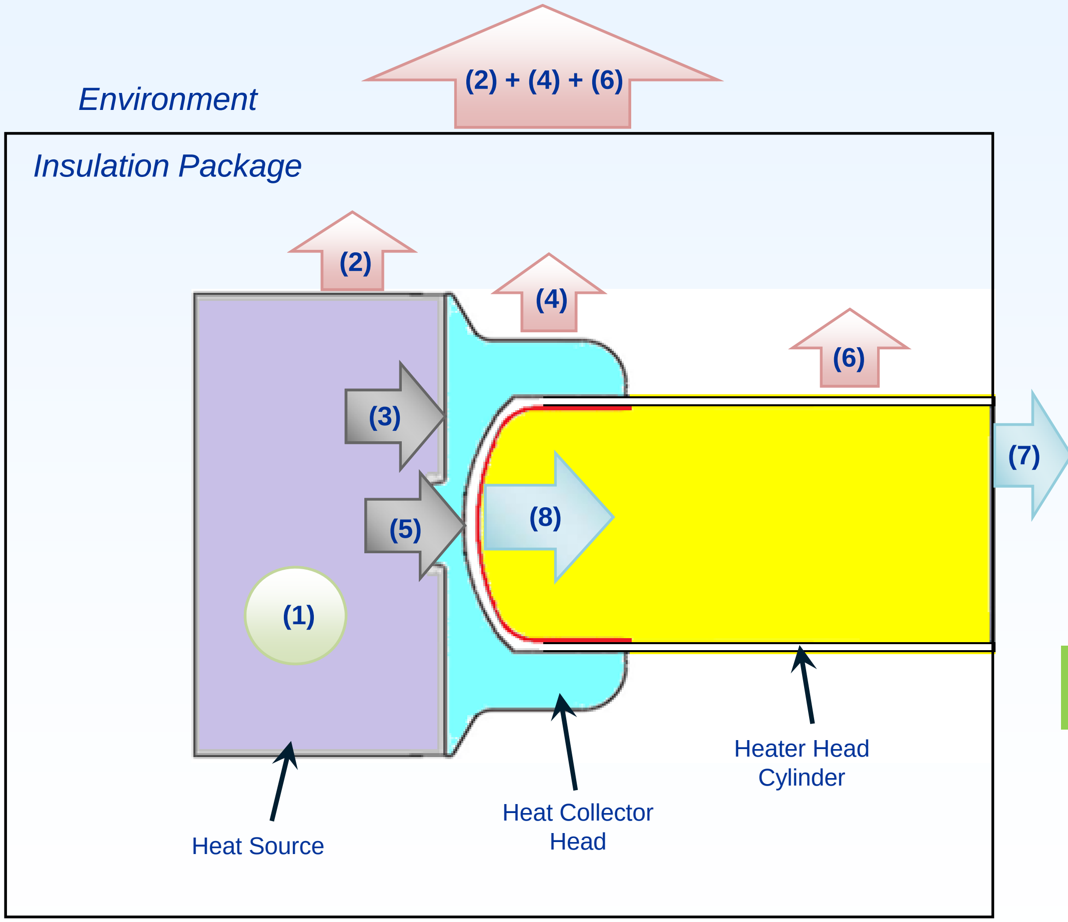
Advanced Stirling Convertor (ASC)



ASC Heater Head Diagram

What is Net Heat Input?

- Net Heat Input is heat energy required for **thermodynamic cycle** heat addition + **parasitic heat transfer losses** inherent to heat engines



(1) Gross heat input to Heat Source
(2) to Insulation Package
(3) to Heat Collector Head
(4) to Insulation Package
(5) to Heater Head Cylinder
(6) to Insulation Package
(7) to Cold End of convertor
(8) to Stirling cycle

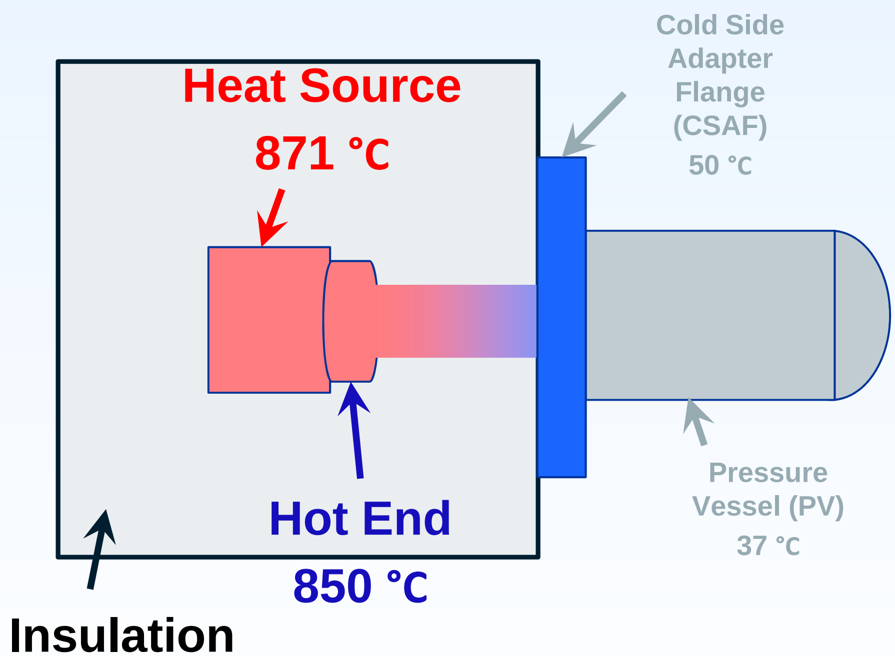
Net Heat Input = (8) + (7)

Outline

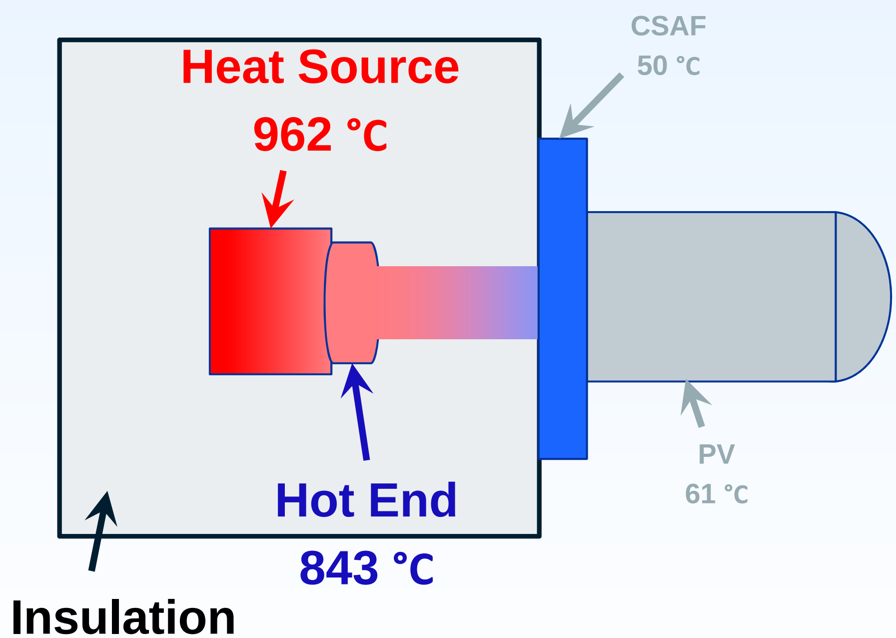
- Problem Statement
- Introduction to the Mock Heater Head
- Role of the Mock Heater Head - Pathfinder
  - Test Configuration
  - Calculations
  - Testing
  - Heat Flow Paths
  - GRCop-84 conducting rod
  - Thermal Imaging
- Conclusions

Problem Statement

During Insulation Loss Testing (Non-operating)



During Normal Operation (Operating)

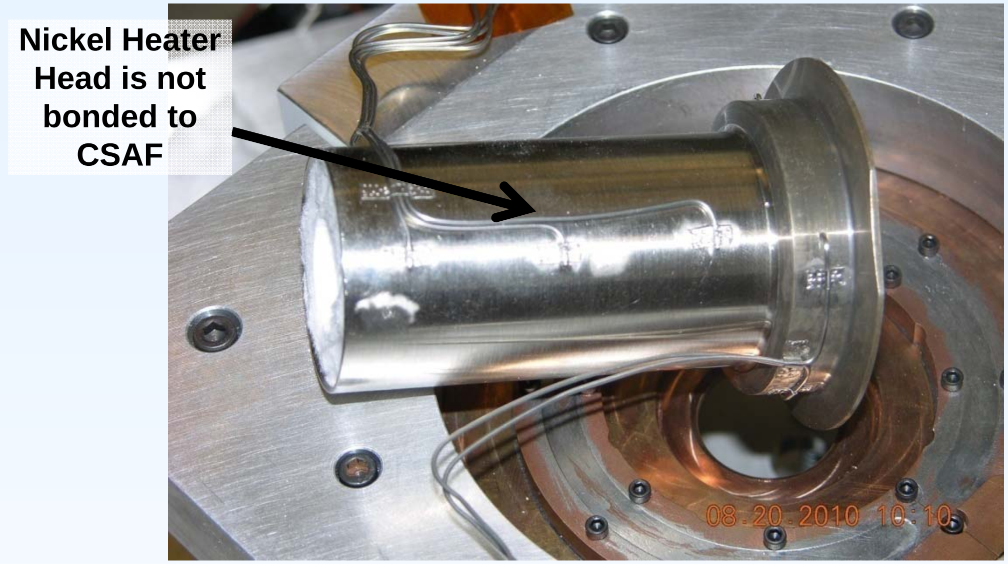


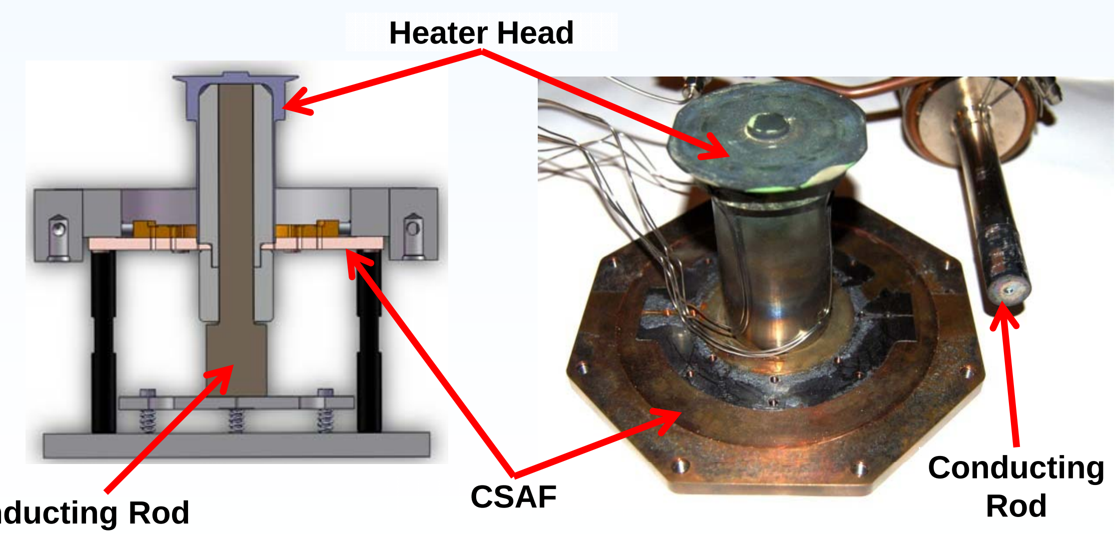
Thermal gradients significantly change during operation compared to Insulation Loss Testing

The Mock Heater Head

- Key Mock Heater Head test components include
  - Nickel heater head
  - CSAF (Oxygen free high conductivity copper)
  - Nickel and GRCop-84 conducting rods

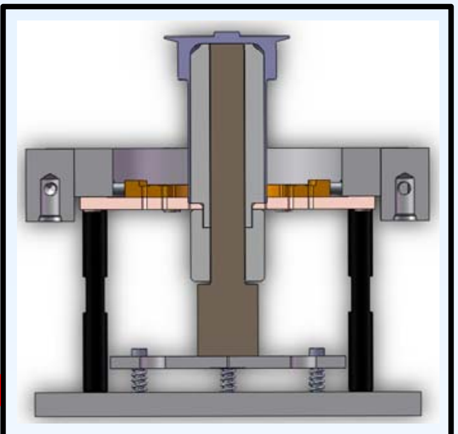
- Nickel heater head modified from existing hardware
- Not stand alone hardware
  - Requires heater preload to affix the heater head
  - Requires additional hardware to use the conducting rods



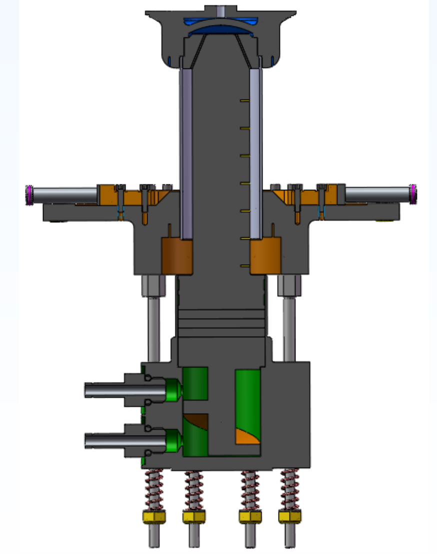


Role of the Mock Heater Head

- The Mock Heater Head served as a path finder and proof of concept for the Thermal Standard:
  - Verified the test methodology and configuration
  - Identified instrumentation locations for calculating heat conducted to the cold end
  - Investigated the use of a conducting rod as a representative Stirling cycle and verified GRCop-84 as a viable material option.
  - Identified features for the heat collector and CSAF
  - Validated use of an IR camera to measure temperatures on the exposed heater components
  - Identified preferred test methods used for characterization
    - Control off of hot-end temperature rather than heater temperature

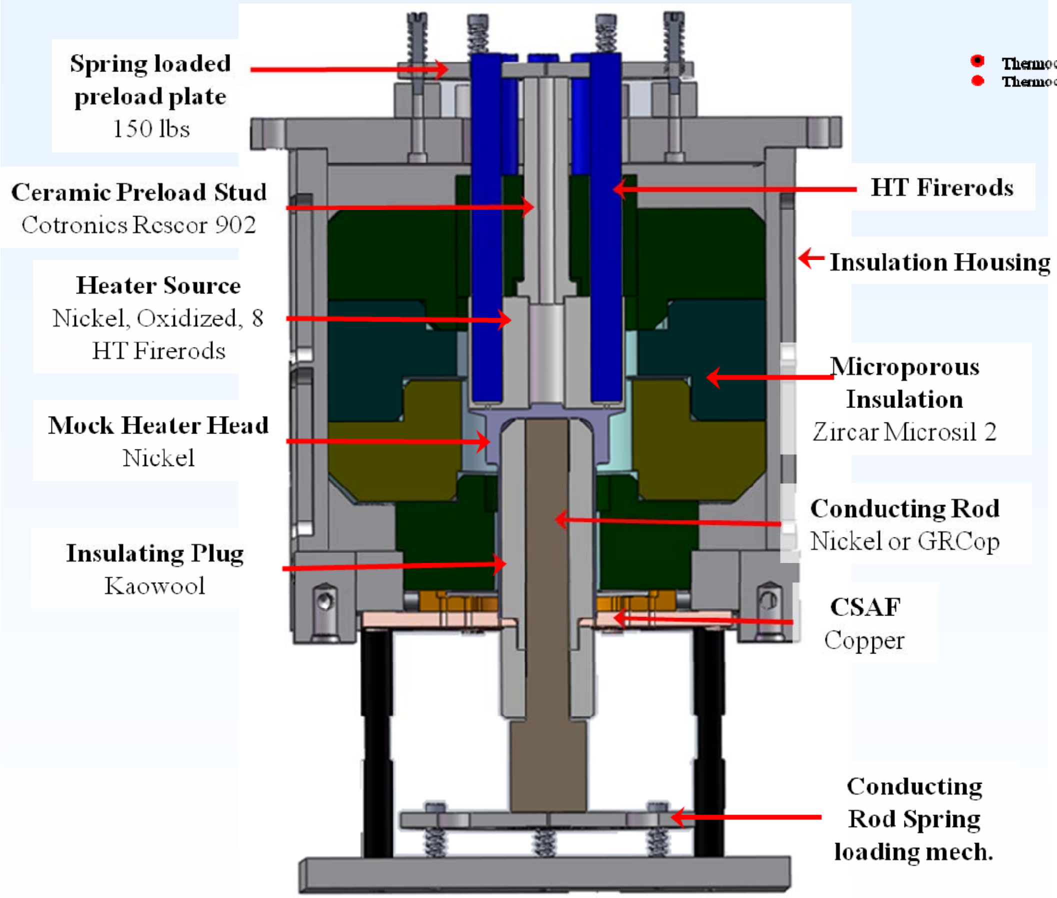


Mock Heater Head

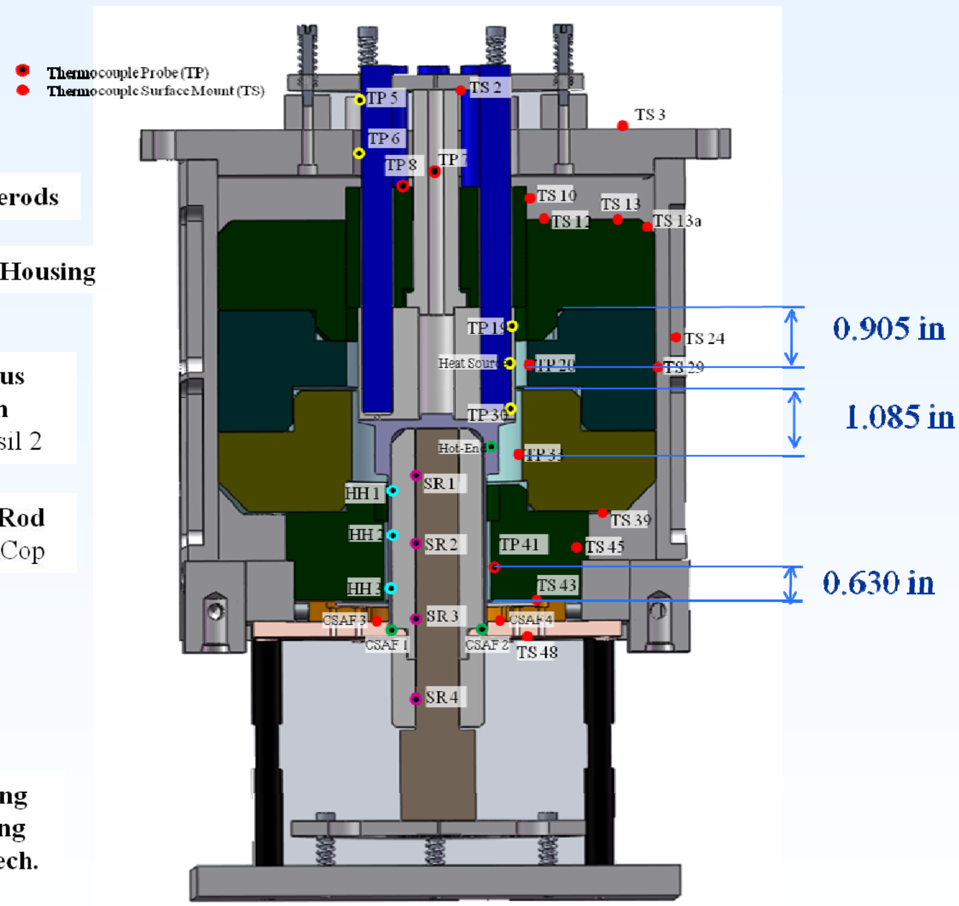


Thermal Standard

Test Configuration

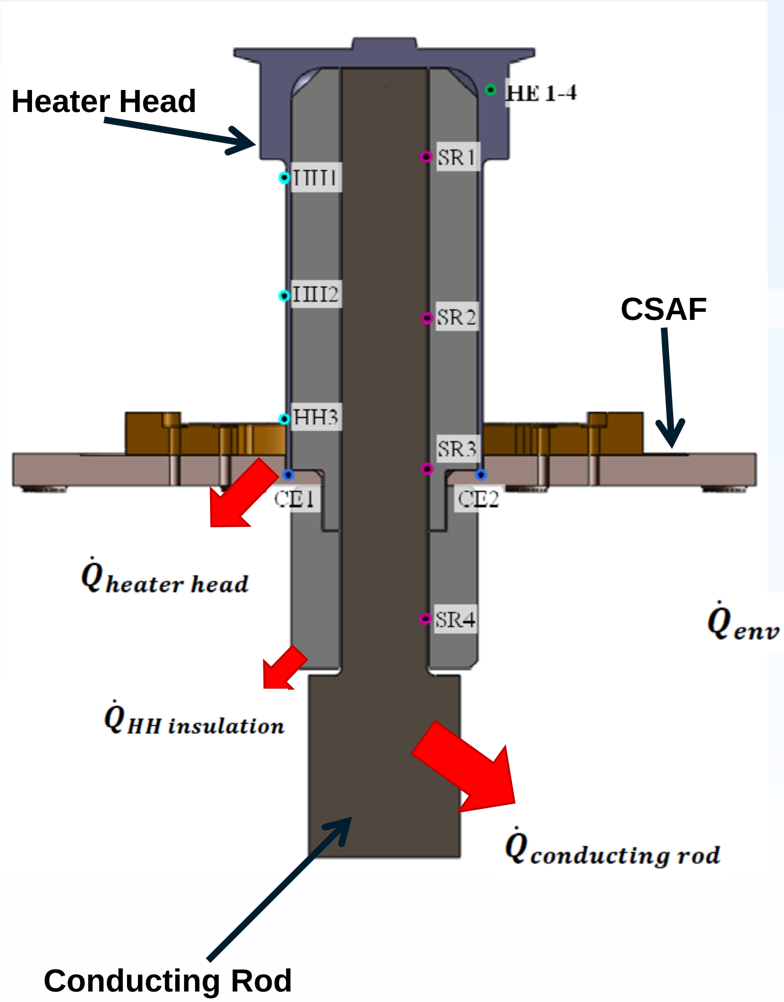


Mock Heater Head Hardware



Mock Heater Head Instrumentation

Calculations



- The Mock Heater Head simplified the problem to purely conduction and provided test data for validation of numerical models.

Fourier's Law: $\dot{Q} = KA\frac{\Delta T}{\Delta X}$

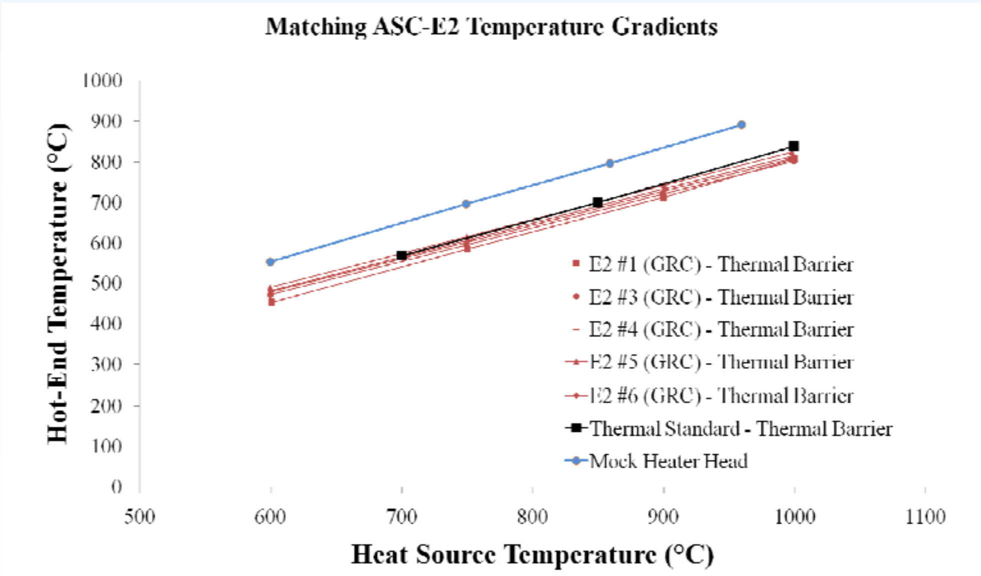
Energy Balance:

$$\dot{Q}_{env\ loss} = \dot{Q}_{heater\ power} - \left(\dot{Q}_{heater\ head} + \dot{Q}_{conducting\ rod} + \dot{Q}_{HH\ insulation}\right)$$

Validated the use of 1D conduction equations in calculating conduction losses

Testing

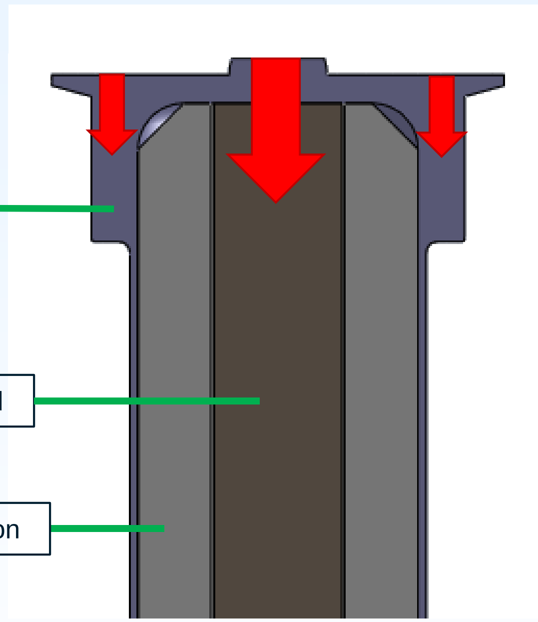
ASC-E2 Convertor Test Sequence			
Test Title	**Interface Material**	**Piston Status**	**Environmental Loss Calculation Method**
Alumina disk	Alumina disk	Stalled	Conduction calculation
Thermal barrier	Ceramic paper	Stalled	Conduction calculation
Nominal operation	Alumina disk	Moving	Empirical model Numerical models



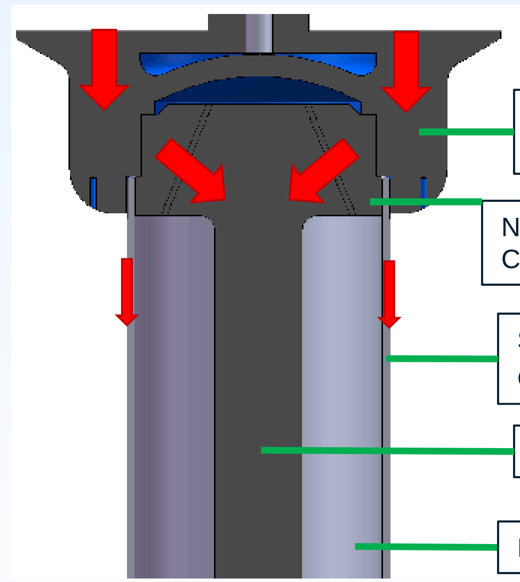
- Developed the test sequence and data reduction methods
- Identified preferred test methods used for characterization
- Temperature profiles didn't match as well as expected

Heat Flow Paths

Mock Heater Head



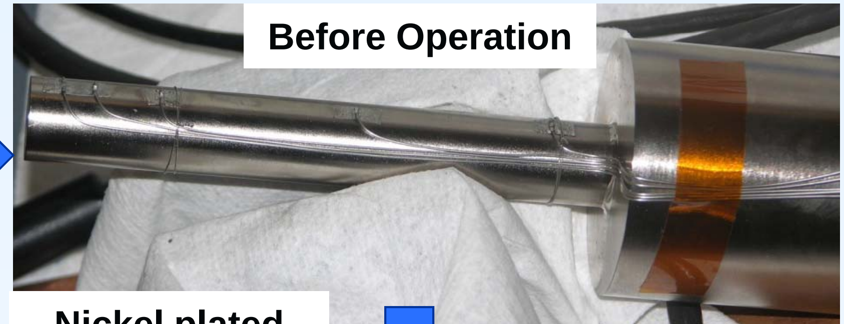
Thermal Standard



- Differences in heat flow paths effected the temperature profile
- Emphasized the need to have accurate heat flow paths in the Thermal Standard

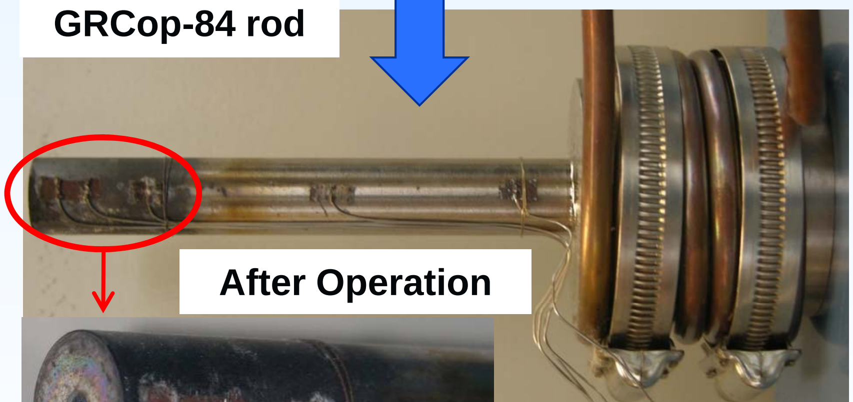
The GRCop-84 Conducting Rod

Raw GRCop-84 Billets



Before Operation

Nickel plated GRCop-84 rod



After Operation

Nickel plating did not flake after 415 hours of operation at 500 °C

GRCop-84

Advantages

-Strength greater than copper

-Thermal Conductivity 80% of copper

Concerns

- Oxidation at elevated temperatures
- TC attachment
- Can it be nickel coated for oxidation protection?

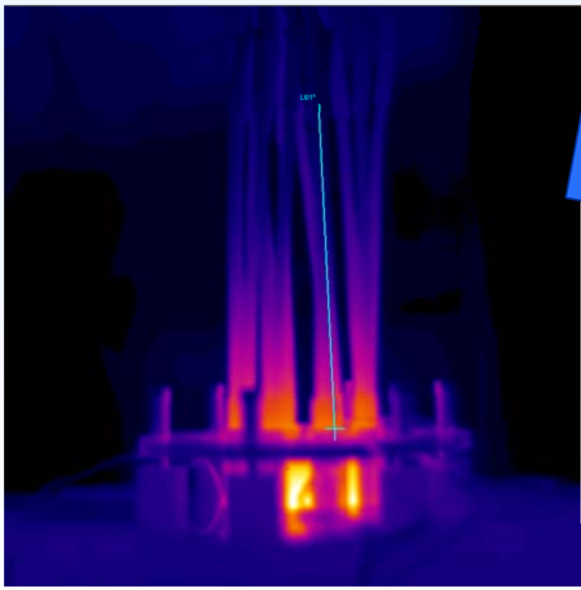
• Verified GRCop-84 as viable material for conducting rod

• Verified nickel plating as viable oxidation protection

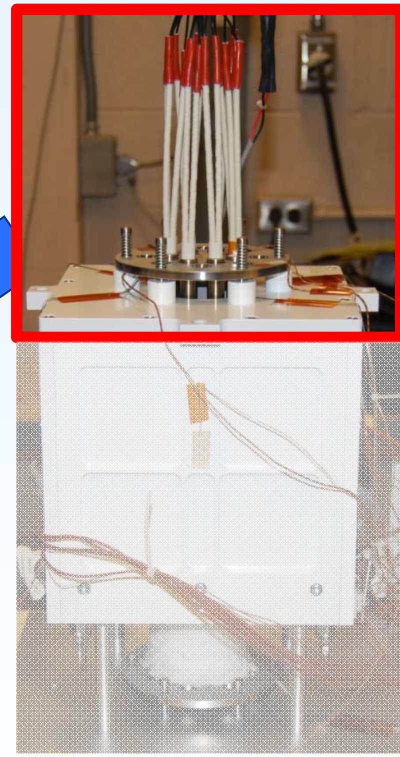
Thermal Imaging of Exposed Heater Components

FLIR Thermal Camera

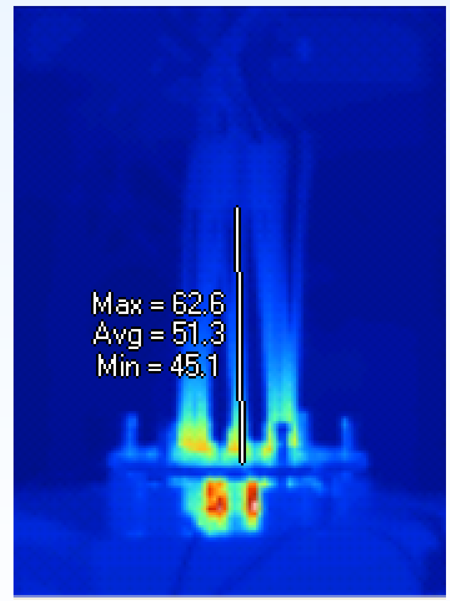
Fluke i45 Thermal Camera



Thermal Image from FLIR Camera



Mock Heater Head Test Setup



Thermal Image from Fluke Camera

Identified and verified use of thermal imaging as a means of defining the thermal profile of the exposed heater components for numerical models

Conclusions

- The Mock Heater Head served as a path finder and proof of concept in the development of the Thermal Standard as part of the Net Heat Input Investigation
  - Verified the test methodology and configuration
  - Identified instrumentation locations for calculating heat conducted to the cold end
  - Investigated the use of a conducting rod as a representative Stirling cycle and verified GRCop-84 as a viable material option
  - Identified features for the heat collector and CSAF
  - Validated use of an IR camera to measure temperatures on the exposed heater components
  - Identified preferred test methods used for characterization
    - Control off of hot-end temperature rather than heater temperature

Results of the Mock Heater Head drove the design of the Thermal Standard

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Any opinions, findings, conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of NASA.