A Stirling Radioisotope Generator (SRG110) is being developed for potential use on future NASA space science missions. The development effort is being conducted by Lockheed Martin under contract to the Department of Energy (DOE). The Stirling Technology Company supplies the free-piston Stirling power convertors, and NASA Glenn Research Center (GRC) provides support to the effort in a range of technologies. This generator features higher efficiency and specific power compared to the currently used alternatives. One potential application for the generator would entail significant cruise time in the vacuum of deep space. A test has been conceived at GRC to demonstrate functionality of the Stirling convertors in a thermal vacuum environment. The test article resembles the configuration of the SRG, however the requirement for low mass was not considered. This test will demonstrate the operation of the Stirling convertors in the thermal vacuum environment, simulating deep space, over an extended period of operation. The analysis, design, and fabrication of the test article will be described in this paper.

NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION

Preparation

Design and ~~Fabrication~~ of a Stirling Thermal Vacuum Test

International Energy Conversion Engineering Conference

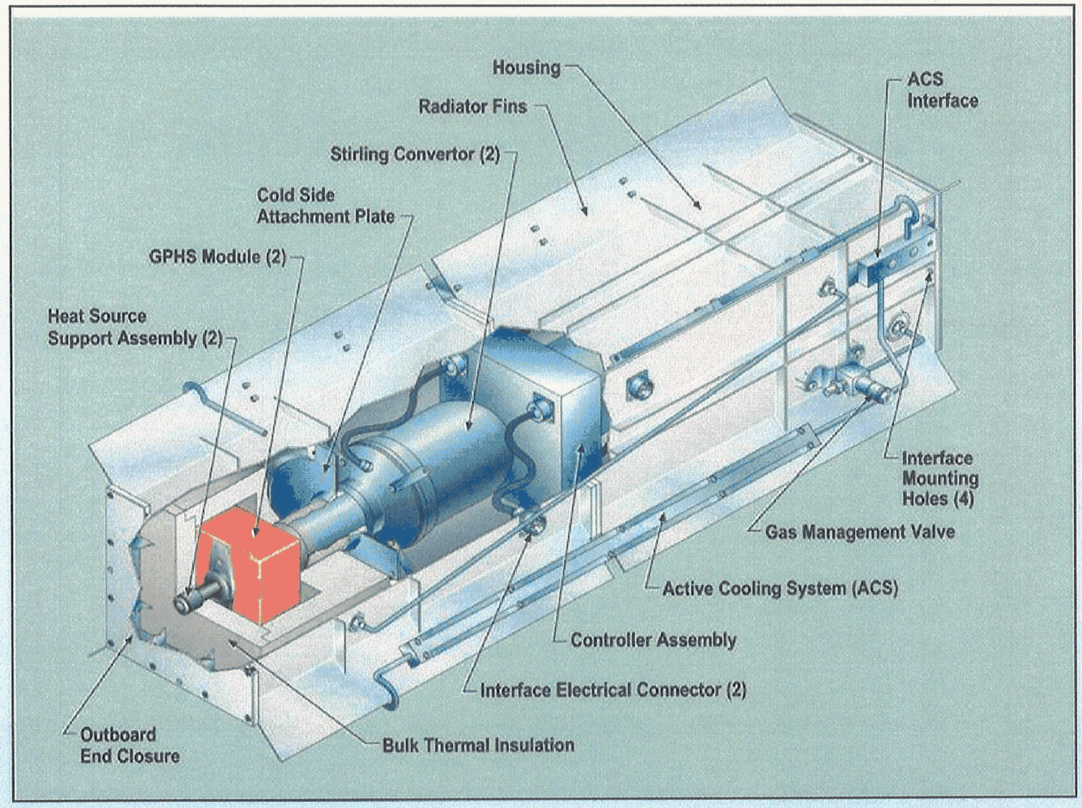
August 17, 2004

Salvatore Oriti
NASA Glenn Research Center
RPT – Thermal Energy Conversion Branch

Stirling Radioisotope Generator (SRG110)

SRG110 Program

- Being developed for flight qualification by Lockheed Martin Astronautics (LMA) under contract to the Department of Energy (DOE)
- Potential use for deep space and Mars surface missions
- 110 watts electrical output nominally
- Powered by two Plutonium-238 general purpose heat sources
- Utilizes two Stirling Technology Demonstration Convertors (TDC's), 55 W_e each
- Offers potential for higher efficiency than currently used conversion technologies
- Dynamic power conversion : Never used in space



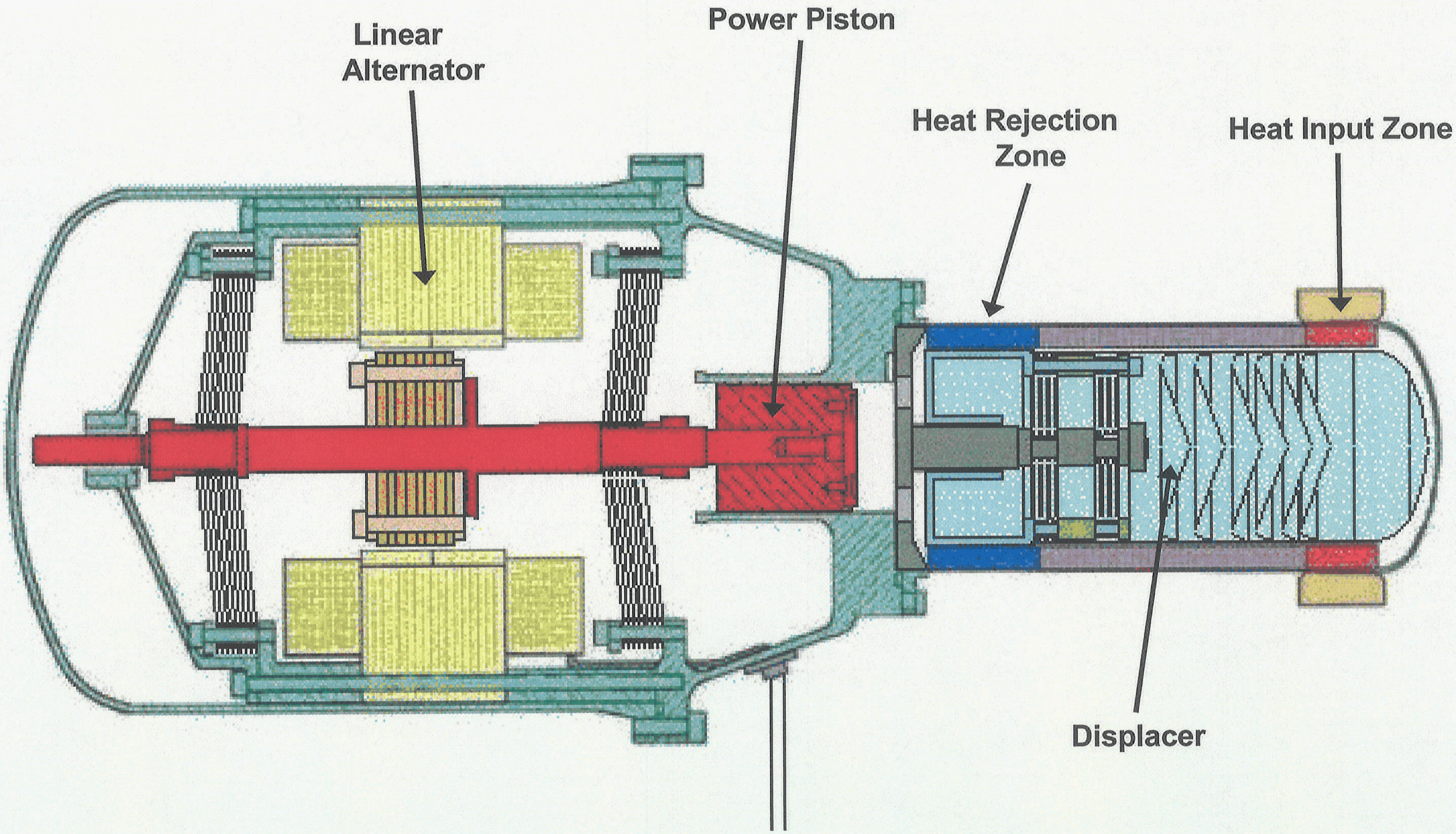
Preliminary SRG110 design by LMA

Stirling Technology Demonstration Convertor (TDC)

LOCKHEED MARTIN

GRC GLENN RESEARCH CENTER at Lewis Field

SRG110 Program



Extended Operation of TDC's in Thermal Vacuum Environment

- **Objectives**
  - Characterize performance of TDC's operating in thermal vacuum conditions
  - Provide data to Lockheed Martin for validation of thermal modeling
  - Simulate SRG similar thermal conditions
  - Demonstrate extended operation of TDC's in relevant environment for transition to TRL 5

- **Methodology**
  - Develop model incorporating ANSYS and Sage Stirling code
  - Develop system level thermal model incorporating all components
  - Utilize data for development of SRG hardware with Lockheed Martin
  - Design and fabricate a mock-up test article of the SRG110 without the mass constraint

Test Article Description

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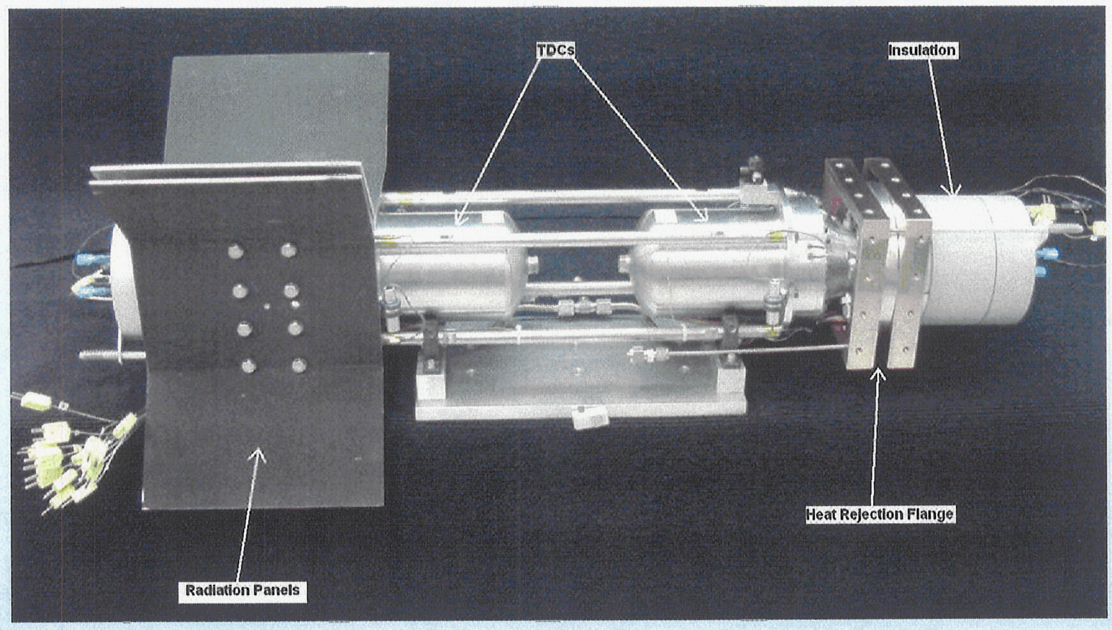
SRG110 Program

- Two Stirling convertors arranged in dual opposed configuration
- Heat supplied by ceramic Boralectric heater coupled to heat collector
- Heat rejected by brazed on Ni/Cu hybrid flange coupled to aluminum radiation panels
- Heater head insulated by Thermal Ceramics Min-K
- All cold-end thermal interfaces utilize Thermagon thermal interface material
- Additional temp control (of what?) provided by coolant loop attached to heat rejection flange



Thermal Vacuum Test Article

Test Article Components

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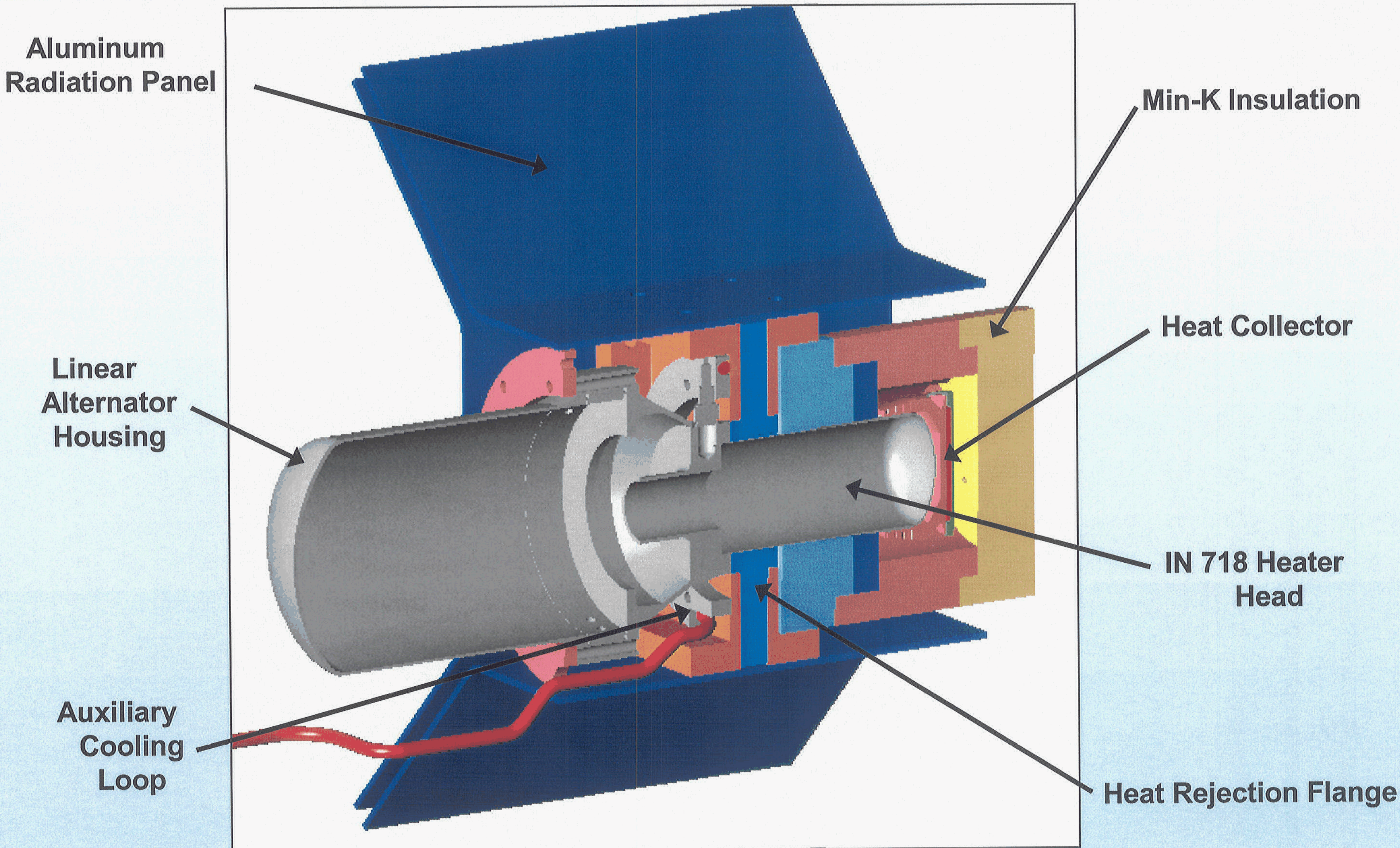
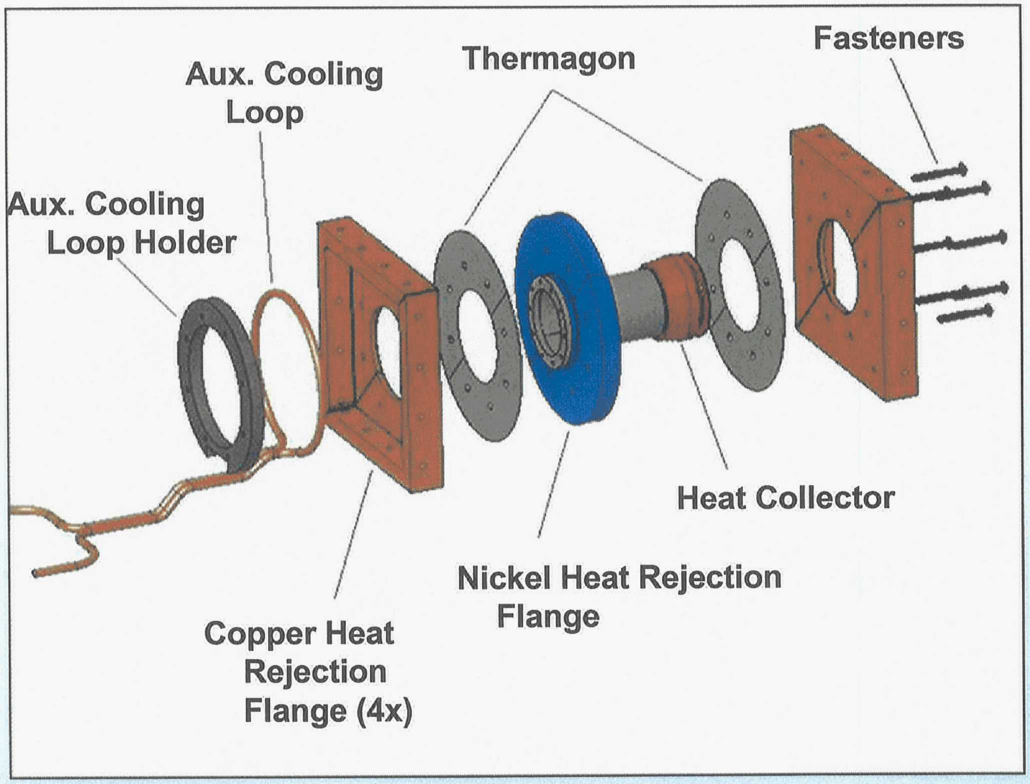
SRG110 Program

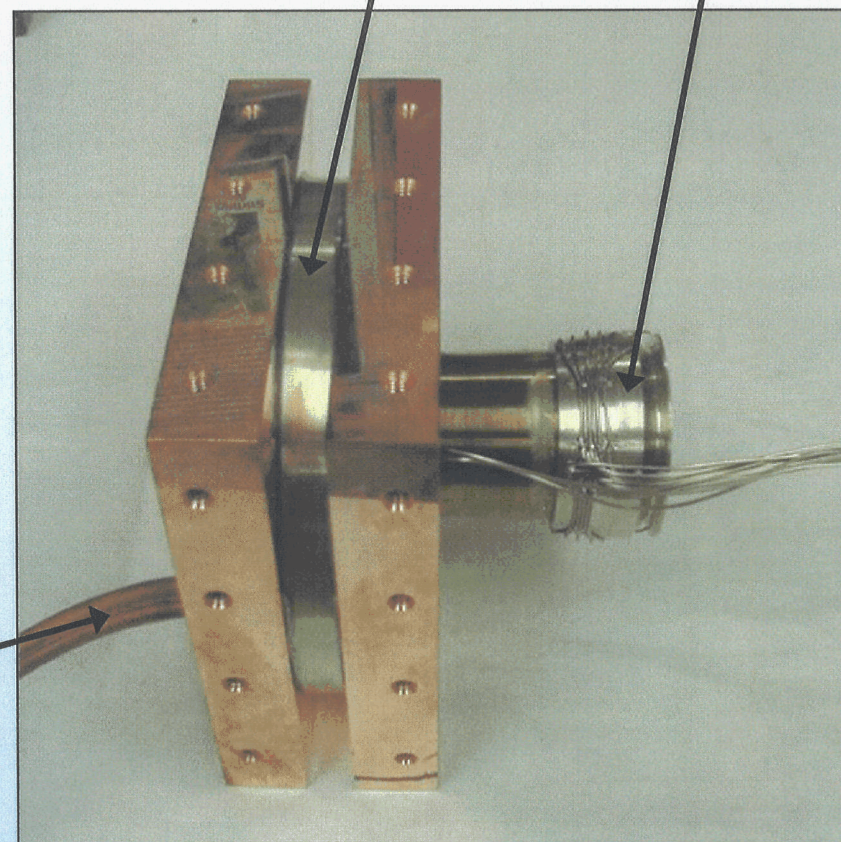


Thermal Vacuum Heater Head Assembly

SRG110 Program

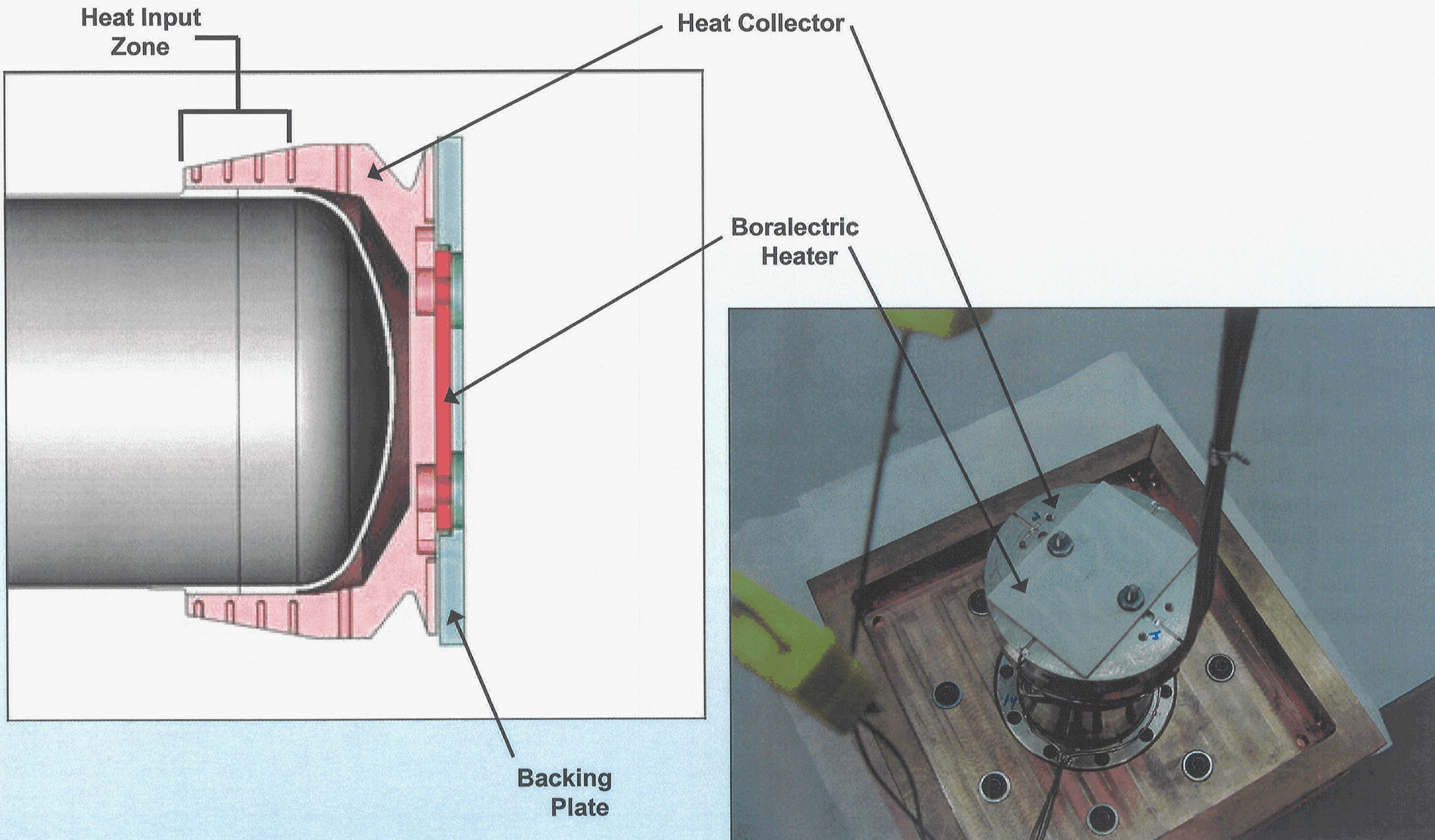


Heater Head Exploded View

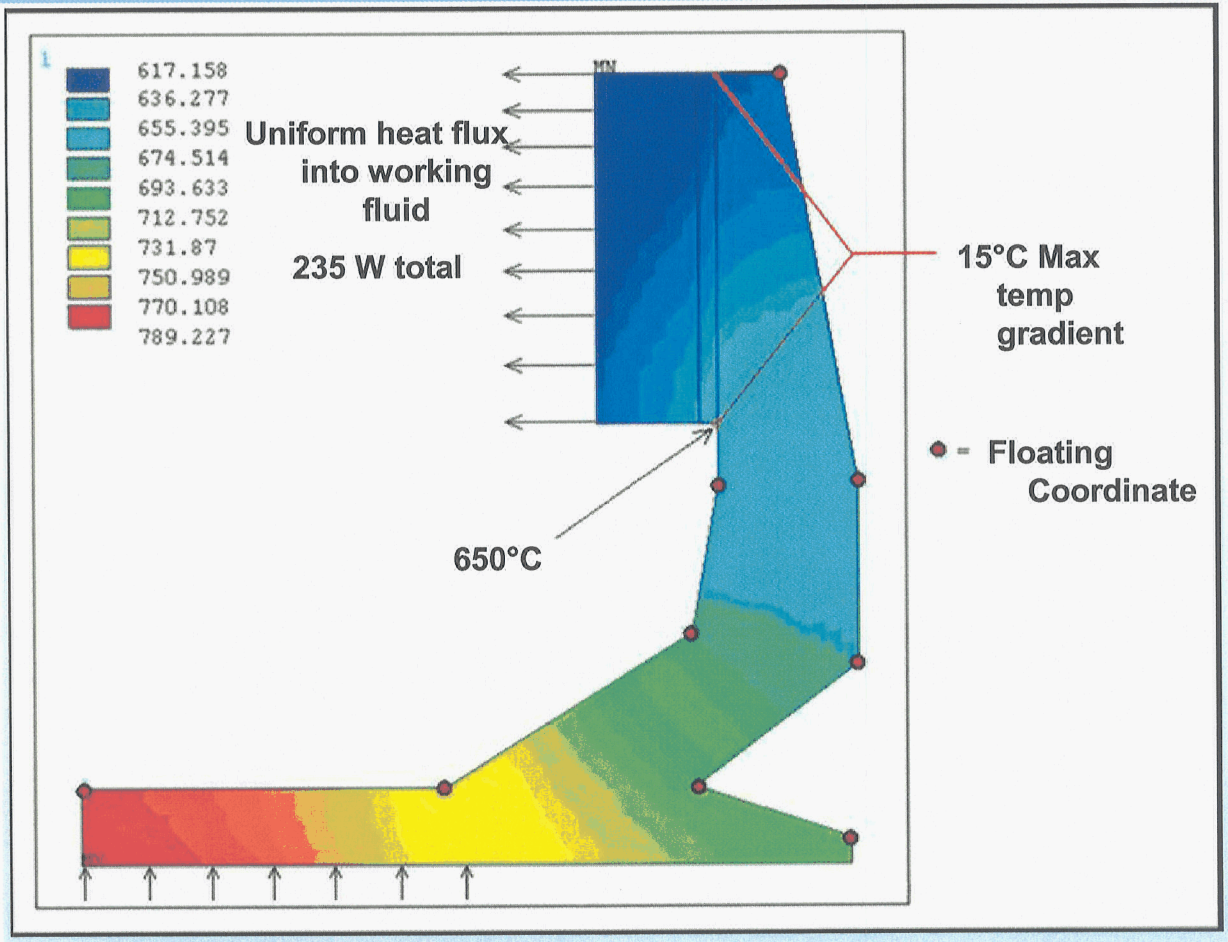


Heater Head Assembled

Heat Collector Optimization Using ANSYS FEA



Heat Collector Optimization Using ANSYS FEA



235 W from heater

- **Optimization constraints:**
  - <790°C on hot face of collector
  - 650°C maximum heater head temperature
  - 15°C maximum axial temperature gradient along heater head interface
- **Parametric analysis setup & boundary conditions:**
  - 2D axisymmetric elements
  - Temperature varying thermal conductivity of Nickel 201
  - Hot-heat exchanger modeled as solid area with equivalent mass and conductivity
  - Uniform heat flux applied to equivalent area of boralectric heater
  - Uniform heat flux out of equivalent heat exchanger
  - 650°C applied to first interface node closest to hot end of collector

Heat Rejection Flange Optimization

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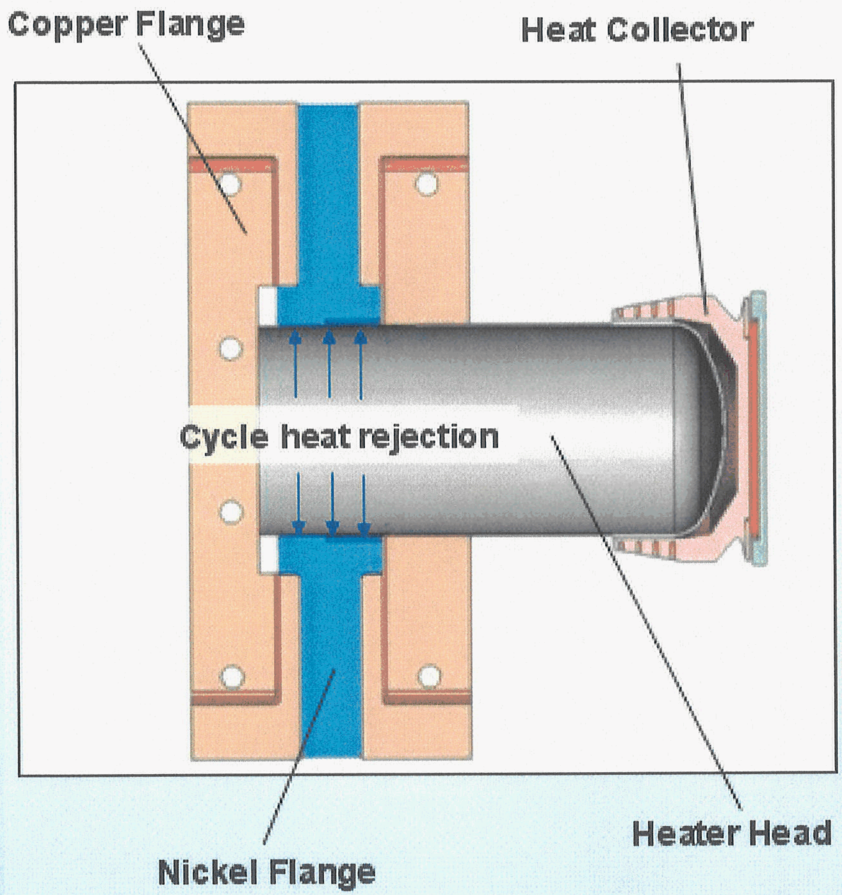
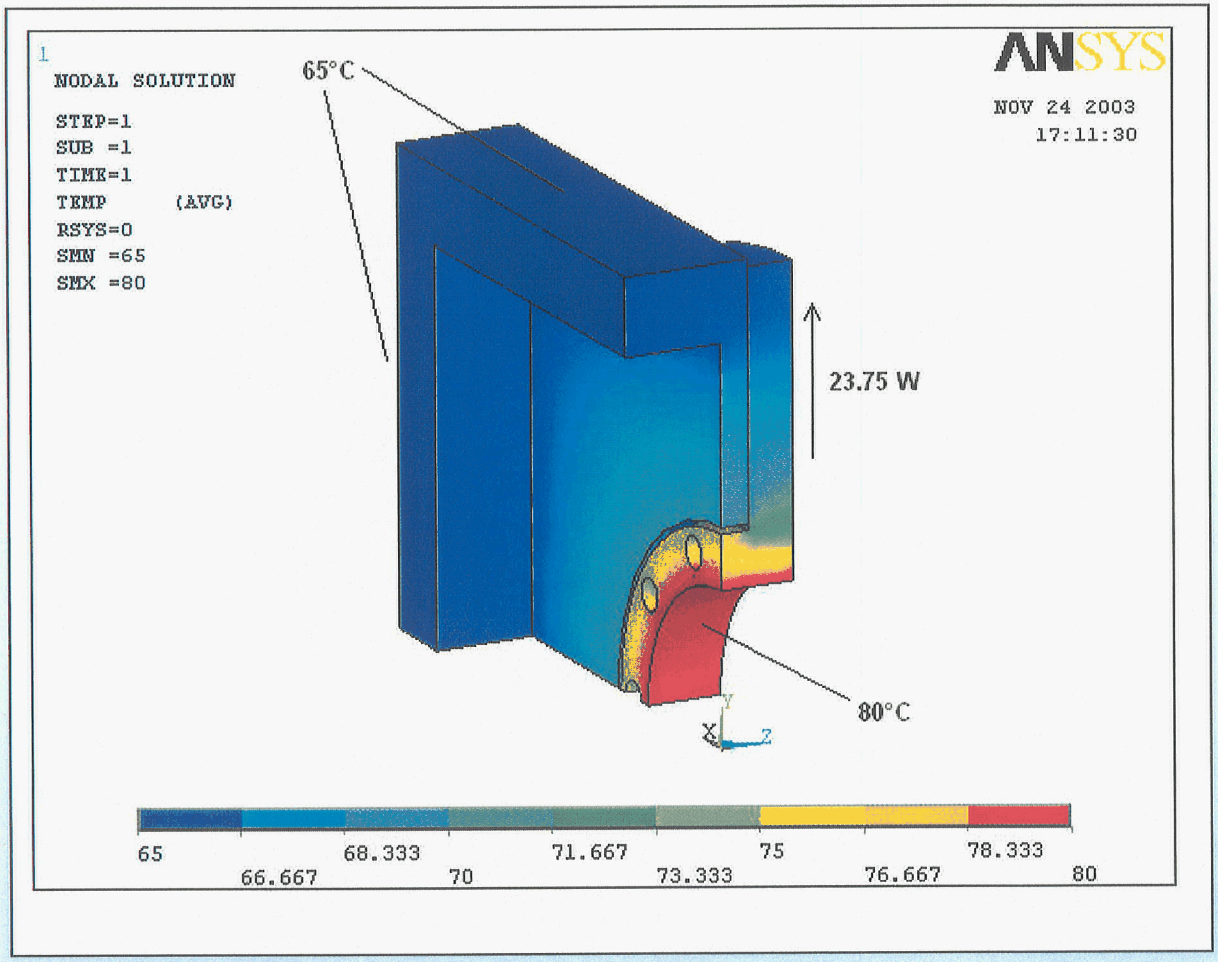
SRG110 Program

- **Nickel / Copper hybrid flange**
  - Nickel brazed to heater head
  - Copper flanged bolted on each side of nickel to increase thermal conductivity
  - Thermagon thermal interface material used between nickel and copper interfaces
  - Radiator panels attach outer surfaces of copper sections



Heat Rejection Flange Optimization

SRG110 Program



- **Analysis Setup and Boundary Conditions:**
  - 1/8th section
  - Constraints: Must conduct 190 W with 15°C temperature drop between heater head and radiation panel attachment
  - Perfect contact assumed between mating surfaces
  - Adjusted geometry of nickel and copper to minimize mass
- **Analysis Setup and Boundary Conditions:**
  - 5mm Copper thickness
  - 14mm Nickel thickness
  - ~20 lbs. total weight
  - 191 W capacity @ 15°C drop

System Level Thermal Analysis

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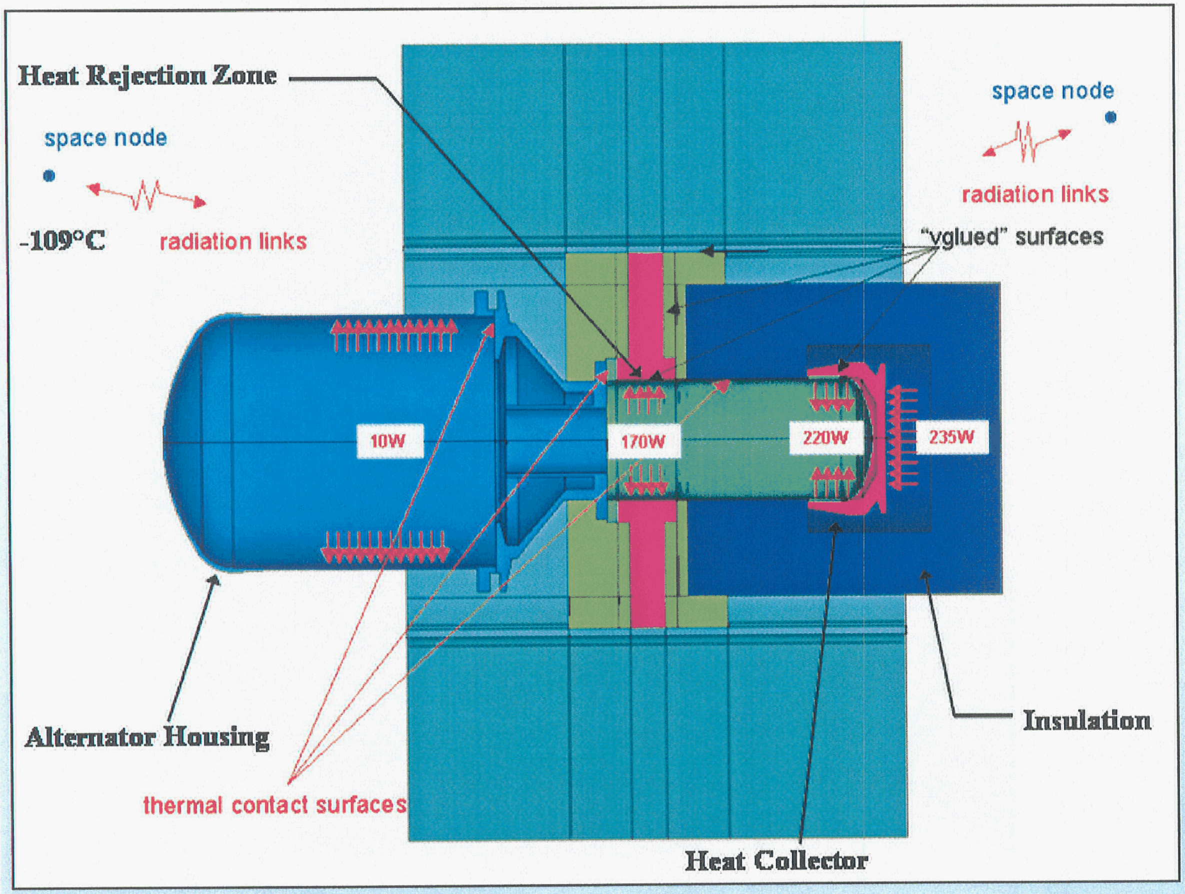
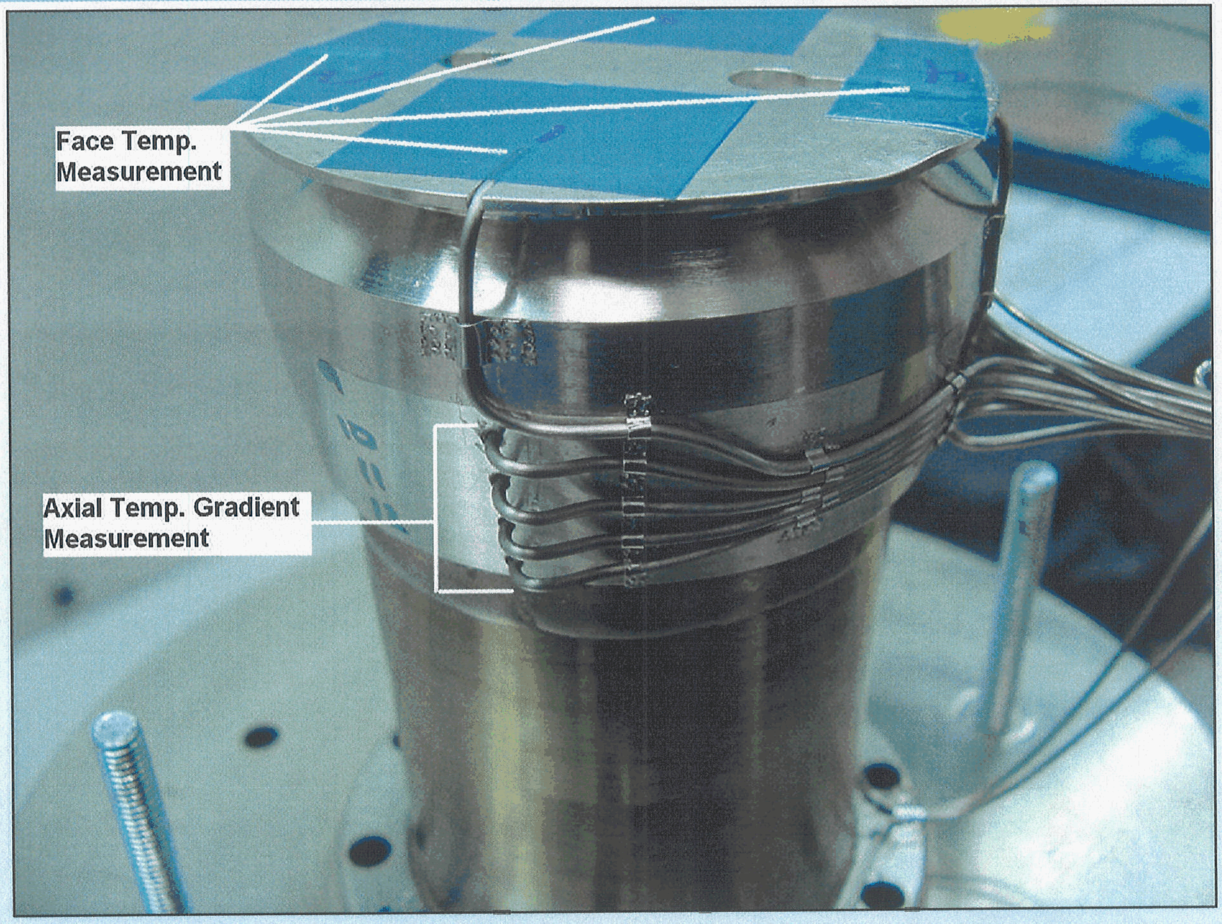


- **Simulated assembled test article inside cold wall**
  - Necessary to obtain estimates of operating temperatures for pressure vessel, magnets, hot & cold ends, and radiator panels.
  - Two radiator panel configurations: 8.5" & 11" long panels
  - 100% enclosure of test article by LN2 cold wall (simulated using space node)
  - Internal components of heater head not modeled
  - Internal heat generation by alternator and conduction into pressure vessel modeled by evenly distributed 10W on inner wall of PV along alternator length
  - 170W into ID of heat rejection flange
  - -109°C cold wall temp.
  - All surfaces radiate with respective emmisivities

Temperature Measurement

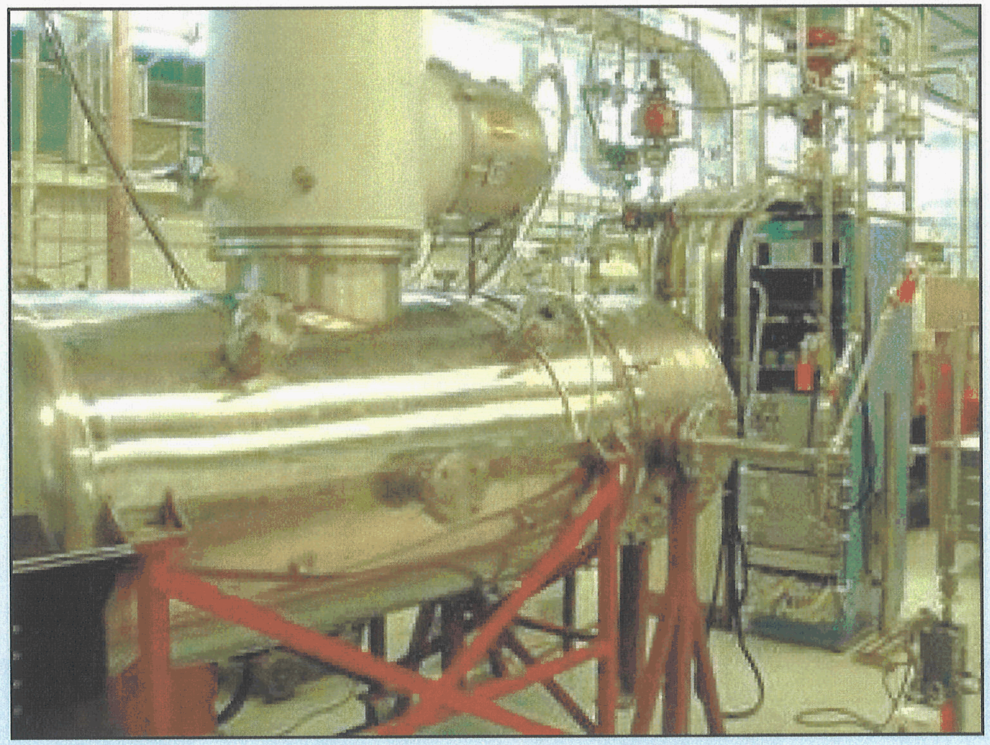
- **Instrumentation**
  - Cold end measured at two places near heater head / cold flange interface
  - Each radiator panel / flange interface temperature monitored
  - Heat collector face temp measured at four places around circumference
  - Axial temperature gradient along heat collector measured at two stations with four points per station
  - Type K & T thermocouples



Heat Collector Thermocouple Configuration

VF-67 Configured for Extended Ops

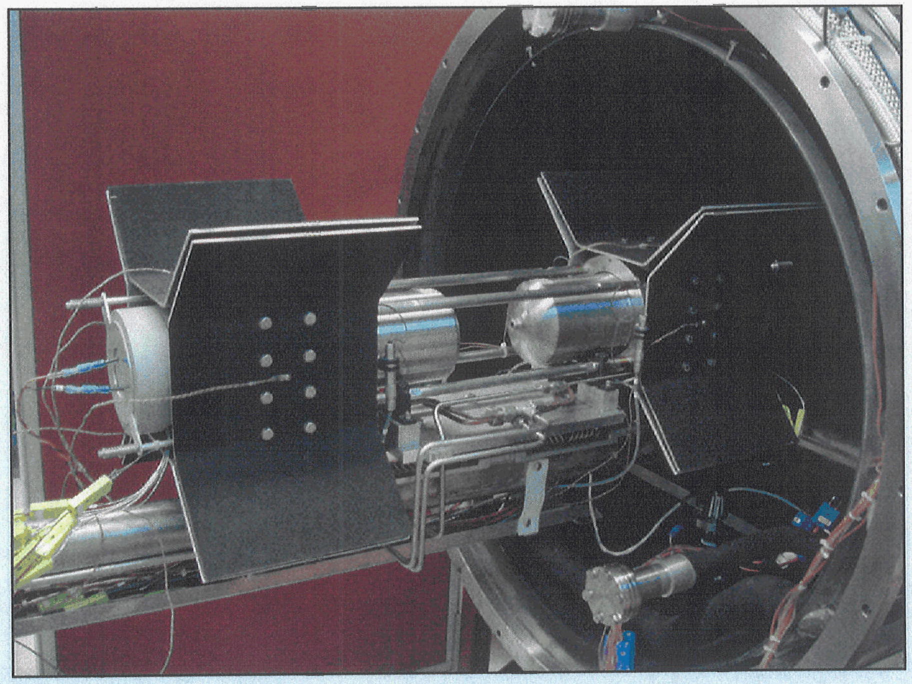
- Roughing pump coupled to Roots blower
- Leybold water-cooled Cryopump
- Liquid Nitrogen cooled cold wall
  - 100% enclosure of test hardware
  - LN2 feed from stationary 55,000 gallon dewar
- Valve, pump, LN2 flow controlled via touch-screen coupled to Programmable Logic Controller (PLC)
- PID loop controlling cold wall temperature via vent valve positioning
- Alarms and automatic operations programmed into PLC
- Vacuum level monitored in several different places, including inside cold wall near test article vicinity
- All operating conditions (temperatures, vacuum levels, valve/pump status) displayed on touch-screen panel
- Cold wall temperature monitored in 22 places
- LN2 inlet and outlet temperatures also monitored



Vacuum Facility 67

TDC's 5 & 6 – Thermal Vacuum Testing

- **Completed Items**
  - Test article installed in VF-67 with radiation panels
  - Electrical wiring complete and checked out
  - VF-67 vacuum and LN2 system buildup complete (5e-9 torr vacuum level attained)
  - Operated as cryocoolers for initial checkout
  - TDC's operated for 8 hrs. at low power under vacuum with LN2 shroud providing cooling
  - >60W_e output from each convertor



Test Article Assembly

- **Remaining Items**
  - 500 hr. bakeout (August '04)
  - Operation at full power and temp. (Sept. '04)
  - Begin continuous extended operation (September '04)