Overview of Multi-Layer Metal Insulation Development for Small Stirling Convertors at NASA GRC

NASA
Glenn Research Center

Daniel Goodell, Nicholas Schifer, Scott Wilson
Thermal Energy Conversion Branch (LET)

PROPULSION ENERGY FORUM

Background – 1 Watt Stirling Convertor Prototype

- Low Power – 1 Watt electrical output
- Radioisotope Power Source
- Two orders of magnitude less power than state-of-the-art convertors.

- Mass and size not a constraint for the development prototype

Heater Head (thin wall)
About 90 mm long

Hot end
350 C

Cold end
50 C

Linear Alternator

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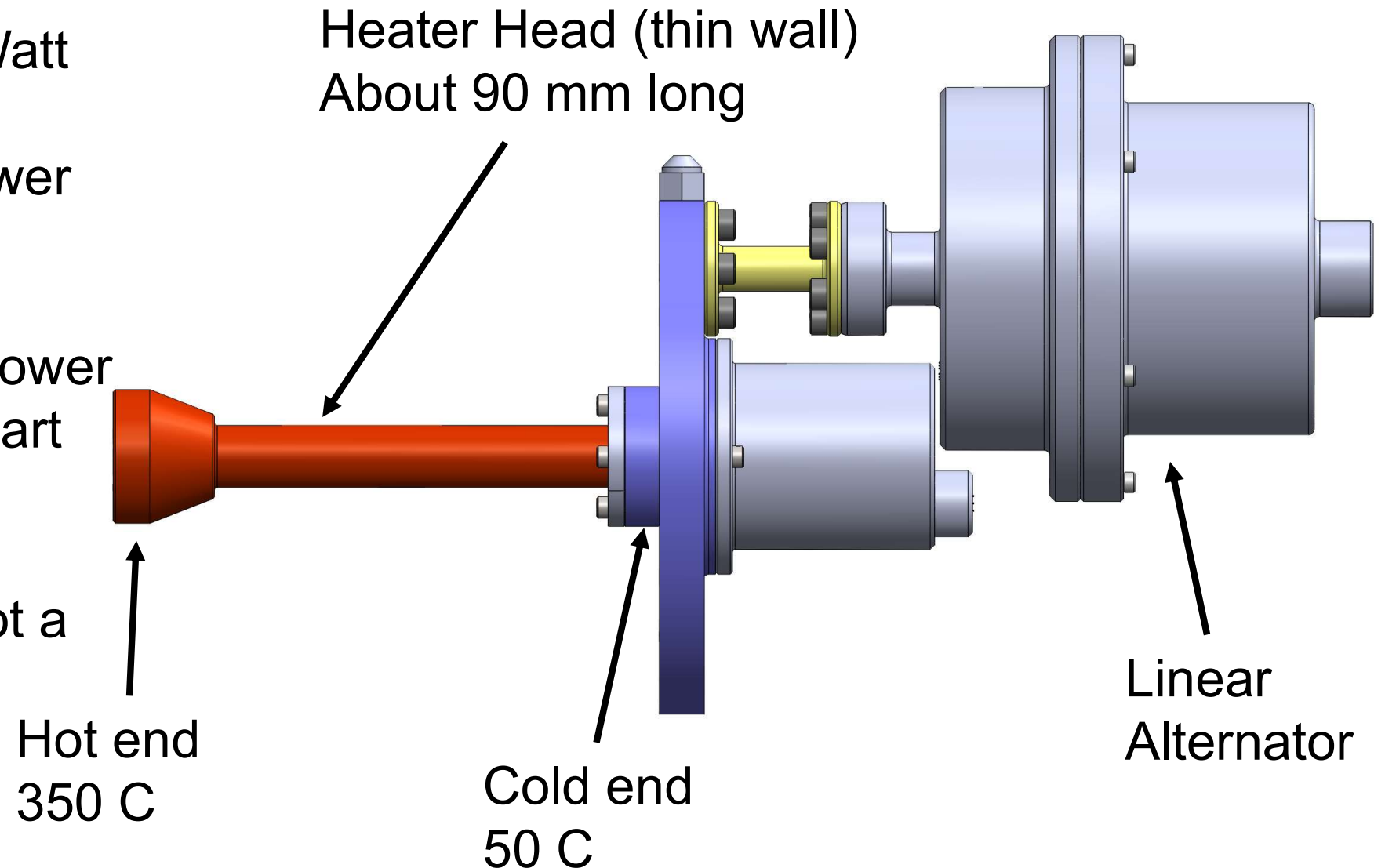
Background – Radioisotope Heat Sources

General-Purpose Heat Source (GPHS)
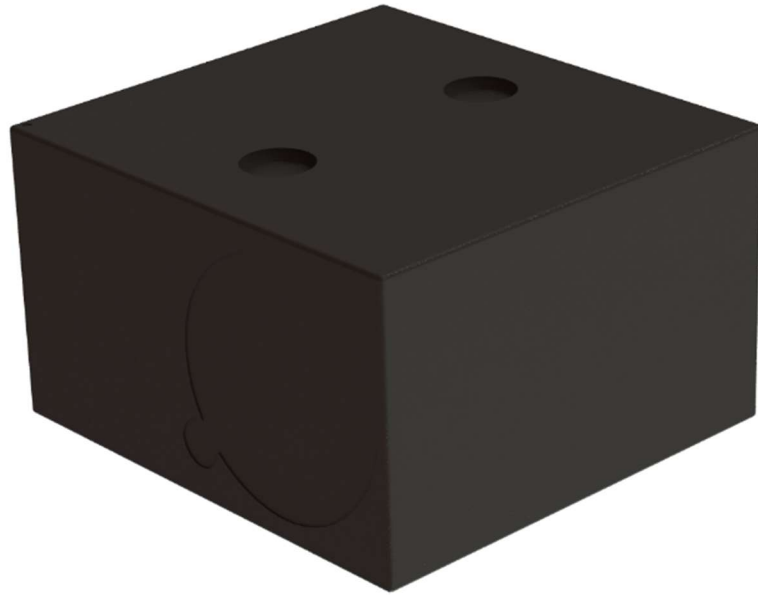
Heat Output:	250 W
Mass:	1770 g
Dimensions:	5.8x9.3x10 cm
Power Density:	0.46 W / cm^3
Power / Surface Area:	6000 W / m^2

Light-Weight Radioisotope Heater Unit (LWRHU)

Heat Output	1 W
Mass:	40 g
Dimensions:	h=3.2 cm, $\varnothing$=2.6 cm
Power Density:	0.059 W / cm^3
Power / Surface Area:	272 W / m^2

LWRHU has much lower power quality than the GPHS

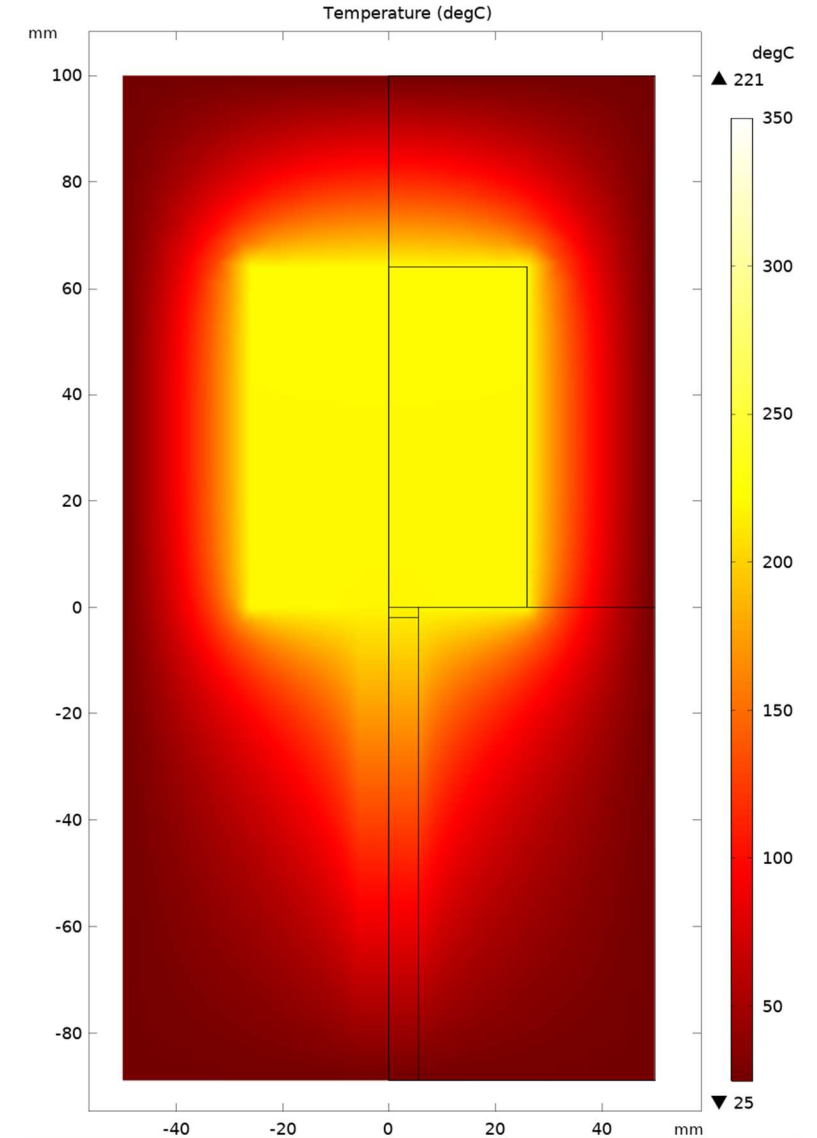Overview of Multi-Layer Metal Insulation Development for Small Stirling Convertors at NASA GRC

Problems

1. Microtherm HT ~ 0.02 W / m * K – not good enough

Need much better insulation for the engine to function.

2. Thin heater head cannot support the mass of a large heat source – Wall thickness is only 100 micron (0.004")
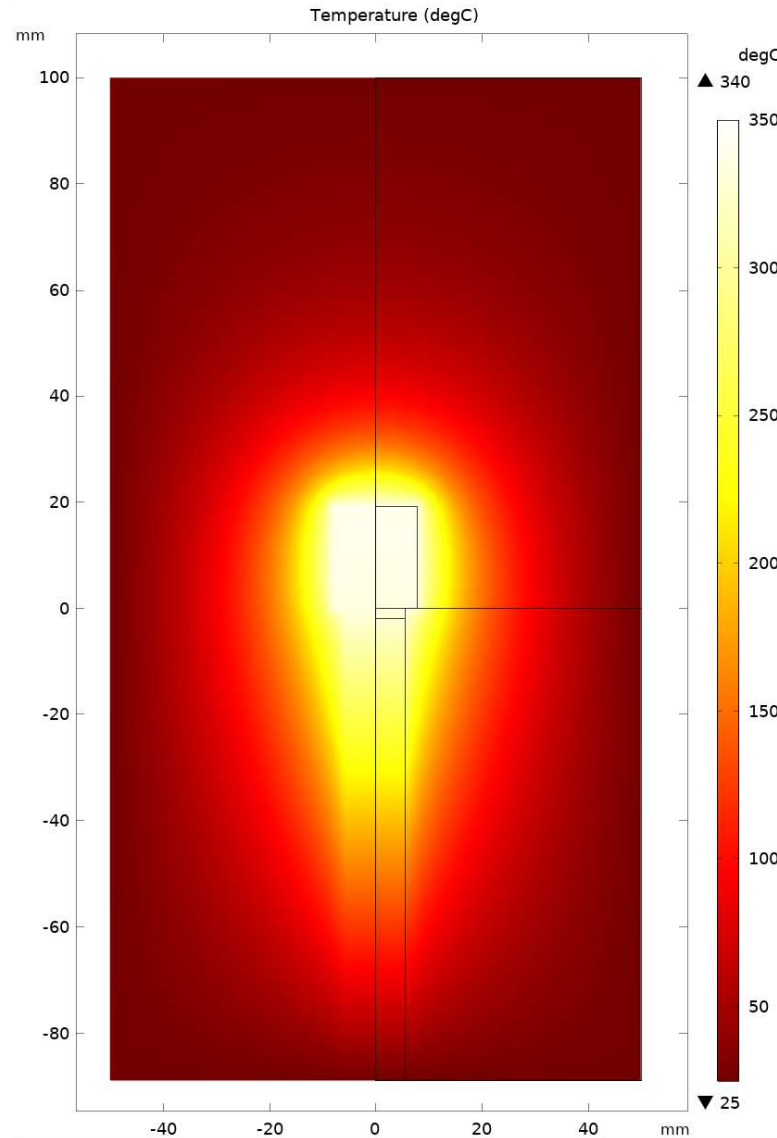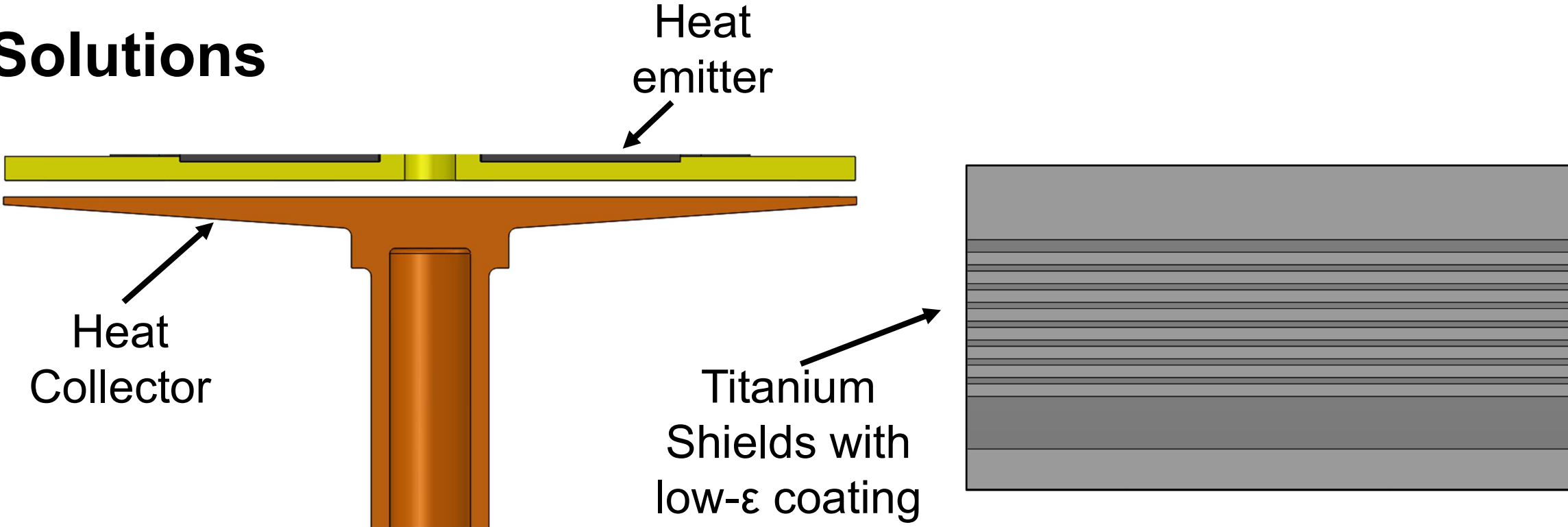

Lost through insulation: 1.5 W 3.9 W

www.grc.nasa.gov

Solutions

Heat emitter

Heat Collector

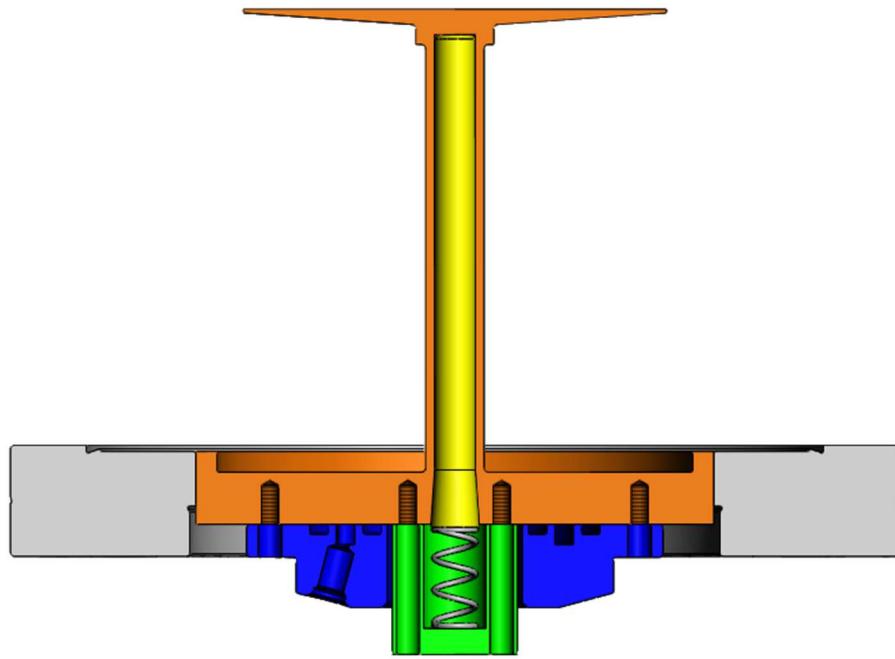Titanium Shields with low-ε coating

Radiative Coupling using large area heat collector.

Multi-layer Metal Insulation (vacuum)

Radiative Heat Transfer equation:

$$P = e\sigma A(T^4 - T_C^4)$$

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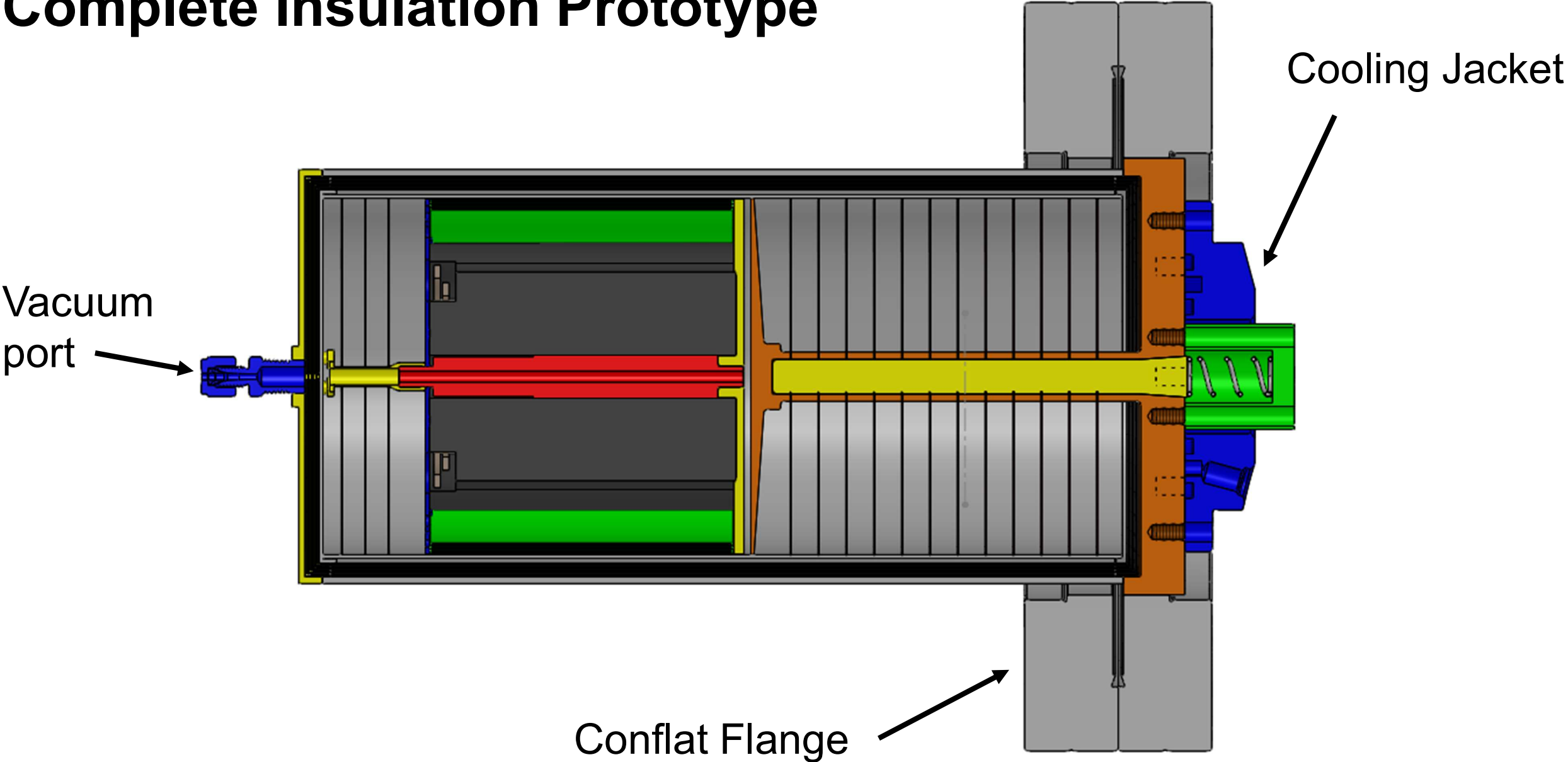
Prototype Development

Thermal Simulator Assembly

simulates 1 W Stirling convertor at full power

Electrical Heat Source

simulates 8 x LWRHU

Complete Insulation Prototype

Cooling Jacket

Vacuum port

Conflat Flange

Thermal Analysis of the Prototype

- Comsol model based on the design of the insulation package but does not include any conduction paths between the heat source and the outer case.

- Results show that this design can meet the design requirements if conduction losses are low and the foil emissivities are low.

- 18 cases run with different ambient conditions, and material properties.

- The largest unknown is the conduction losses. A comparison between the thermal model and test results will help to resolve this.

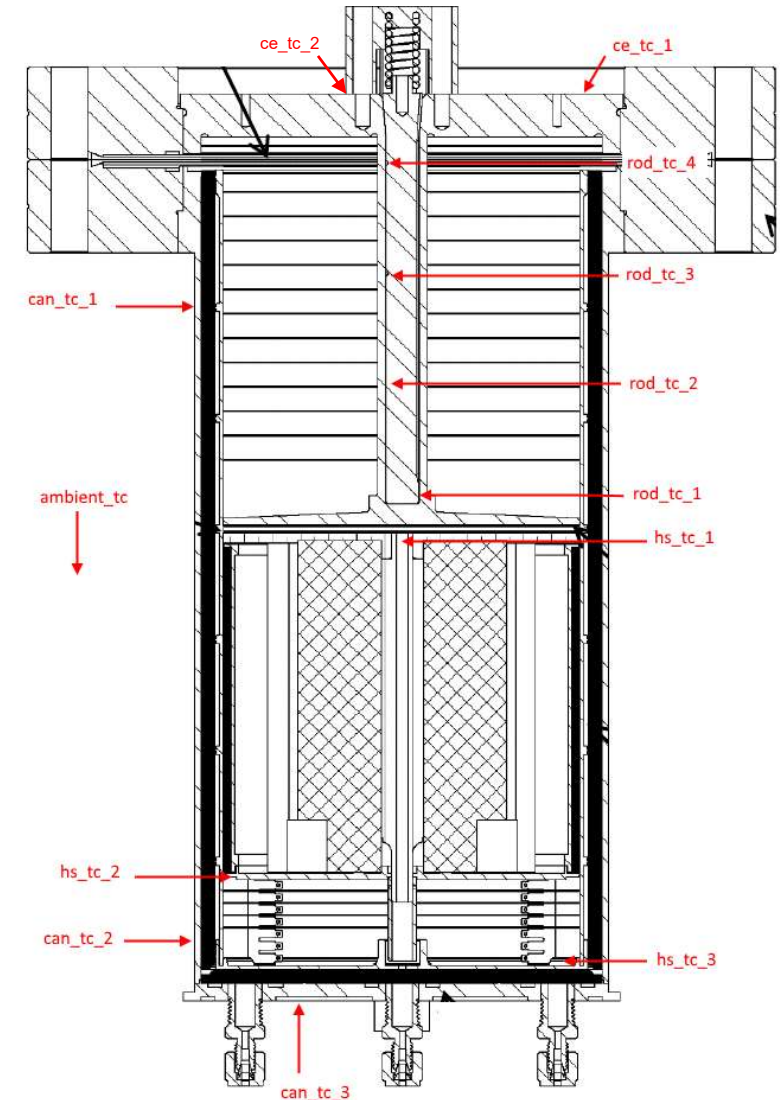|	
358.64	
342.81	
326.99	
311.16	
295.33	
279.5	
263.67	
247.85	
232.02	
216.19	
200.36	
184.54	
168.71	
152.88	
137.05	
121.22	
105.4	
89.57	
73.74	
50	
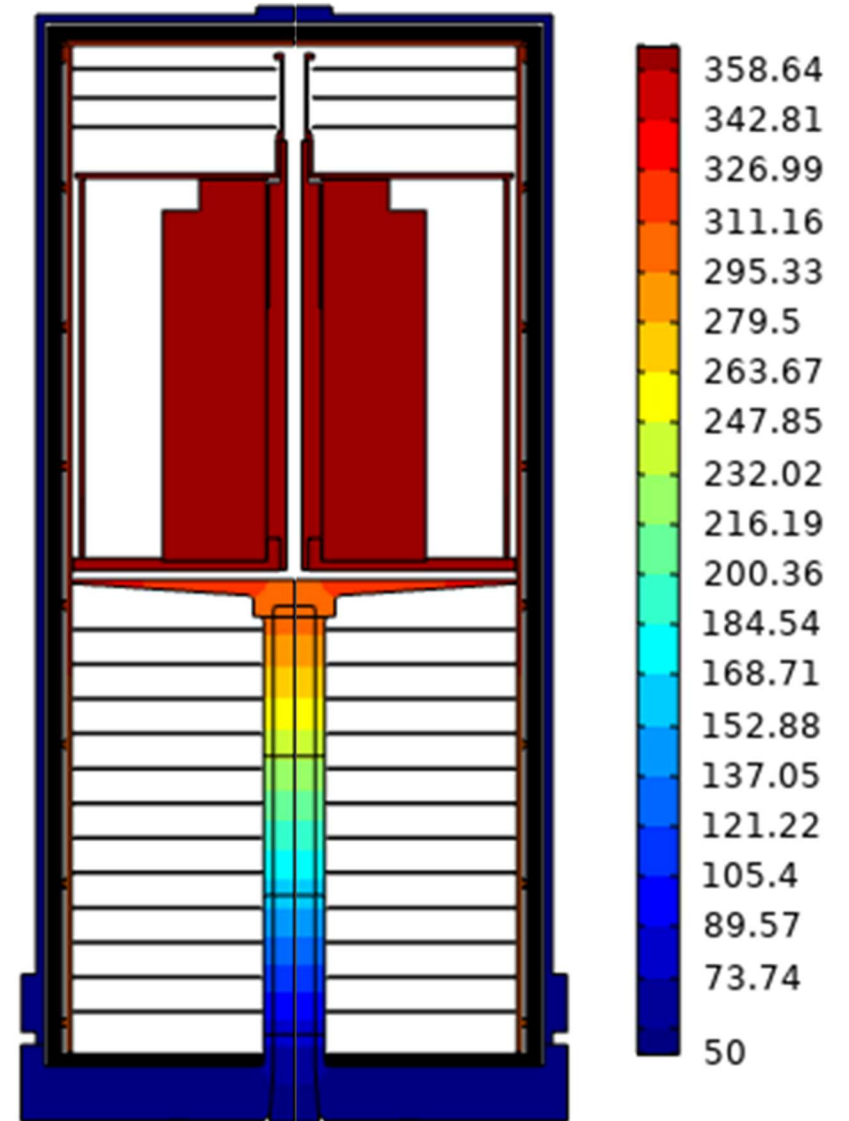
Testing

Test Setup:

- PID controlled heater

- Circulated chiller

- 13 thermocouples

- LabVIEW data collection

- High-vacuum, oil-free pumping station

Test Matrix:

- rod_1_tc :100-300 C

- 25 & 50 C circulator setpoints

Test Results

		100 C	150C	200 C	250 C	300 C
Rod 1 TC	C	99.3	150.8	200.7	251.4	300.3
Rod 2 TC	C	81.2	120.8	159.6	199.3	237.1
Rod 3 TC	C	61.4	87.5	113.3	140.3	166.1
Rod 4 TC	C	39.6	50.3	61.1	72.6	84.0
Heat Source TC	C	182.1	250.2	314.9	363.4	407.5
Cold End TC	C	25.1	26.9	27.9	29.2	30.8
Outer Case 1 TC	C	33.7	42.0	51.2	66.3	90.6
Outer Case 2 TC	C	31.6	38.8	47.3	62.1	86.8
Outer Case 3 TC	C	28.6	33.8	40.1	52.1	73.0
Electrical Heat Input	W	**5.8**	**10.6**	**16.2**	**25.5**	**40.6**
TS Heat Flow Calc.	W	1.5	2.5	3.4	4.4	5.3
Ins Heat Loss Calc.	W	4.3	8.1	12.7	21.1	35.3
% Through Insulation	%	74.5	76.6	78.8	82.9	87.0

Goal: <= 1.5 W insulation loss at 350 C
Prototype: 35 W insulation loss at 300 C

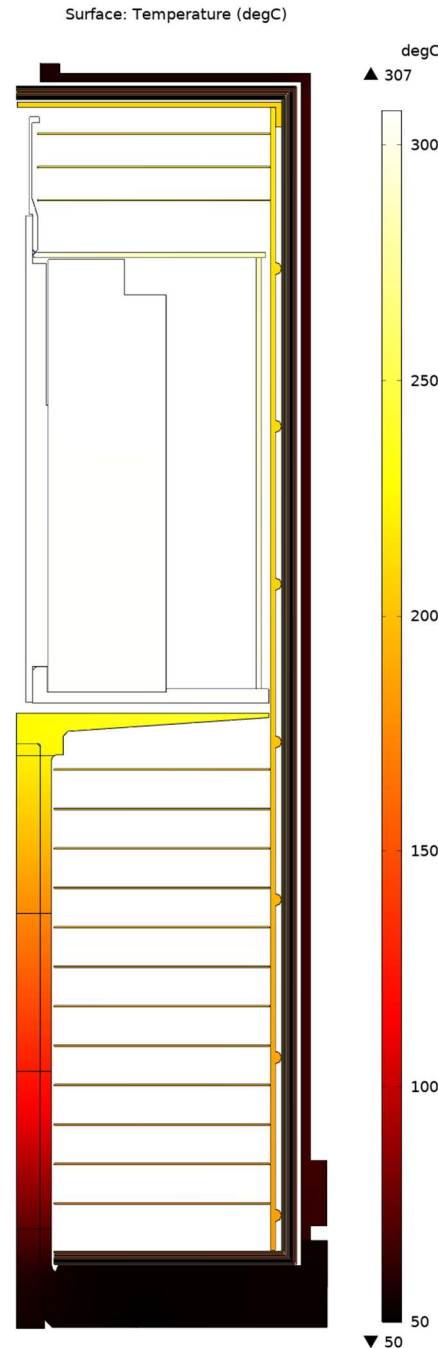Heat through Engine
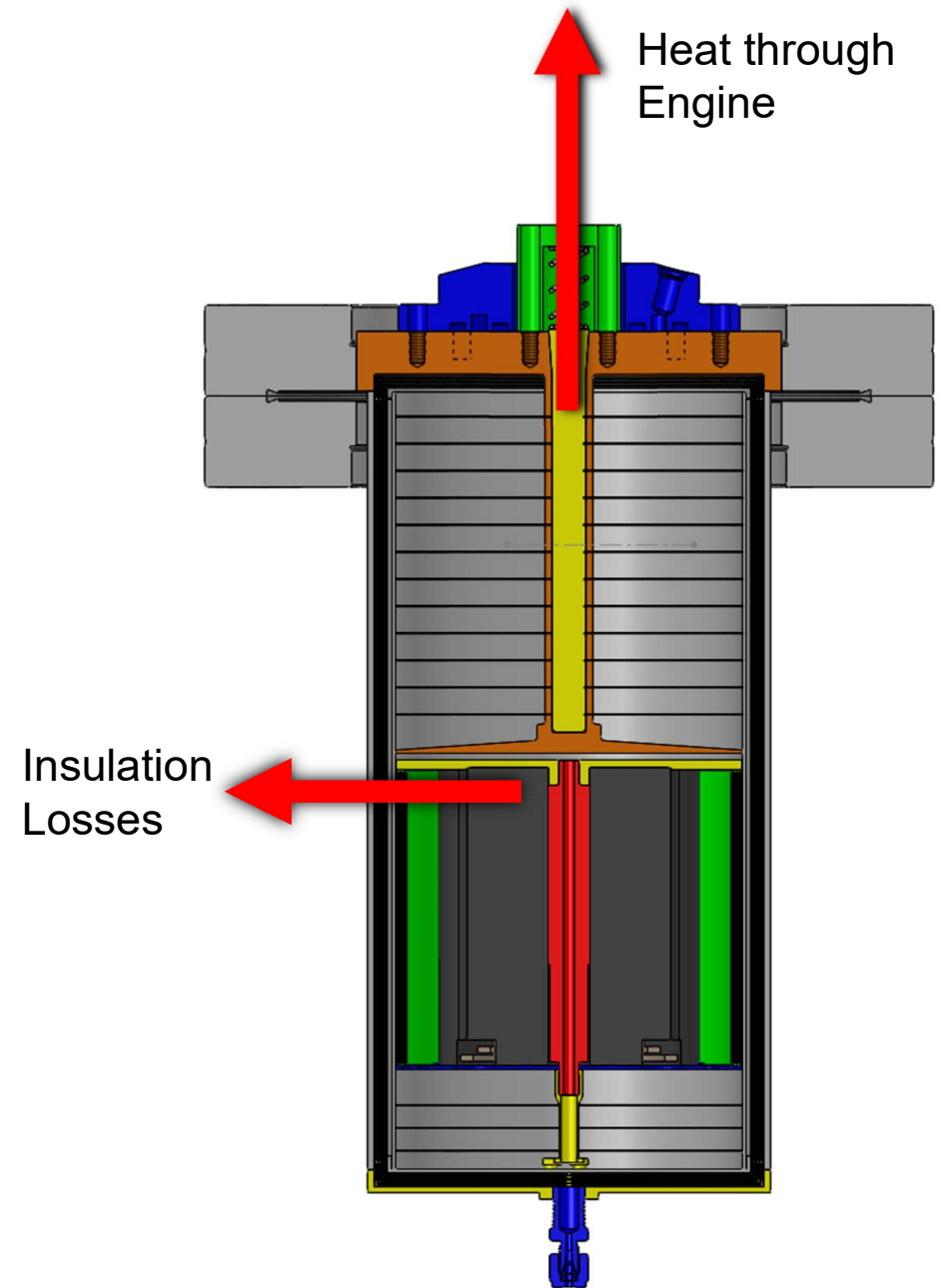
Insulation Losses

Comparison With Model

The model only includes radiation losses from the heat source, the conduction is not modeled.

The model was adjusted to match a test point. The difference in heat inputs is the conductive insulation loss.

Conduction losses are much larger than expected. This suggests that either the insulation has much more conduction than expected or it is not well evacuated.

Surface: Temperature (degC)

		Model	Test
Heat Source TC	C	306	308
Outer Case 1 TC	C	65.0	66.9
Outer Case 2 TC	C	57.0	57.5
Rod 1 TC	C	221	223
Rod 2 TC	C	175	181
Rod 3 TC	C	126	135
Rod 4 TC	C	73.0	82.5
Cold end TC	C	52.0	49.7
Electrical Heat Input	W	10.2	22.2
Heat Through Engine	W	3.64	3.67
Insulation Loss	W	6.6	18.6
% Insulation Loss	%	64.3	83.5

Estimated conduction losses 18.6-6.6 = 12 W

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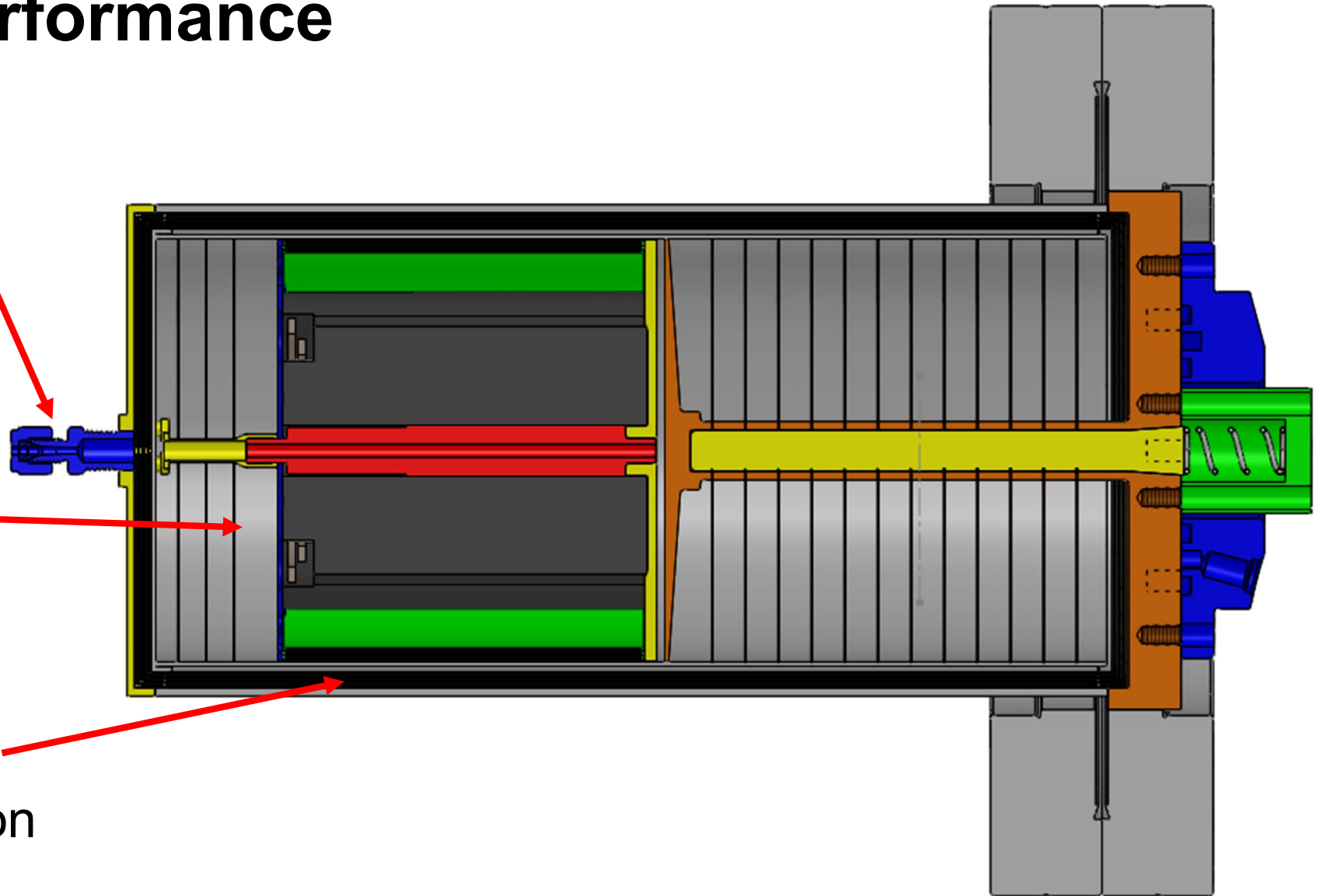
Problem - Underperformance

1. Long pump down times due to small port. 0.022" (0.56mm) inner diameter

$$\text{pumping rate} \propto \frac{d^3}{l}$$

2. Unknown vacuum level inside the insulation package.

3. Cylindrical shield emissivities higher than the expected 0.1. Actual value estimated to be 0.6 based on assembly images.

Next Steps

- Larger vacuum port & direct vacuum level measurement

- Disassemble package, understand the actual emissivities of the materials and update model with this info to increase accuracy.

- Modify the insulation prototype to improve some material properties, such as improving shield emissivity.

- Once we fully understand the performance of our prototype we will design and manufacture a more accurate prototype.