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POWERING THE FINAL FRONTIER

Assembly, Integration, and Initial Test Results of the Stirling Generator Testbed

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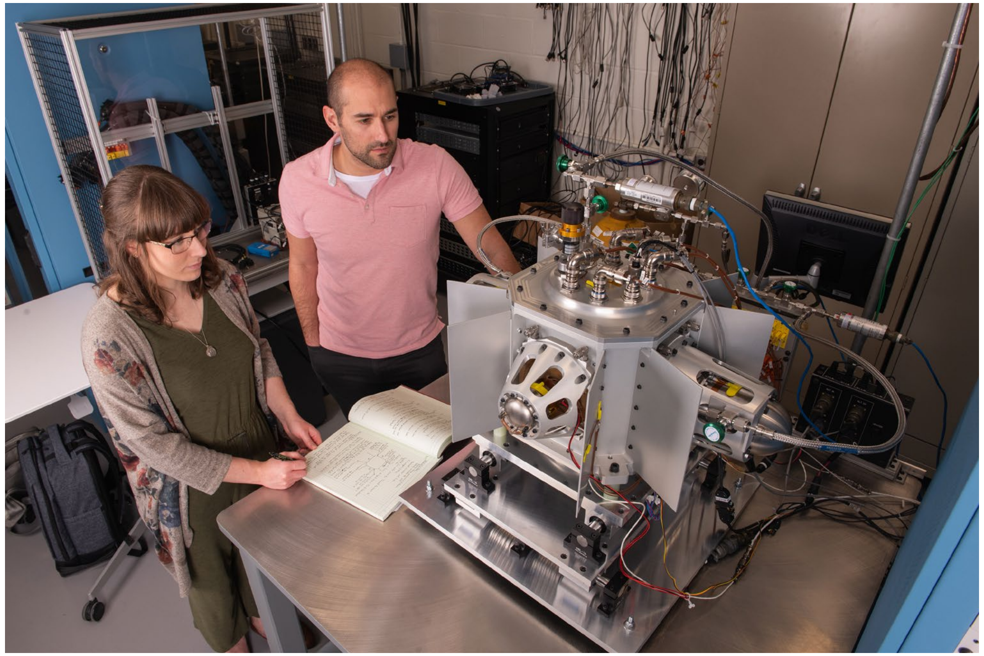
Background

NASA GRC has initiated operation of a multi-convertor Stirling generator testbed

Enables new types of experiments to demonstrate Stirling RPS topology

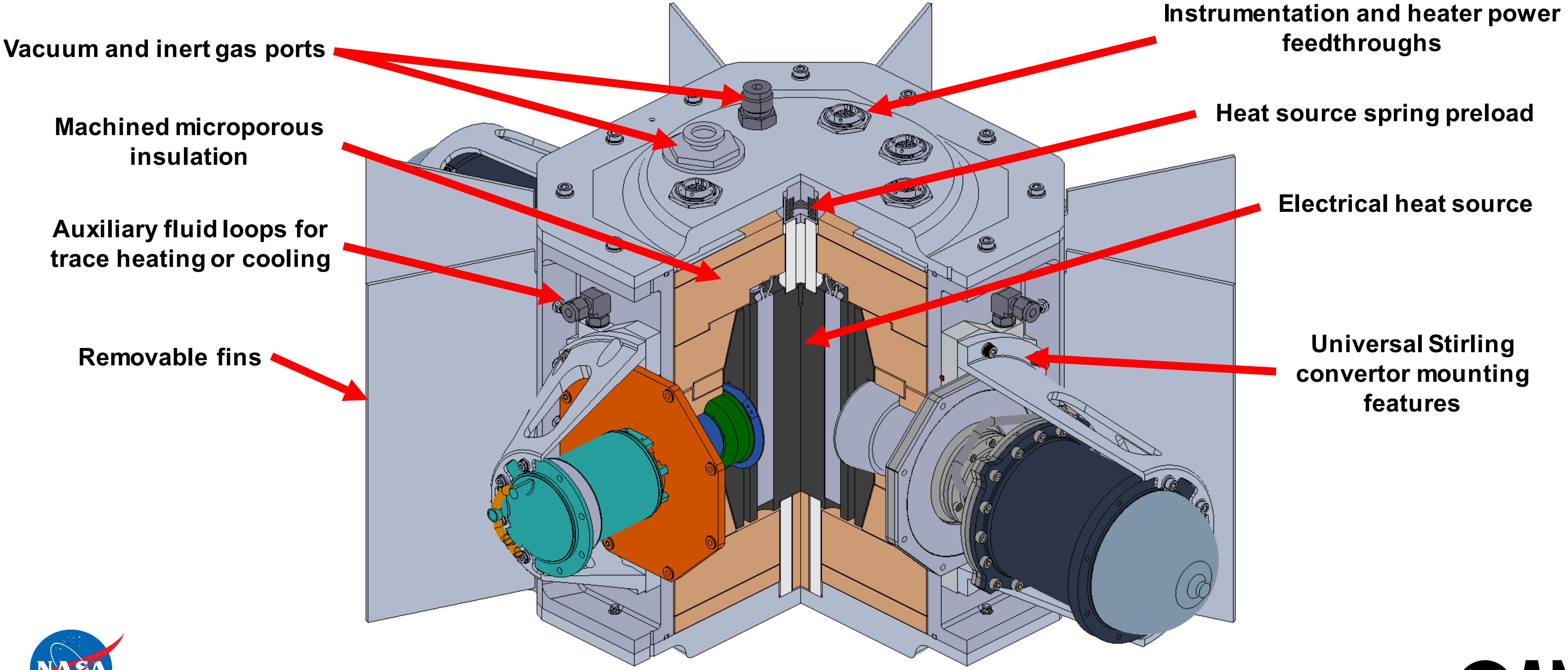
- Flexible for installation of many convertor types
- Demonstrate latest convertor-redundant topology
- Arrayed convertors with central heat source
- Radiantly coupled heat source
- Electrical heat source sized for 3 GPHS modules
- Maintain cold-end of convertors below 100°C
- Capable of in-air natural convection and thermal vacuum
- Optional auxiliary cooling via pumped loop
- Replaceable housing fins
- Internal inert cover gas or evacuated
- Initial assembly iteration uses two pairs of differing Stirling convertor designs
- **Assembly completed and first operated in May 2023**



NASA GRC's in-house developed Stirling Generator Testbed – Installed on test station

Stirling Generator Testbed Features

Emulates the most recent trend for Stirling RPS configuration: Redundant convertor array around a central heat source



NASA GRC's in-house developed Stirling Generator Testbed – Section view

Test Plans

Enables new generator-level test capability

1. **Baseline performance measurement** – All four convertors operational, 2-GPHS (500 W_{th}) source, then adjust convertor piston amplitude to maximize power output from the generator
2. **Thermal insulation loss characterization** – Measure the amount of heat lost from the source
3. **Convertor pair failure simulation** – Stall one pair of convertors, and throttle the remaining pair to maintain power output
4. **Performance optimization** – Demonstrate method for maximizing system efficiency while the heat source decays (can be constant convertor hot-end temperature, or constant piston amplitude).
5. **Off-nominal thermal environment** – Demonstrate capability with nonuniform heat rejection such as when one side is facing the Sun and the other deep space.
6. **Launch ascent simulation** – Demonstrate capability to survive the thermal transient that results from cover gas removal during launch ascent.
7. **Phase range characterization** – Deliberately force the phase of the convertors to be off nominal, to measure the worst case residual disturbance force

Assembly – Heat Source

Simple and inexpensive heat source proven capable for the Testbed

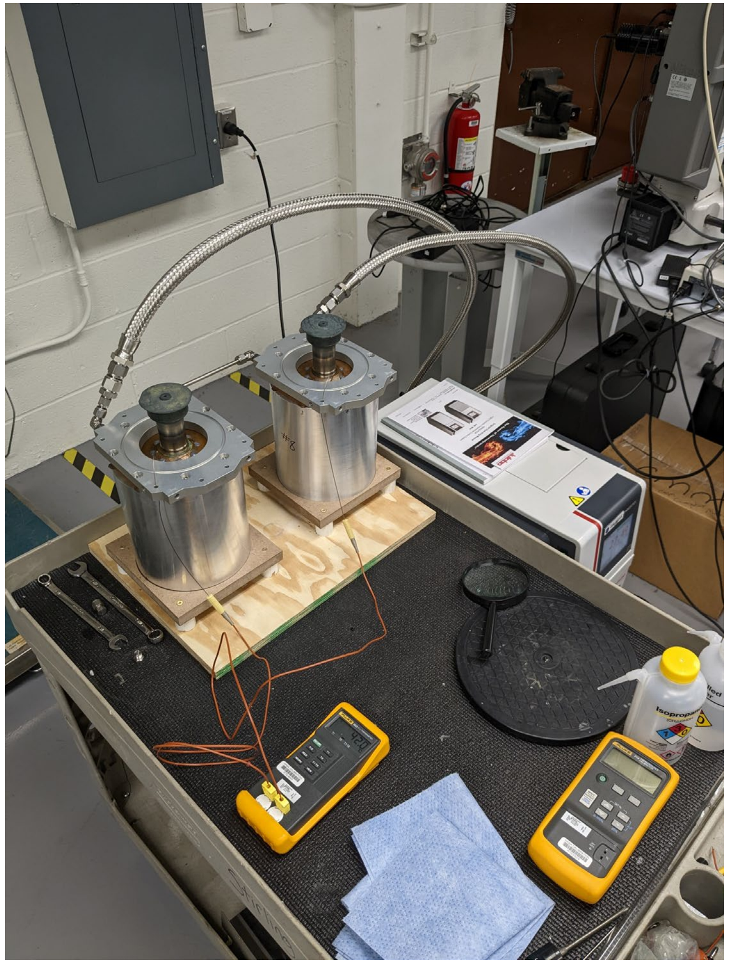
- Graphite block
- Nichrome element cartridge heaters
- Minimized heat flux to maximize heater life
- High-emissivity coating applied to surfaces
- Capable of at least 1500 W_{th} output
- Dedicated thermocouple channels
- Welded nickel bus bar interconnects
- Geometry of 3 GPHS modules
- Check-out tested up to 300C in-air

Electrical multi-GPHS simulator

Assembly – Convertor Preparation

Sunpower Advanced Stirling Convertors (ASCs) needed flange joint leak paths addressed

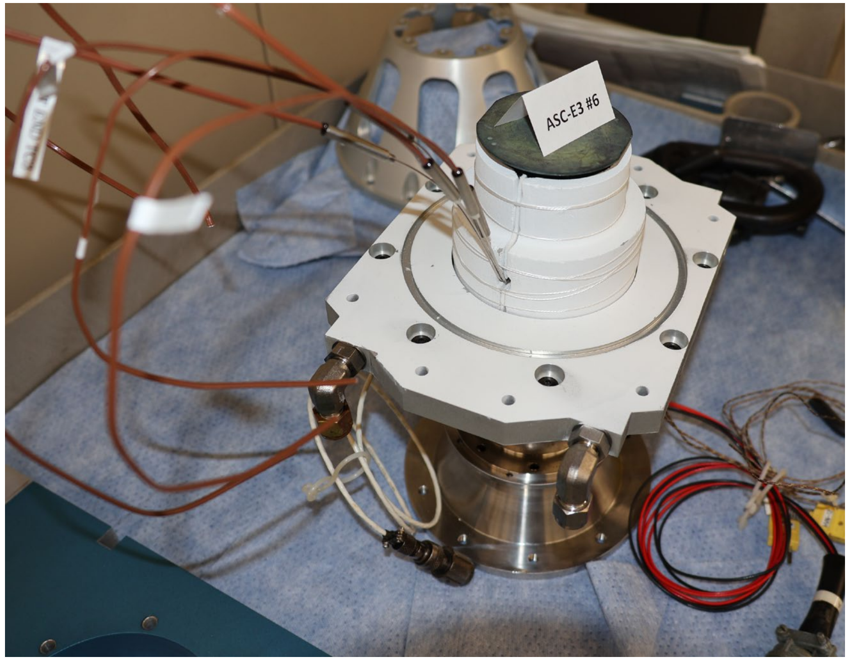
- Heat rejection flange of ASCs was not designed to seal generator housing pressure boundary
- (Convertor working gas is still hermetically sealed)
- Braze joint and fastener pattern leak paths
- Required sealing to engage interior-vacuum option
- Spent several months attempting to seal
- Could not achieve sufficient seal to use interior vacuum option, reverted to inert gas fill (Argon)



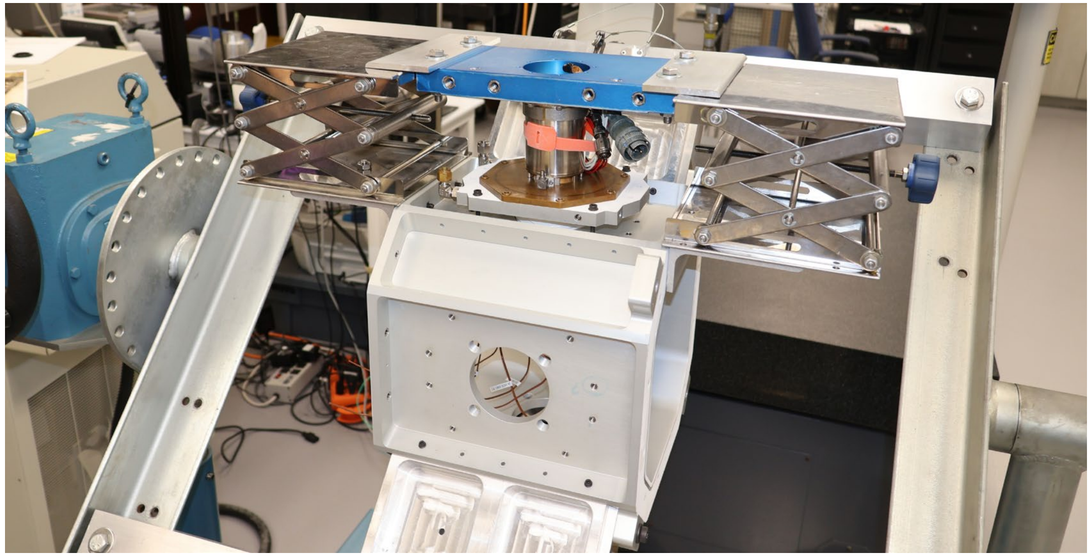
Leak check vessels for ASCs

Assembly

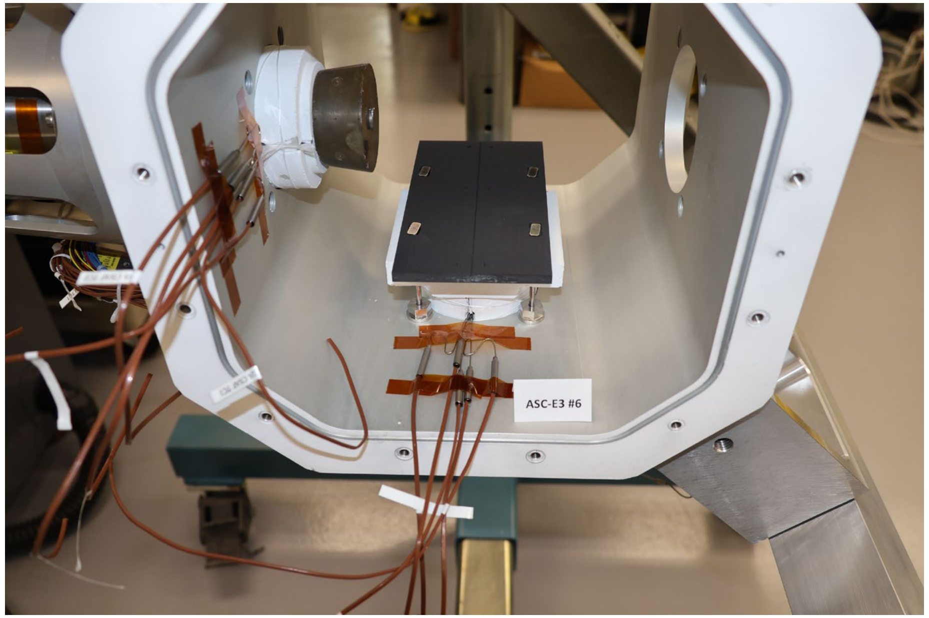
Thermocouple installation



Hot-end clamshell insulation

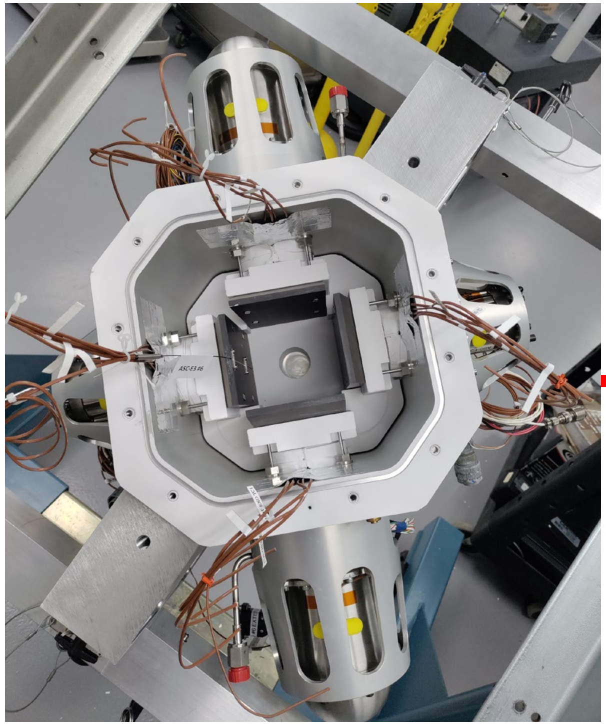


Scissor-jack mechanism for convertor insertion

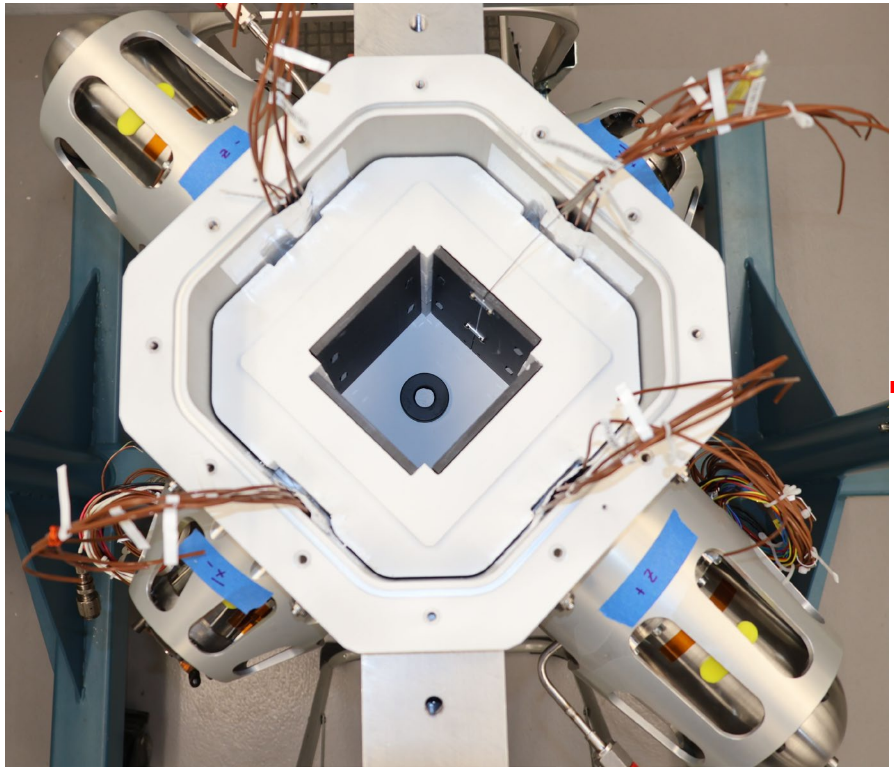


Spring loaded heat collector plate install

Assembly



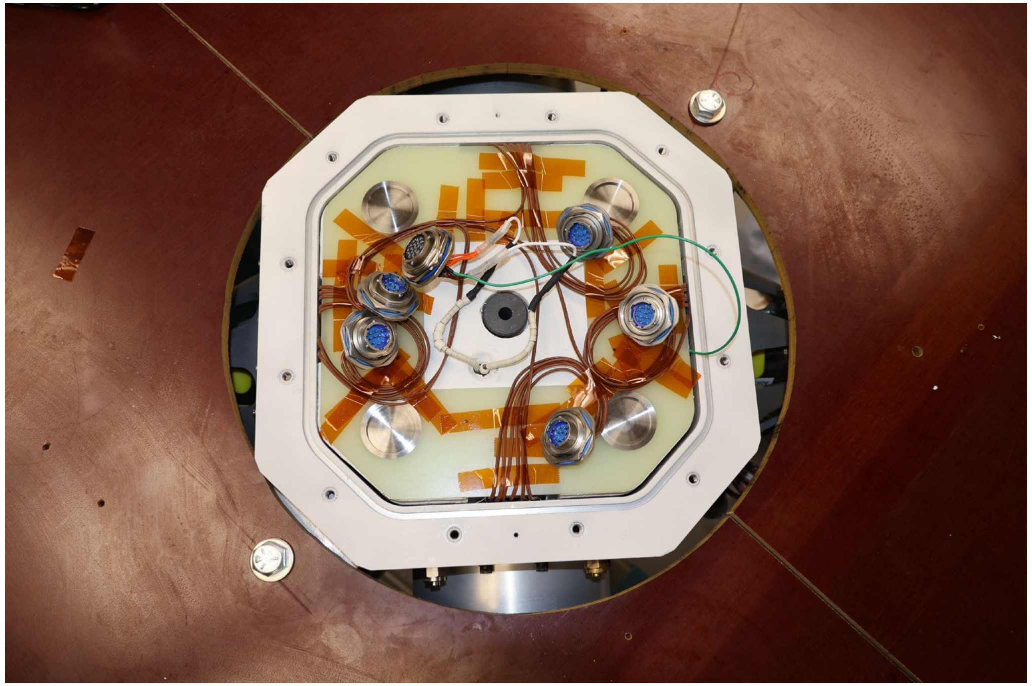
Thermocouple wire routing



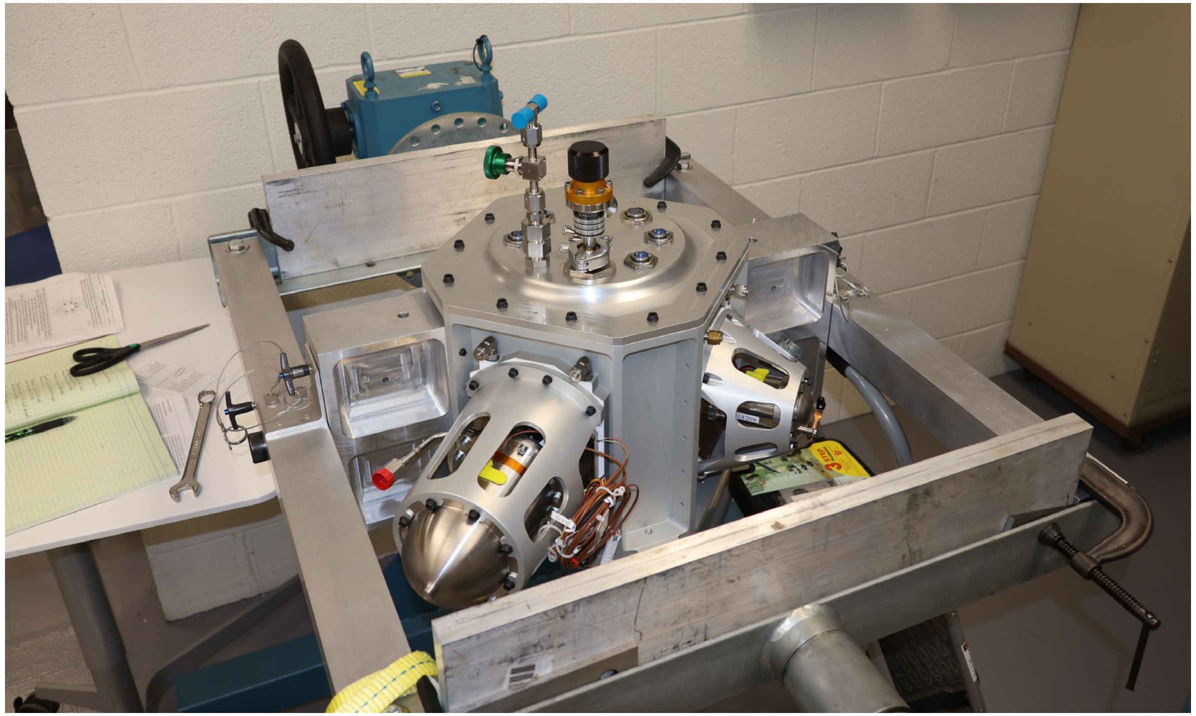
Placing machined microporous insulation pieces

Inserting electric heat source

Assembly



Feedthroughs wired

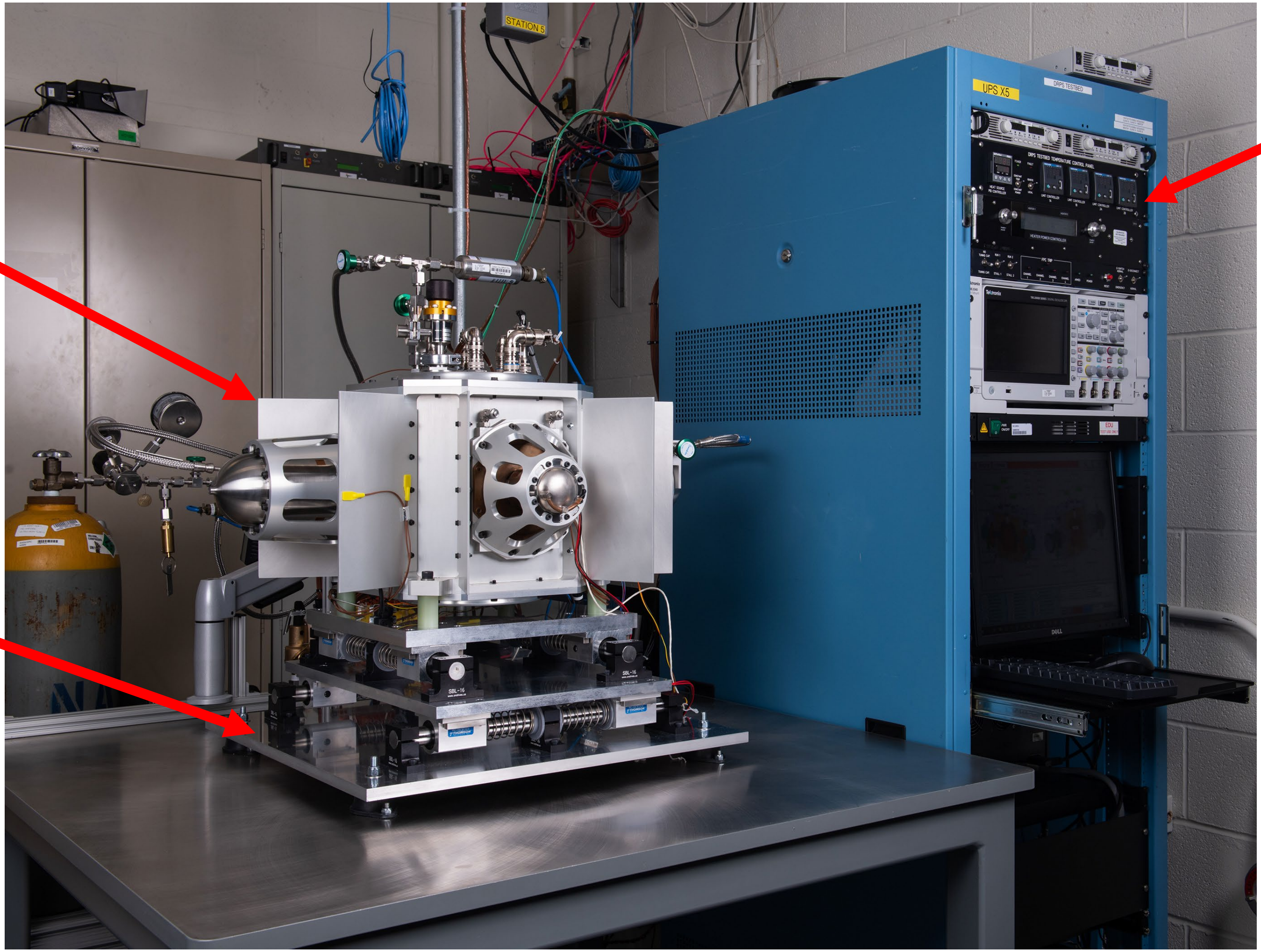


Assembly complete

Assembly

Assembled mass
60.5 kg
(unoptimized)

3 DOF isolation
mount



4-convertor test
support
equipment rack

Installed at test station

Checkout Testing

Target Operating Point

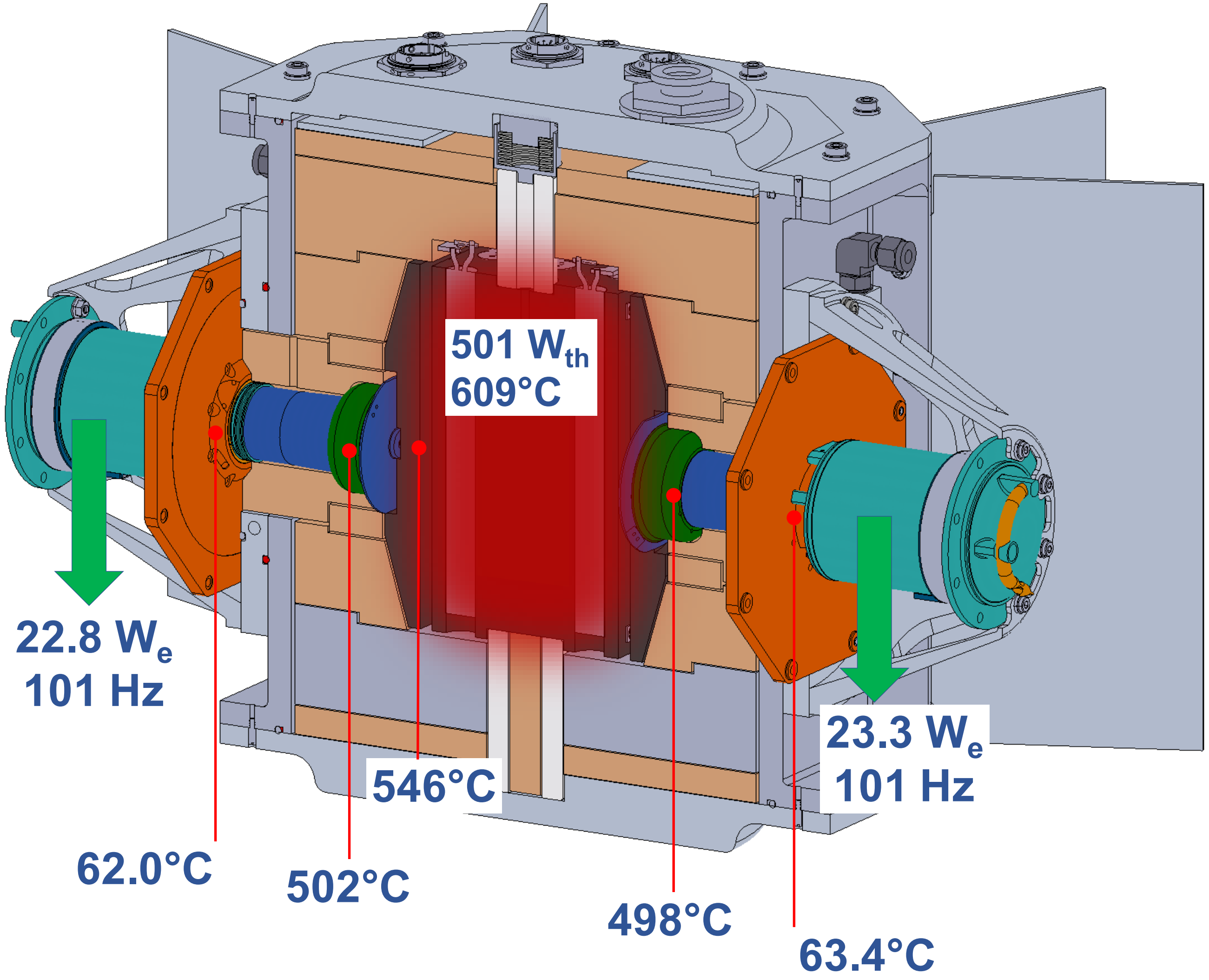
- 500 W_{th} , constant heater power (simulating 2 GPHS modules)
- Modulate convertor piston amplitude until 500°C hot-end temperature is achieved
- (Stirling convertors operating at less than half nominal throttle)
- 23 psia argon cover gas
- Attended operation for first 24 hours
- No auxiliary fluid loop cooling (rely only on housing radiation and natural convection)

Results

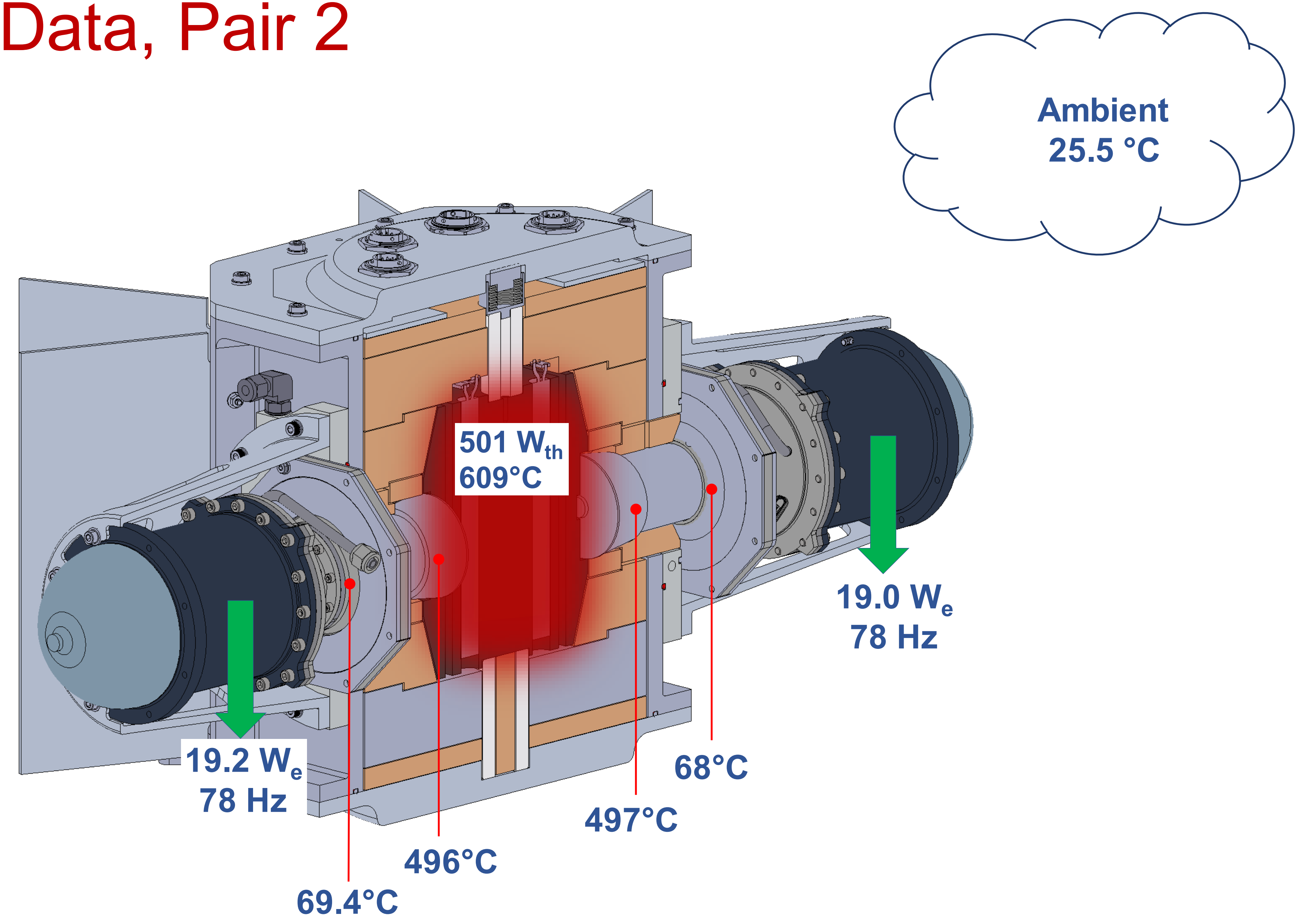
- **Output power: 84.3 W_e, 16.8% gross efficiency, 1.4 W_e/kg**
- Unoptimized operating point, performance will improve in later expolrations
- Thermal design of housing heat rejection validated
- Heat source radiant heat transfer design validated
- Imperceptible residual imbalance, no detriment of differing pair operating frequencies
- 4-convertor test support equipment and new procedures validated

Performance Data, Pair 1

Ambient
25.5 °C



Performance Data, Pair 2



Conclusion

- Multi-year effort to design, build and test a convertor-redundant generator test article was successful
- Most recently studied Stirling RPS topology was demonstrated viable
- Engineering of generator-level features validated
  - Radiant heat transfer for thermal input
  - Passive cooling for heat rejection
- Performance potential demonstrated, with many opportunities for improvement
- Test article will be used to perform planned sequence of investigative experiments
  - Thermal insulation efficiency measurement
  - Operating point optimization
  - Failure simulation and response