



NASA GRC Stirling Research Lab

University of Tennessee, Knoxville
Guest Lecture (virtual)
December 4, 2025

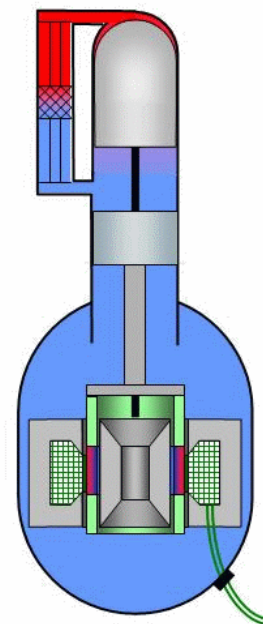
Tyler R. Steiner, PhD.
Thermal Energy Conversion Branch
NASA Glenn Research Center
tyler.r.steiner@nasa.gov

Dynamic Radioisotope Power – *Stirling Conversion*

- The efficiency of conversion from thermal to electrical can be increased significantly by using the Stirling thermodynamic cycle
 - Alternate heating and cooling on volume of gas creates a pressure wave that drives a piston attached to an alternator
 - Heat can be supplied by any source – radioisotope
 - Cooling must also be provided for the waste heat portion of the cycle –radiant heat transfer to space
 - Up to 40% thermal-to-electric efficiency
 - Dynamic : has moving parts

Cycle operation:

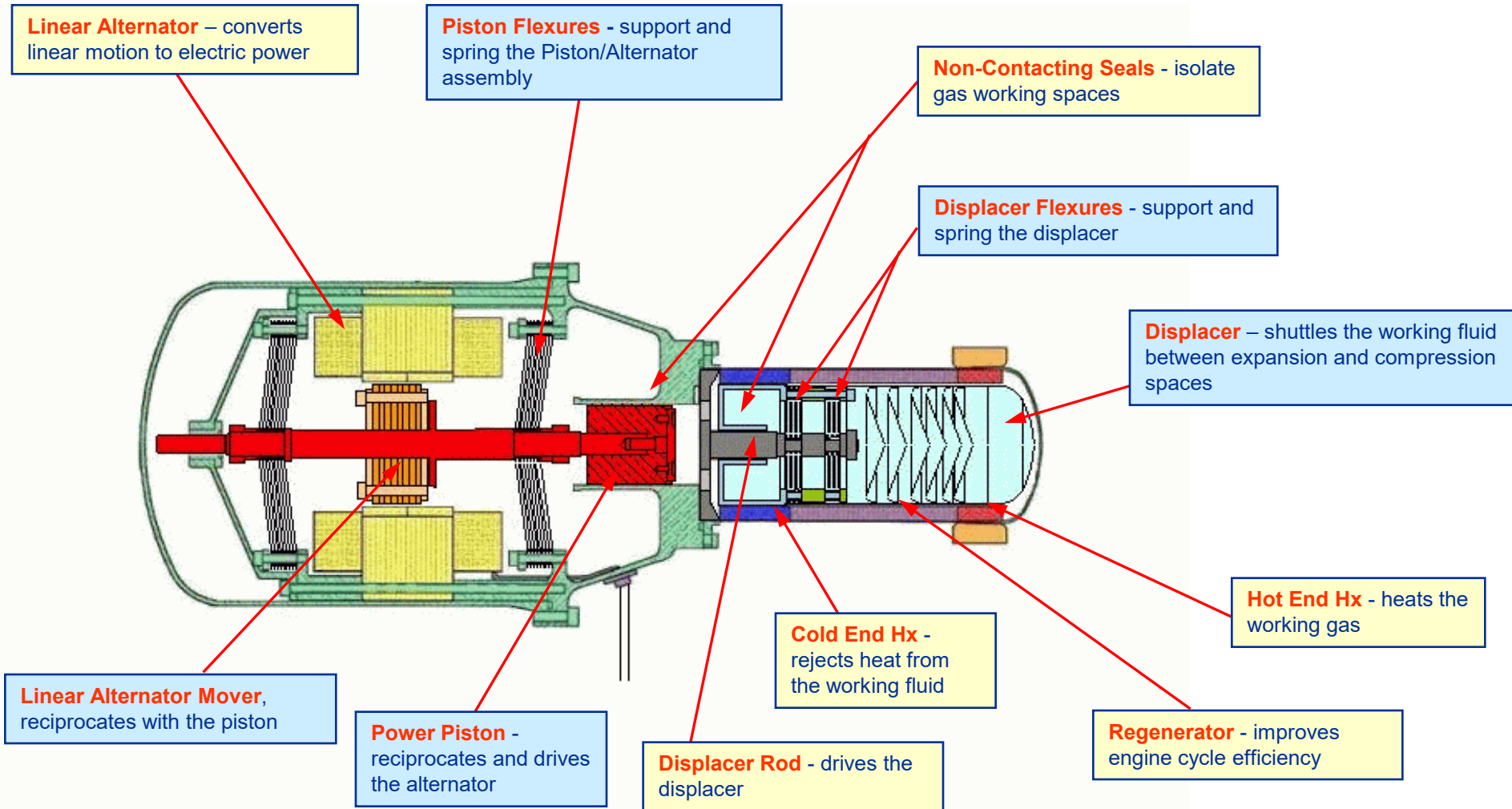
- A displacer shuttles gas between the hot and cold ends to raise and lower the gas pressure
- With displacer at the top, gas is pushed towards cold end, lowering the pressure
- With displacer at the bottom, gas is pushed towards the hot-end, raising the pressure
- The piston's mechanical energy can then be utilized as desired – for electrical power it is coupled to an alternator
- The motions of the piston and displacer can be controlled by mechanical linkages (kinematic) or by the working gas pressure (free piston)
- NASA is developing free piston Stirling convertors – eliminates wear mechanisms



Radioisotope Power – *Free-Piston Stirling Conversion*

- Non-contacting operation of a **flexure-based** Stirling conversion device

Moving Components in blue

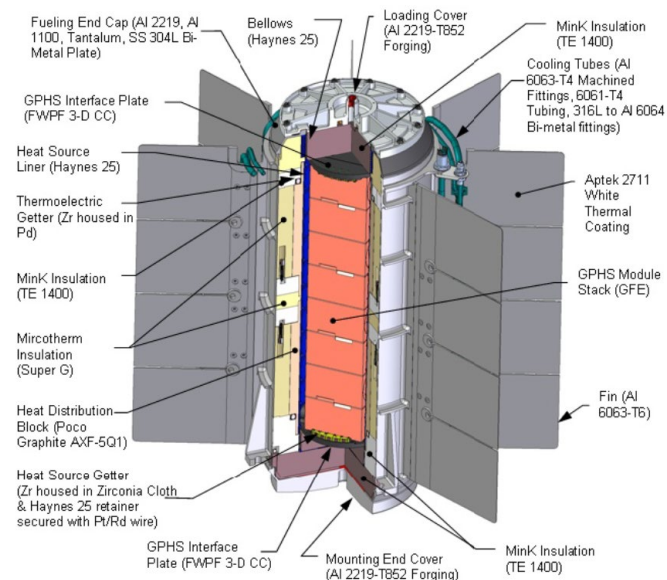
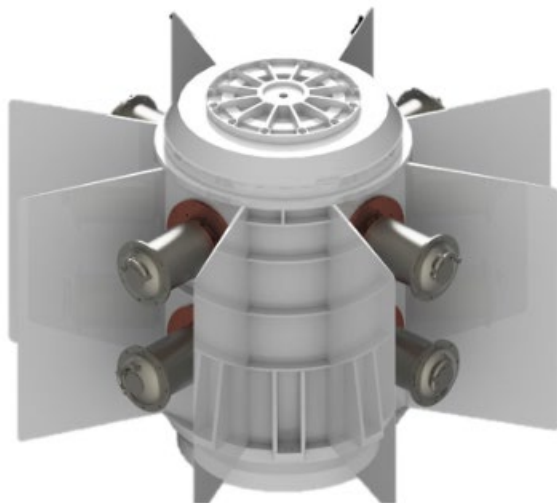


Stirling TDC manufactured by Infinia, Corp.

DRPS and RTGs

DRPS	RTGs
Efficiency > 20 %	Efficiency > 5 %
Successful environmental testing on Earth	Successful space missions
“very little conversion degradation”	4 %/year degradation: thermoelectrics
Demonstrated kW	Demonstrated hundreds of W
OD (fin-to-fin): 30 in. Height: 30 in.	OD (fin-to-fin): 25 in. Height: 26 in.
2.6 We / kg	2.8 We / kg

MMRTG





Dynamic Radioisotope Power – “Mission” Scope

- Aerojet Rocketdyne was awarded a one-year design contract in 2021

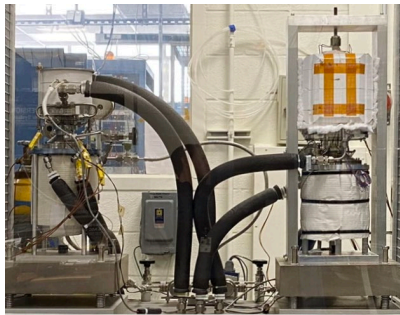
Item	NASA Requirement	AR System Model
Design life	17 years	> 17 years
Power output BOL	300 W _e	293 W _e
Power output BOM	289 W _e	284 W _e
Power output EODL	241 W _e	242 W _e
Conversion eff.	> 20 %	19.5 %
Specific power	> 2 W _e / kg	2.6 W _e / kg
Mass	< 150 kg	112 kg

BOL =	beginning of life =	0 years after fueling
BOM =	beginning of mission =	3 years after fueling
EODL =	end of design life =	17 years after fueling

- SRL has long history of testing Stirling convertors

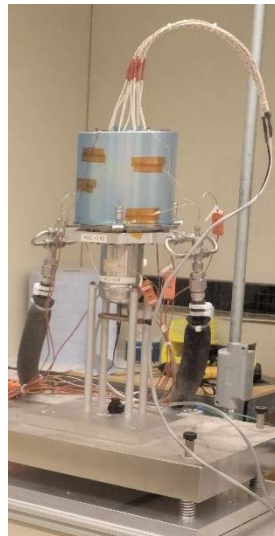


- Current fleet of 16 convertors under test

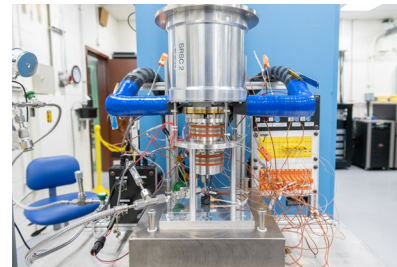


TDC #13

SES #2



ASC-0 #3



SRSC #2

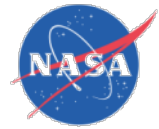


SRSC #3, 4, 5

Sunpower Robust Stirling Convertor

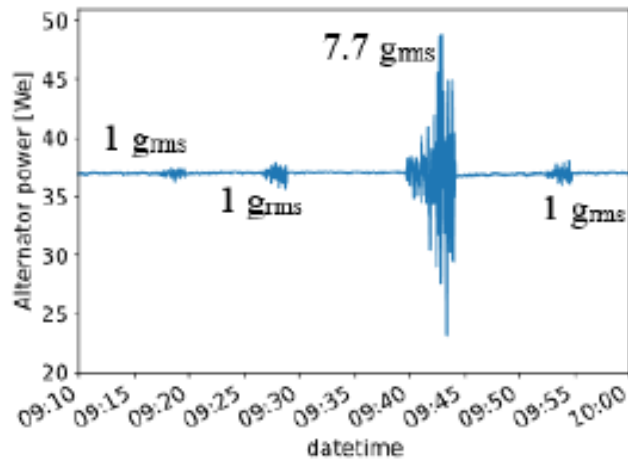
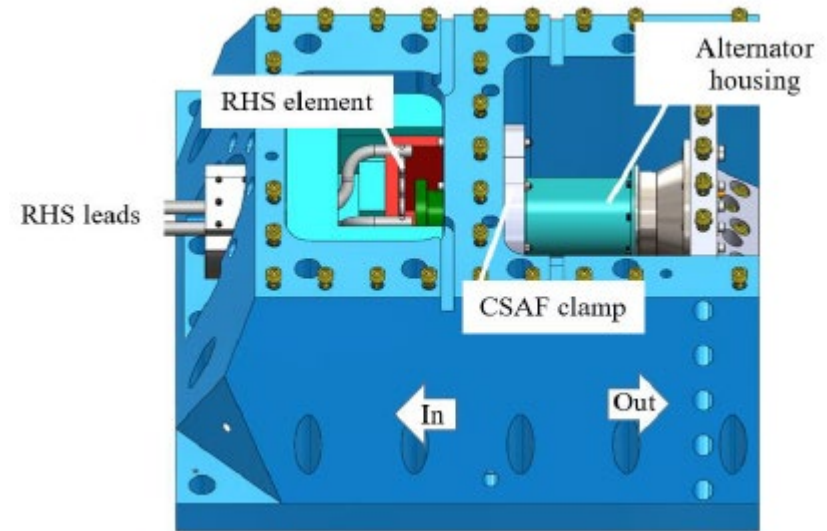
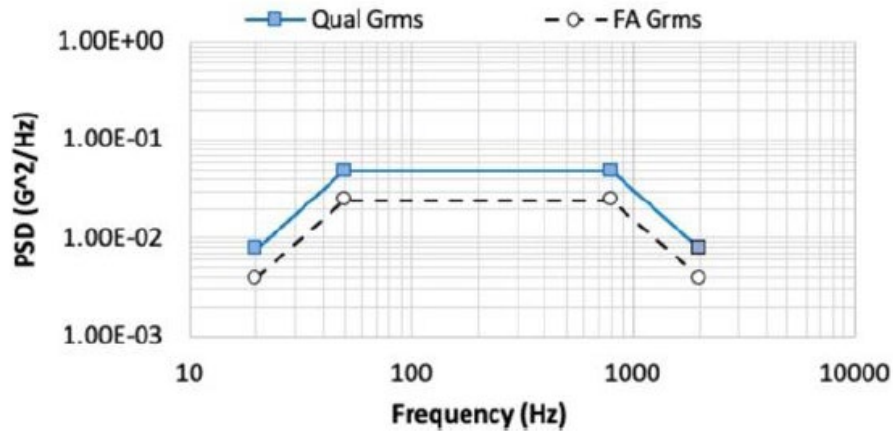
- Most advanced design

DRPS at NASA GRC – SRSC Environmental Testing



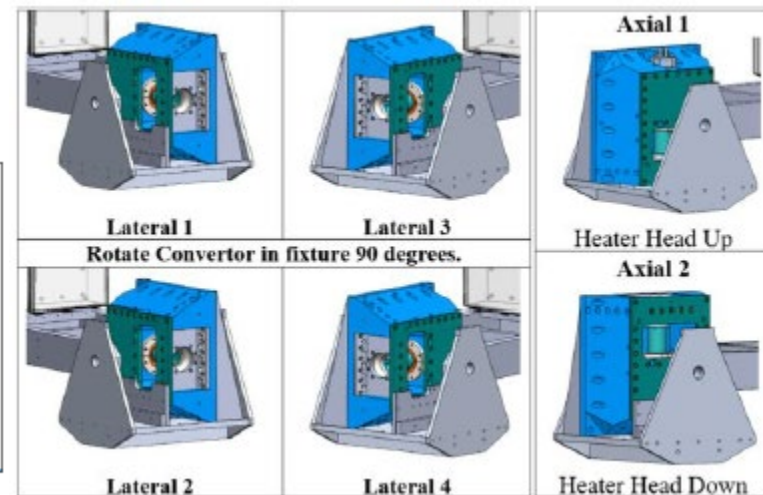
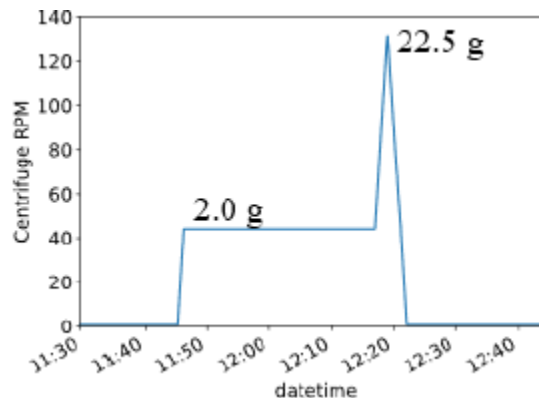
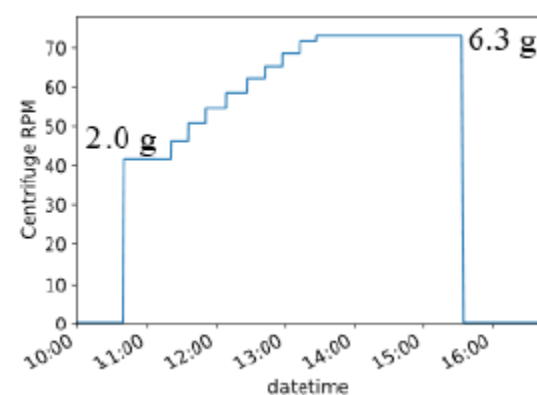
Qualification-level vibration testing

- Simulate launch
- BOM
- 7.7 grms random vibrate in 3 axes

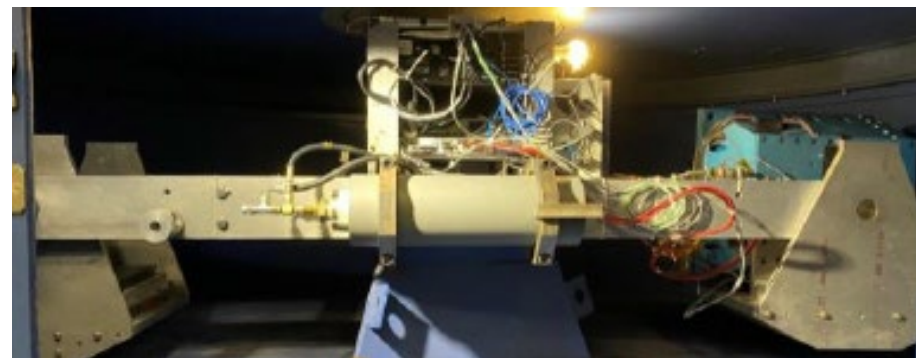
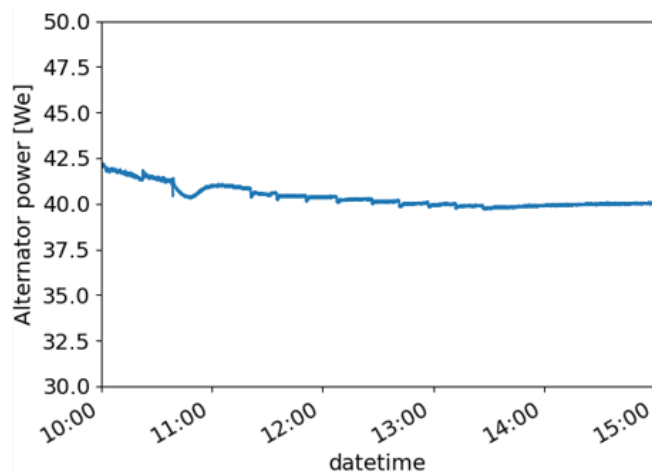


DRPS at NASA GRC – SRSC Environmental Testing

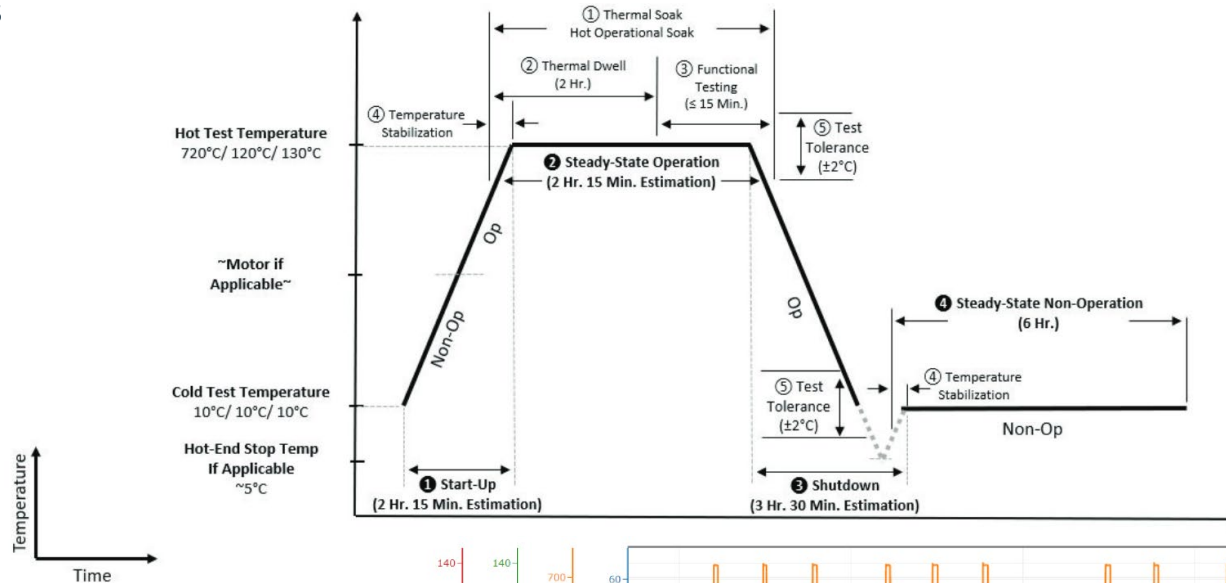
- Qualification-level static acceleration testing
 - Simulate booster, spin, and parachute
 - EODL
 - 6.3 g for 120 minutes in 3 axes
 - 22.5 g for 5 seconds in 3 axes



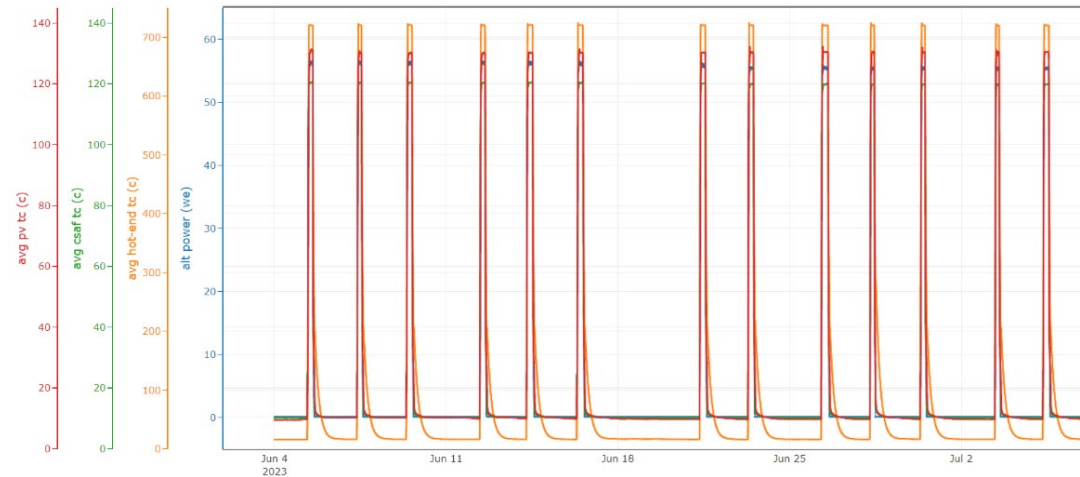
SRSC #3
6.3g



- Qualification-level thermal cycle testing
 - Simulate ground tests during generator processing
 - 13 thermal cycles



Parameter	Pre-T. Cycle	Post-T. Cycle
Alternator power [W_e]	55.78	55.75
Avg hot end [$^\circ\text{C}$]	701.0	700.2
Avg cold end [$^\circ\text{C}$]	100.1	99.6
Avg pressure vessel [$^\circ\text{C}$]	110.7	110.6

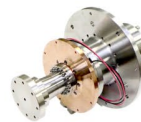
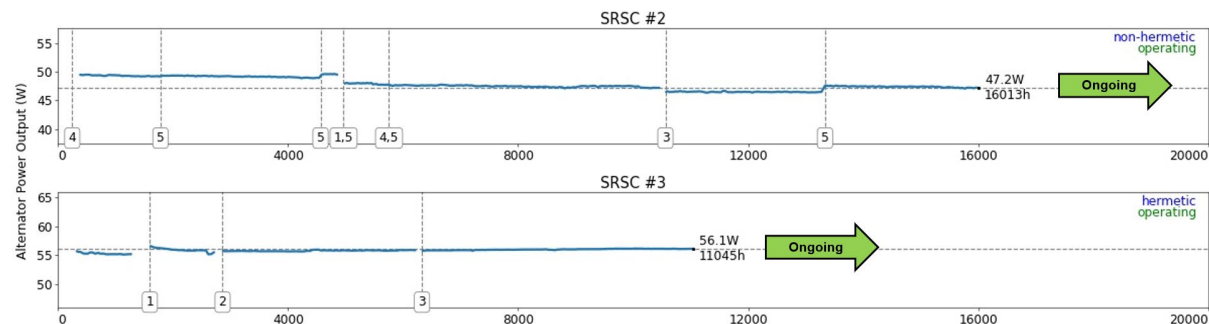


DRPS at NASA GRC – *Extended Operation Testing*

As of Sept 22, 2025, the currently operating convertors are:

TDC #13	161,566 op hours
TDC #15	158,870 op hours
TDC #16	158,870 op hours
SES #2	54,360 op hours
SES TB #5	1,382 op hours
SES TB #6	1,382 op hours
ASC-0 #3	128,275 op hours
ASC-L	74,875 op hours
ASC-E3 #4	60,314 op hours
ASC-E3 #9	46,457 op hours
SRSC #1	13,903 op hours
SRSC #2	20,121 op hours
SRSC #3	24,990 op hours
SRSC #4	18,751 op hours

Total
924,116 op hours
38,504 days
105 years

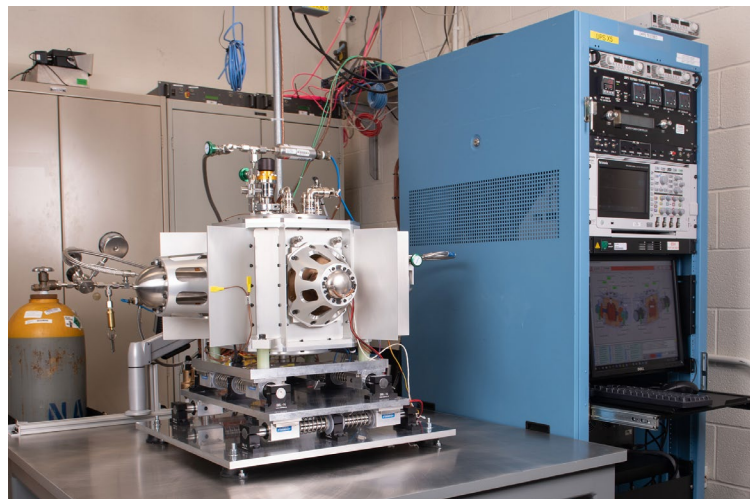
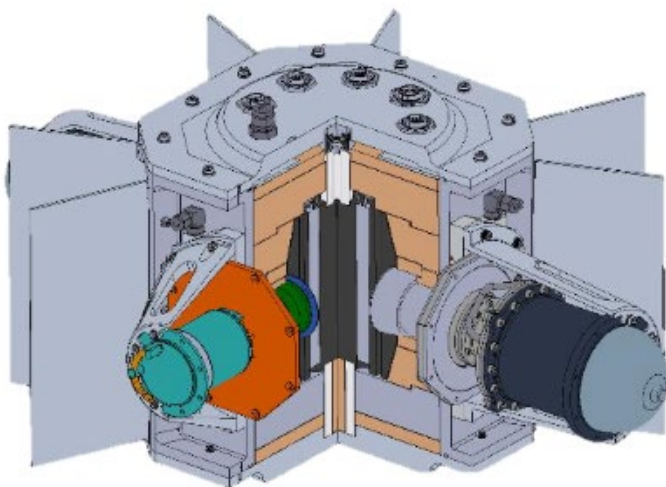


Hours of Operation as of 2024-01-24
Key: 1=Vibe Test, 2=Spin Test, 3=Thermal Cycling, 4=Inspection/disassy, 5=Fresh Helium Fill, 6=Rack Calibration, 7=Operating Point Adjustment

#2 – non-hermetic
#3 – hermetic

DRPS at NASA GRC – Pu-238 *Generator Testbed*

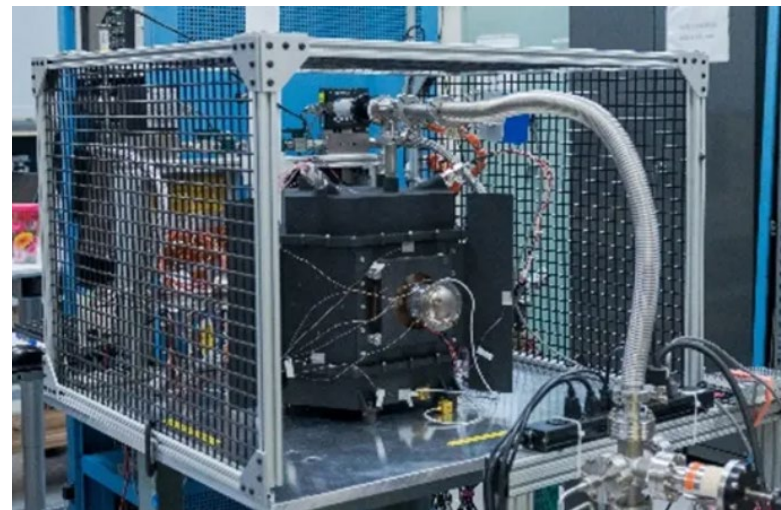
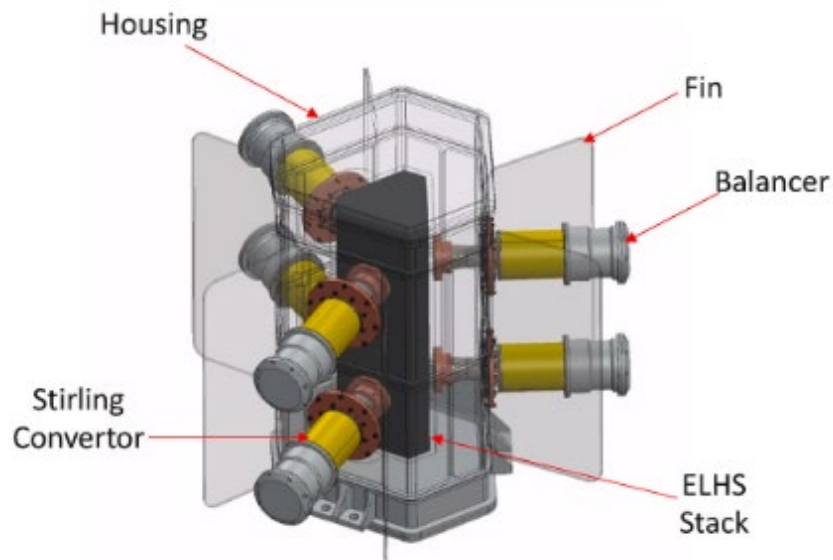
- Arrayed co-planar, dual-opposed pairs of Stirling convertors – cancel vibration
- Can simulate 2 or 3 GPHS modules
 - Heat source is identical in size and form of 3 GPHS modules
- Capable of dissipating waste heat while maintaining convertor cold ends at 100 °C



	Alt power [W_e]	Avg hot end temp [°C]	Avg cold end temp [°C]	Avg pressure vessel temp [°C]
Convertor 1A	22.8	501.5	62.0	57.3
Convertor 1B	23.3	497.9	63.4	55.9
Convertor 2A	19.2	496.4	69.4	49.7
Convertor 2B	19.0	497.4	68.0	47.0
Total	84.3	-	-	-

DRPS at NASA GRC – Am-241 *Generator Testbed*

- 3 arrayed co-planar, convertors/simulators + balancers
- Can simulate 4 ELHS modules
 - Heat source is identical in size and form of 4 ELHS modules



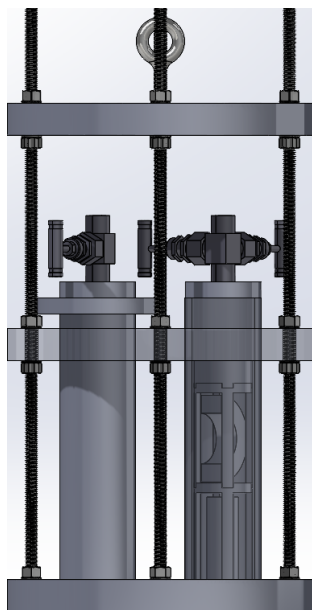


Stirling Alternator Radiation Test Article (SARTA) - 2009

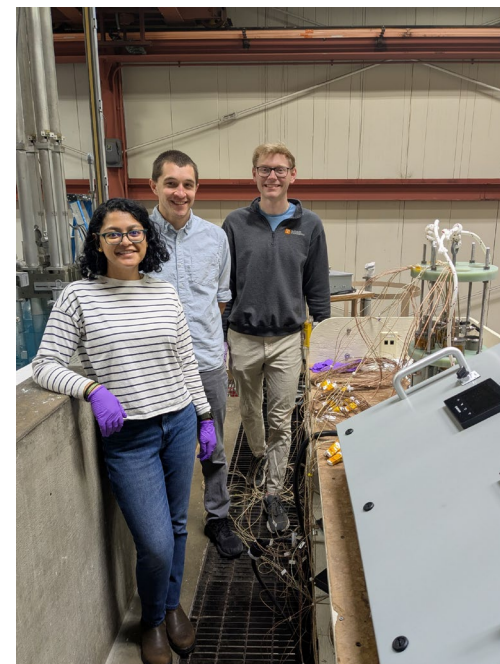
- Free-piston Stirling engine linear alternator
- Sandia National Lab Gamma Irradiation Facility
 - 40 Mrad (!)
 - DRPS expected to expose PCS to about 5 Mrad over mission duration
- Disassembled and inspected at GRC
 - Organics looked good
- Operation of alternator was largely unchanged at 40 Mrad
 - Post-processing suggests a short in stator coil windings

Irradiation of Stirling Organics - 2025

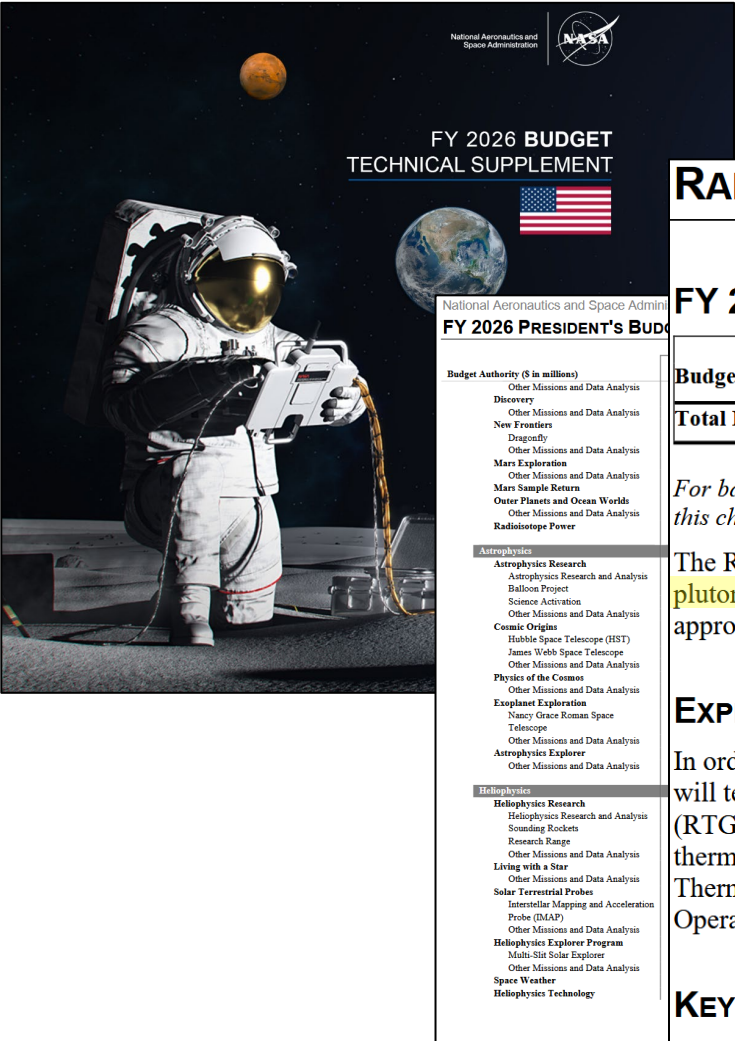
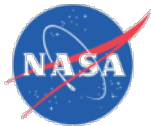
Vessel	Temperature [K]	Time [mo]	Pres [psig]	Expected neutron fluence [n/cm ²]	Target gamma dose [krad]	TCs
4	415	8	600	2E16	2.2E4	5
3	395	8	600	2E16	2.2E4	5
2	375	8	600	2E16	2.2E4	5
0-along	N/A	N/A	N/A	2E16	2.2E4	0
1-control	Ambient	8	600	0	0	5



Organic	Component	Quantity
Xylan	Piston (and displacer)	1 whole piston per vessel
Hysol Nomex Polyimide coating	Coil windings	1 half coil per vessel
ETFE	Electrical lead insulation	60 mm per vessel
PEEK	Heat shrink tubing	15 mm per vessel
Loctite 246	Nuts and bolts	5 nuts/bolts per vessel
Markez	O-ring	1 half of o-ring per vessel



What is next for RPS?



RADIOISOTOPE POWER

FY 2026 Budget

Budget Authority (in \$ millions)	Op Plan FY 2024	Enacted FY 2025	Request FY 2026	FY 2027	FY 2028	FY 2029	FY 2030
Total Budget	175.5	—	139.0	21.0	19.1	0.0	0.0

For background information on FY 2024 and FY 2025 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2026 President's Budget Request Summary."

The Radioisotope Power Systems (RPS) program works in partnership with the DoE to ensure continuing **plutonium-238** production and operations infrastructure. The program also supports nuclear launch approval activities and the implementation of RPS on NASA and international partner missions.

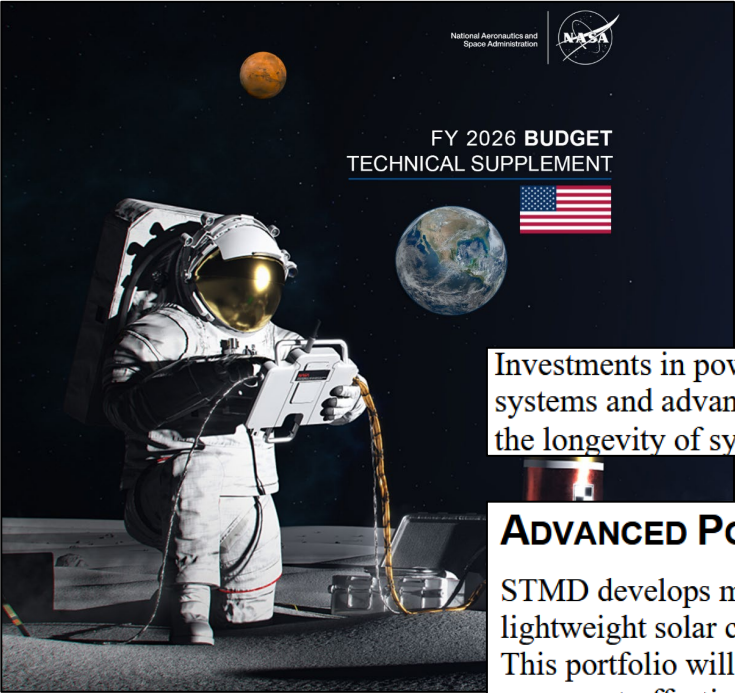
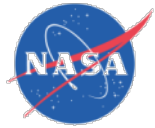
EXPLANATION OF MAJOR CHANGES IN FY 2026

In order to achieve cost savings, reductions are made to all elements of this program. Reductions to RPS will terminate mission integration activities, including Next Gen Radioisotope Thermoelectric Generator (RTG) industry sustainment, RTG power prediction model validation and updates, and long-term thermoelectric testing. This budget provides the funding to complete the MultiMission Radioisotope Thermoelectric Generator (MMRTG), the power source for Dragonfly, and provides funds to DoE Operations & Analysis for the required **plutonium**.

KEY ACHIEVEMENTS PLANNED FOR FY 2026

NASA plans to complete the General Purpose Heat Source RTG Flight Unit 5 refurbishment. NASA will complete construction of the MMRTG for the Dragonfly mission at Aerojet Rocketdyne and will deliver it to Idaho National Lab.

What is next for RPS?



FY 2026 BUDGET TECHNICAL SUPPLEMENT

Investments in power generation and management, including **non-plutonium**-based radioisotope power systems and advanced battery technologies, will advance industry manufacturing capabilities and extend the longevity of systems operating in challenging and extremely cold lunar and Mars environments.

ADVANCED POWER AND THERMAL

STMD develops modular high-specific-energy storage solutions with common interfaces, flexible and lightweight solar cells for multiple user applications within the Advanced Power and Thermal portfolio. This portfolio will build on the current Harmonia Radioisotope Power Source to evaluate and mature more cost-effective radioisotope sources, including **Americium**, to manufacture advance power and thermal management technologies for continuous operation in extremely cold environments, which would be valuable for long-distance human or science missions. Improvements in battery storage performance and reliability allows for lower launch costs (i.e., lighter weight) as well as enhanced conventional batteries with benefits easily translated to terrestrial applications.

What is next for RPS? (This is not an exhaustive list)



Game Changing Development

Harmonia Radioisotope Power Supply for Artemis (Harmonia-RPS-TP)

Active Technology Project 141 views

Download PDF Download Excel



Project Description

The Harmonia-Radioisotope Power System (RPS) Tipping Point (TP) Project is developing a **Stirling Converter** enabled radioisotope power system that utilizes a long lived, thermally constant heat source, **Americium-241** (Am-241). The Harmonia-RPS Tipping Point Project will perform an initial technology readiness assessment to establish the technology readiness level (TRL) of a novel Am-241 heat source design. Once determined, technology maturation plans will be developed to improve the TRL of the Am-241 heat source to TRL 5 by project completion. Additionally, the Harmonia-RPS Tipping Point Project will develop an RPS design that will provide heat and power to an Intuitive Machine's lunar lander and enable long-duration access to lunar surface destinations, including survive-the-night capabilities and long mission durations in permanently shadowed regions. The Harmonia-RPS Tipping Point Project will deliver an Electrically heated Stirling Generator (ESG) that is compatible with the Am-241 heat source design to conduct testing in relevant lunar environments, including thermal vacuum (TVAC). Execution of ESG testing in relevant environments will mature the ESG technology to TRL 6 by project completion. Harmonia-class RPS technology directly aligns with the requirements that contribute to Space Technology Mission Directorate (STMD) and NASA's broader science, technology, and exploration objectives. Other important national objectives include the near-term demonstration of Stirling conversion for an RPS, as recommended in a recent Planetary Science Decadal Survey, and the commercial development of space nuclear power systems per Space Policy Directive-6. Compared to the "state of the art," Harmonia will establish an affordable private-sector radioisotope capability, supporting new government and commercial applications.

<https://techport.nasa.gov/projects/147008>



RPSs historically have provided safe, reliable, and long-endurance power in off-grid terrestrial environments where alternative power sources are infeasible. From the 1960s through the 1980s, the U.S. government utilized strontium-90 (Sr-90) RPSs in maritime environments to power navigational buoys and undersea sensing equipment. In reestablishing this technological capability for government customers, Zeno Power is combining a novel **Sr-90** heat source with **Stirling power conversion** to provide improved performance compared to legacy systems.

<https://www.zenopower.com/news/zeno-awarded-contract-to-build-and-demonstrate-radioisotope-power>



Intuitive Machines' \$9.5 million JETSON Low-power contract, awarded in 2023, is developing a new spacecraft concept and design which utilizes a compact Radioisotope Power System ("RPS") to provide electrical power. The RPS will use a **Co-60** heat source from USNC to heat a **Stirling cycle dynamic power conversion system**, which in turn will provide electrical power for on-orbit mobility, thermal regulation, and payloads.



<https://www.intuativemachines.com/post/intuitive-machines-advances-radioisotope-power-system-for-afrl-space-vehicles-directorate>



Questions

tyler.r.steiner@nasa.gov