National Aeronautics and Space Administration

RADIOISOTOPE POWER SYSTEMS PROGRAM

4th Interstellar Probe Exploration Workshop

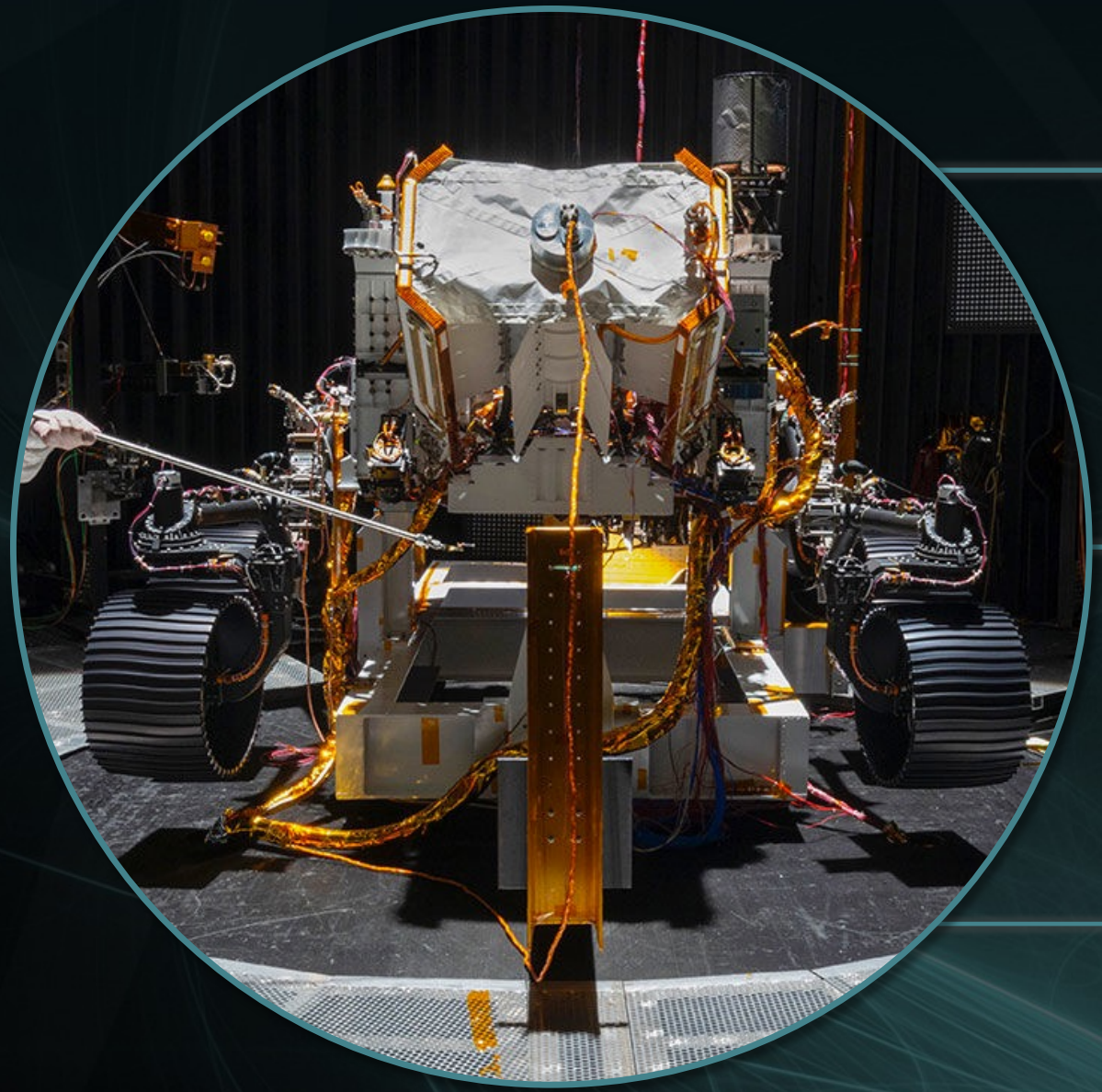
September 30, 2021

Radioisotope Power Systems Update

June Zakrasjek

RPS Program Manager

Power to…



EXPLORE

DISCOVER

UNDERSTAND

Current RPS State

- RPS Program is investing in a dynamic team with recent personnel changes allowing for long term continuity and implementing a roadmap for success
- RPS Program is investing in new technology for higher performing RPS to be considered for infusion in next decade
- RPS Program, this decade, is investing in system development
  - Next Gen RTG – bringing back the GPHS-RTG production line
  - DRPS – developing higher efficient robust dynamic conversion-based RPS
- Constant Production Rates (CRP) provided to DOE meet NASA needs in this decade
  - Sized to meet PSD mission needs, reevaluated on a yearly basis with a 10-year sliding window
  - Yearly Average Rates: 10-15 Fueled Clads per year and 1.5 kg HS-PuO_2 starting in 2026
  - DOE has designed capacity into CRP and could increase rates at NASA's request – requires additional funding and finite time to reach higher CRP rates

DOE
Constant Rate Production (CRP)

Radioisotope Power System Program Office
PM: June Zakrajsek (GRC)
DPM: Concha Reid (GRC)
➢ **DPM: Lucas Rich (IPA/INL)**
CE: Leah McInytre (GRC)
CSO: Lauren Clayman (GRC)
Admin: Patty Gross (GRC)

Strategy Team
JPL: Ron Reeve
APL: Paul Ostdiek
GRC: Tibor Kremic
GSFC: Mike Amato
DOE: Steve Johnson
Includes: PM, DPM, CE

Level II

Program Integration
Colleen Van Lear (GRC)

NEPA and Launch Approval Management
Bethany Eppig (GRC)
Ryan Edwards (GRC)

Systems Formulation
David Woerner (JPL)

RPS Radioisotope Power Systems

Stakeholder Engagement
Kerri Beisser (APL)
Kristin Spear (GRC)

Mission Integration
J Michael Newman (GRC)
Ryan Edwards (GRC)

Technology Management
Laura Evans (GRC)
Sabah Bux (JPL)

Level III

NG RTG Project
Rob Overy (GRC)

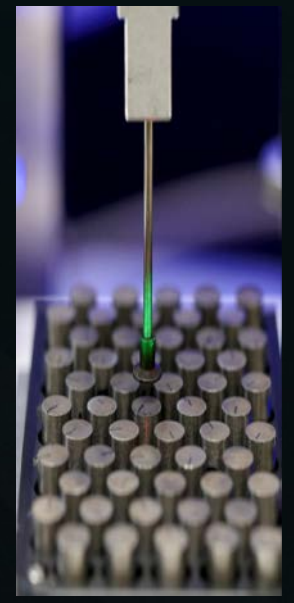
DRPS Project
Mark Hickman (GRC)

Aug 2021

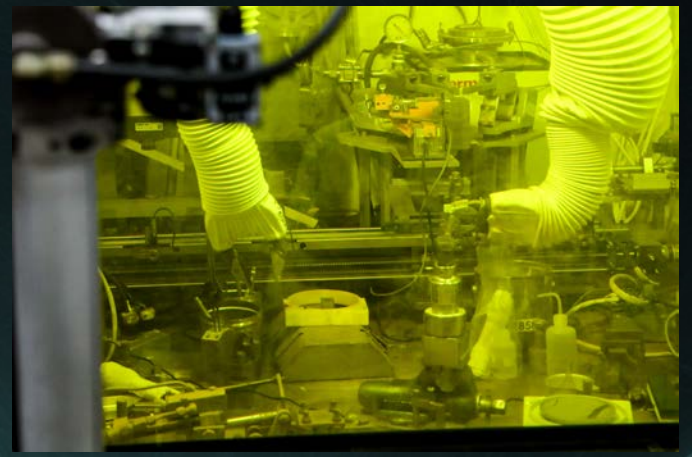
Constant Rate Production

- Initial Actions Complete
  - **Material management model:** Developed a material inventory model that optimizes utilization of material for production
  - **Heat source and RPS production plan:** Developed annual Integrated Program Plan
  - **Integrated risk tracking:** Developed approach to track shared risks between NASA and DOE including limited industry source and aging infrastructure
- Current Focus
  - **Scaling of operations**: technical, chemical processing, target qualification, production goals
  - **Optimizing** of processes
  - **Maintenance, modernization and replacement** of aging systems and infrastructure

Neptunium Glovebox



Automated Pellet Press



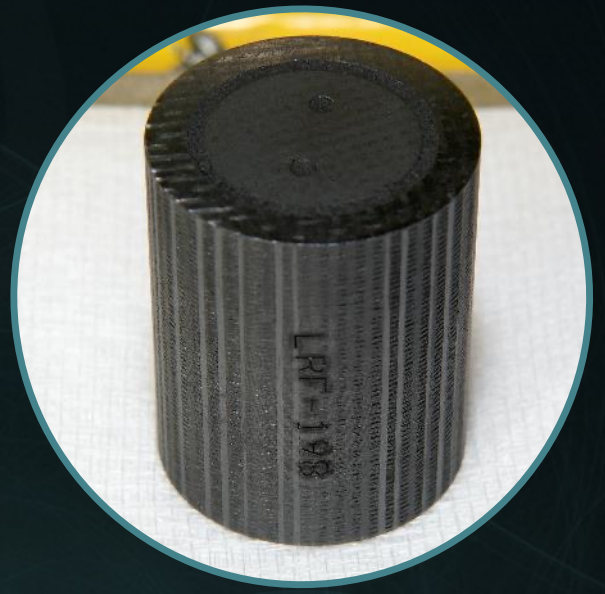
ORNL Load Out Cell testing and preparations for readiness assessment

Current RPS Systems

- Multi-Mission Radioisotope Thermoelectric Generator (MMRTG): F3 is at INL ready for a mission, F4 is under contract, F5/F6 options
- LWRHU: Inventory available

MMRTG

Multi-Mission Radioisotope Power System



LWRHU

Light Weight Radioisotope Heater Units

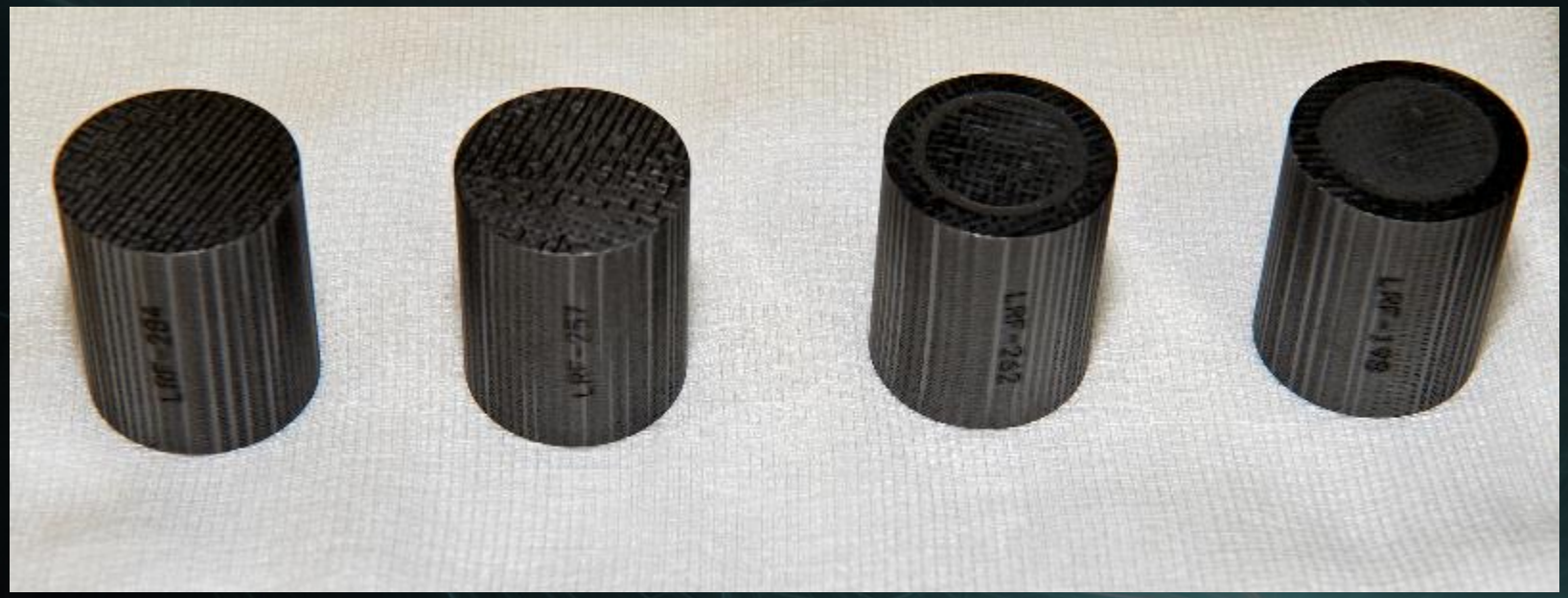
Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)

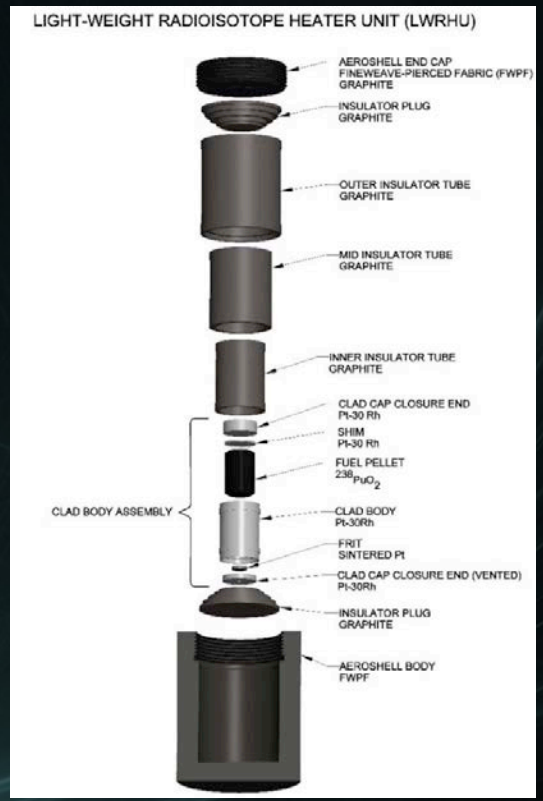
- **F1** on Mars on Curiosity
  - Current Power 82.9 W_e
- **F2** on Mars on Perseverance
  - Current Power 112.7 W_e
- **F3** at INL ready for a mission
  - Completed 1–MMRTG 48-couple module
- **F4** under contract

* Current as of August 2021

Lightweight Radioisotope Heater Units (LWRHU)

- LWRHU provide heat for missions
  - Current LWRHU inventory available
  - DOE developed plan for reconstituted LWRHUs
    - Complete ORNL hardware capability in place
    - Portions of LANL capability in place
- LWRHU Programmatic EA completed
- LWRHU System-Specific DSA to be completed 2021



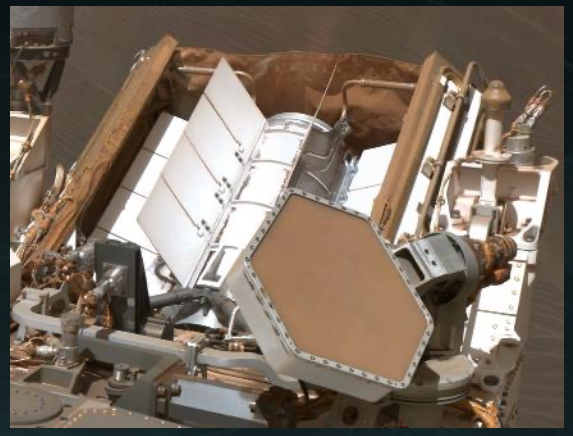


RPS Technology Investments

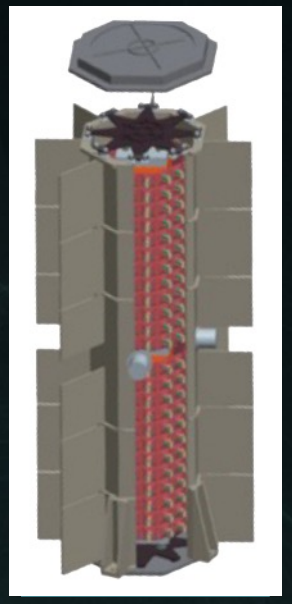
Simplistic RPS Decade Power–CRP Analysis

Current System

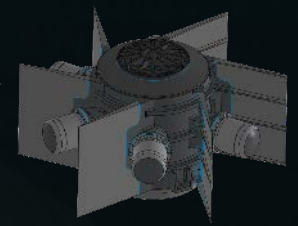
MMRTG
Curiosity, M2020, *Dragonfly*



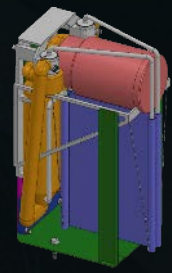
Next Gen RTG Mod 1



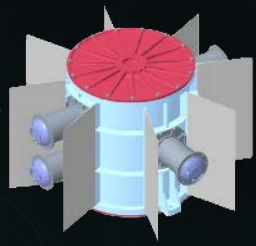
AMSC/ FISC



Creare/ TBC



Sunpower/ SRSC

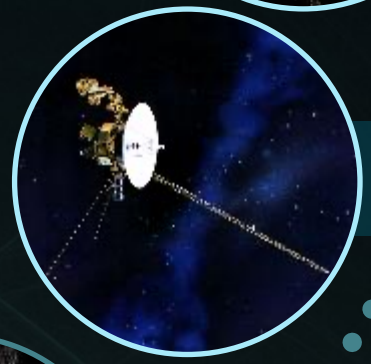


	Current System	Next Gen RTG Mod 1	AMSC/ FISC	Creare/ TBC	Sunpower/ SRSC
Possible Quantity of Fueled RPS	3 to 4 MMRTG	1.5 to 2 GPHS RTG			4 to 6 DRPS
Possible Power Provided (BOM)	330 to 440 W_e MMRTG	368 to 490 W_e GPHS RTG			964 to 1446 W_e DRPS

Next Gen Mod 1 = ~GPHS-RTG

- A revectored design of the **heritage GPHS-RTG** was the results of a DOE Phase 1 industry effort for a new technology-based system
- Aerojet Rocketdyne under INL letter contract
- Reestablish GPHS RTG production capability by 2027
  - Use of proven heritage design with proven long life and low degradation
  - More cost effective
  - Less risk
- 90% heritage design, but lower heat; lower power; 2 trades going on to consider change to stretch the housing; more efficiency of the couples; EODL~177-210 W_e
- Maintains opportunity for enhancements providing increased performance & greater efficiency (Mod 2)

Voyager 2
Aug. 20, 1977–Present
3 MHW RTG: @~158 W_e BOL



Voyager 1
Sept. 5, 1977–Present
3 MHW RTG: @~158 W_e BOL

New Horizons
Jan. 19, 2006–Present
GPHS RTG: 245 W_e BOL

Cassini
Oct. 15, 1997–2017
3 GPHS RTG: @~292 W_e BOL

LES 9*
Mar. 14, 1976–2020
2 MHW RTG: 158 W_e BOL

LES 8*
Mar. 14, 1976–2004
2 MHW RTG: 158 W_e BOL

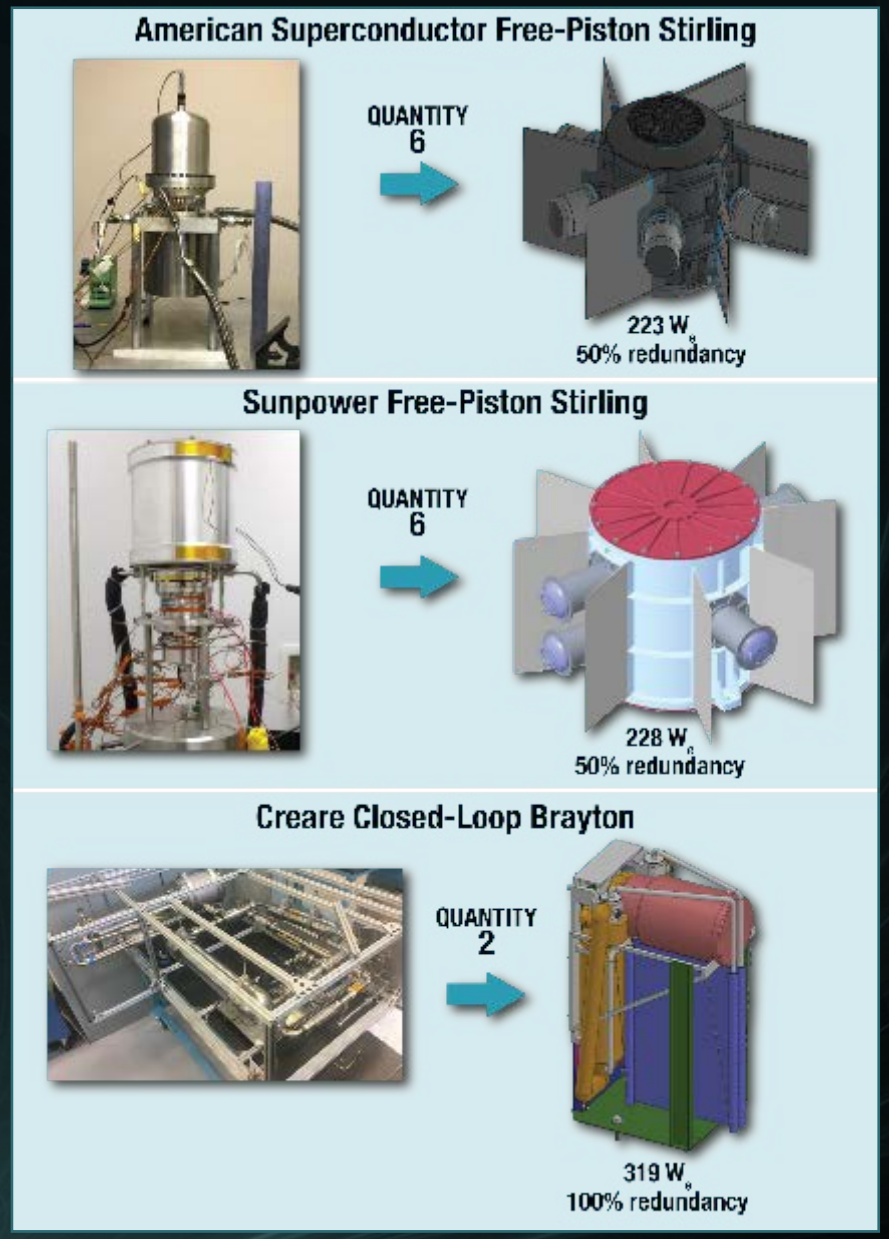
* U.S. Air Force Mission

Next Gen Mod 2 = Potential Thermoelectric Upgrade to Mod 1

- Technology activities continue via thermoelectric expertise under the Program's Technology Management element
  - Developing interface requirements for higher efficient thermoelectric couples
  - BOL reproducibility study
  - Completed selection of initial n- and p- HT metallization candidates
  - On track to complete summary of metallization screening results
  - Fabricated 16 pucks/coupons for chemical reactivity (co-hot pressed) & adhesion strength testing and annealed 11
- Current level of SMD directed funding is lower than needed to complete TRL 6 to transition to Next Gen at completion of Mod 1 (2027)
  - Completion funding can be reevaluated at next PPBE

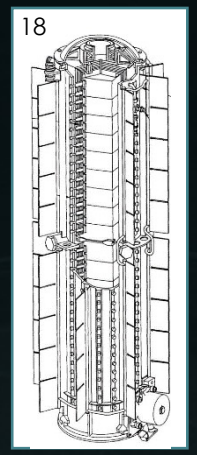
Dynamic Radioisotope Power Systems (DRPS)

- DRPS provide multi-mission capability with significantly lower Heat Source consumption and thermal properties that uniquely enable some science missions
- Investment in multiple robust dynamic conversion technologies
  - 2 technologies have multiple ground units that have individually continuously operated for over 14 years without maintenance demonstrating life and low degradation rates
- Initiated DOE flight system design in FY21 with procurement process to select System Integrating Contractor
  - Multi-mission design with protoflight lunar system
  - Current budget provides for PDR and system level brassboard development necessary to prove technology readiness for full protoflight development
- Protoflight unit to target lunar demonstration
  - Demo serves as pathfinder for dynamic conversion which is required for fission-based power designed

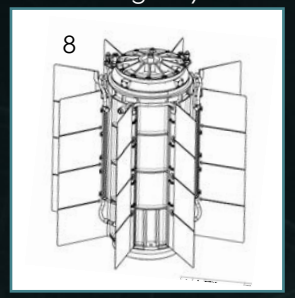


Performance Comparison

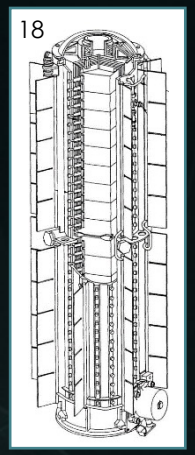
GPHS-RTG:
Cassini, Galileo, Ulysses, New Horizons



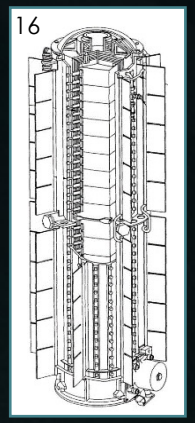
MMRTG:
Curiosity, M2020, *Dragonfly*



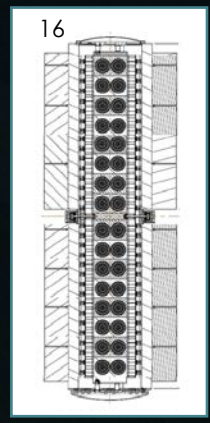
GPHS-RTG:
Cassini, Galileo, Ulysses, New Horizons



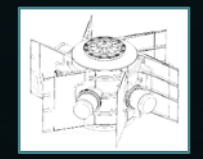
Next Gen RTG Mod 1



Next Gen RTG Mod 2



AMSC/FISC



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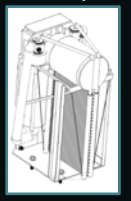

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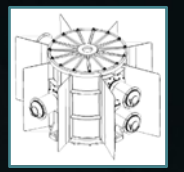
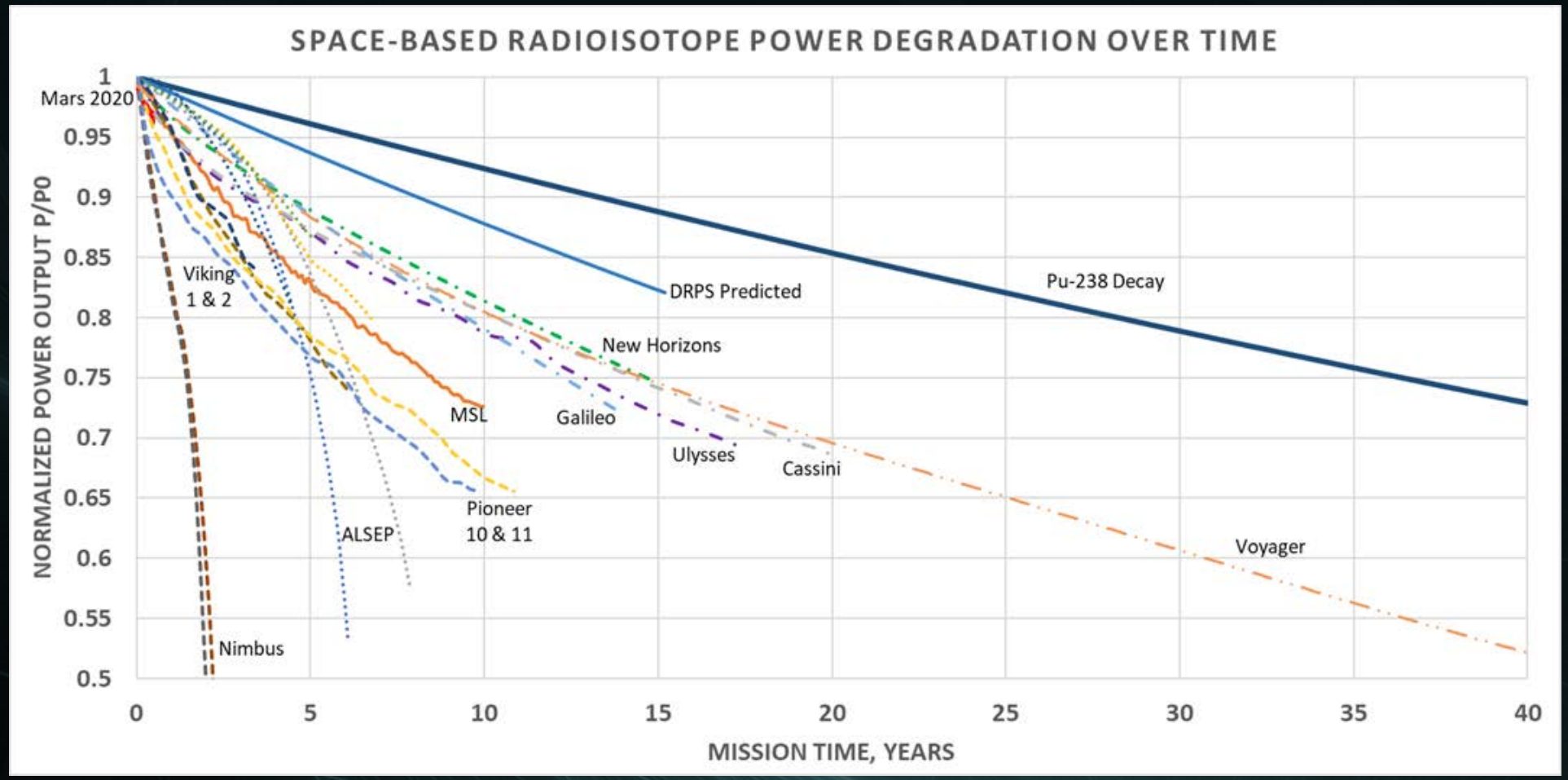


Parameter	GPHS-RTG	MMRTG	Next Gen Mod 0	Next Gen Mod 1	Next Gen Mod 2	DRPS
P_{BOL} (W_e)	291	110	293	245	400	300 to 400
Mass (kg)	58	44	56	56	56	100 to 200
Q_{BOL} (W_{th})	4410	2000	4500	4000	4000	1500
P_{EODL}, $P=P_0*e^{-rt}$ (W_e)	N/A	63	208	177	290	241 to 321
Maximum Average Annual Power Degradation, r (%/yr)	1.54	3.8	1.9	1.9	1.9	1.3
Fueled Storage Life, t (yrs)	2	3	3	3	3	3
Flight Design Life, t (yrs)	16	14	16	14	14	14
Design Life, t (yrs)	18	17	18	17	17	17
Allowable Flight Voltage Envelope (V)	22-34	22-34	22-34	22-36	22-36	22 to 36
Planetary Atmospheres (Y/N)	N	Y	N	N	N	Y
Estimated Launch Date Availability	N/A	Now	2026	2029	2034	2030

Power Degradation Chart



- EODL of 17 years allows for equal comparison of systems
- MHW RTG and GPHS-RTG (SiGe couples) degrade gracefully and do not fail
- Lifetimes 40+ years demonstrated and life prediction models indicate power at 50 years ~ 100 W_e

*Initial chart courtesy of R. McNutt

RPS Focus on Mission Community

Affordability

- Mindful of the balance between RPS funding and PSD mission funding
- Continually looking to reduce RPS costs to missions
  - Systems contracts with multiple copies
  - CRP produces hardware on the shelf ready for missions, reducing mission specific costs, schedule, and risk
- Policies
  - NEPA EA vs. mission specific EIS
  - Technology specific safety documentation for Nuclear Launch Authorization Safety Analysis Report (SAR) development
  - Preparing for on-ramping of future launch vehicles

Availability

- User's information, model, and simulators
- Capacity in system currently sized to PSD (NASA's current, single user of RPS) needs
- Sustaining capabilities at critical providers (DOE, NASA, vendors)
- Long lead/higher risk items processed earlier
  - CRP
  - Generators and key hardware
- Investing in new technology for higher performing RPS to be considered for infusion in next decade

NASA & DOE are Ready to Support Decadal Missions

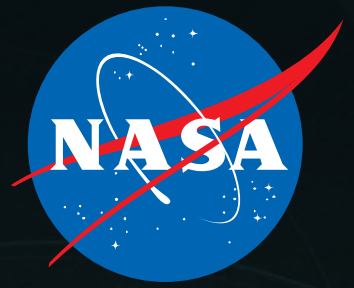
- Constant Rate Production in Place
  - Plutonium-238 heat source production
  - Fueled clad production
  - Maintaining essential infrastructure
  - Capacity in the system
- Power System
  - MMRTG available now for missions
  - GPHS RTG available late 2020s for missions
  - DRPS TRL 6 by mid-2020s, with funding available late 2020s for missions

Mission Demand Oriented:

- **Decadal Provides the Vision**
- **Congress Provides the Funding**
- **NASA SMD/PSD maps the need to the flight missions and key technology investments**
- **RPS Program and DOE Provides the Fueled Systems and key technology investments**

Committed to Mission Success

The RPS Program has increasingly demonstrated its value to NASA and the space science community and recommends the Program investments be continued.

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POWER TO EXPLORE

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