NASA's Radioisotope Power Systems Program

Presentation to NRC
Committee on Astrobiology and Planetary Science
March 4, 2014
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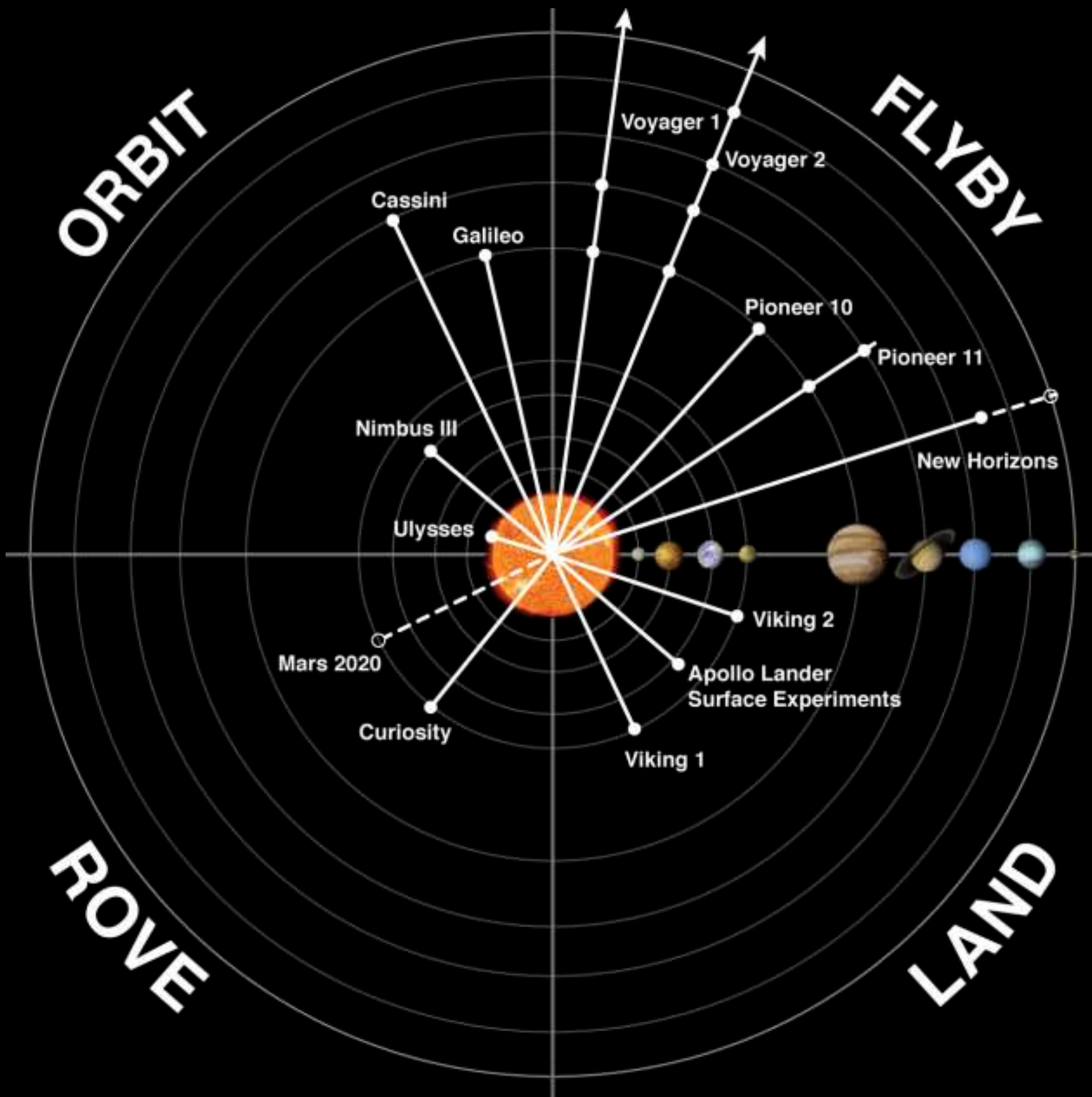
Program Executive

Outline

- RPS Program Status
- DoE Infrastructure Review
- SRG and MMRTG systems comparison
- Current Program plans
- Looking to the future, Stirling & fission power
- Summary

Over 50 years of RPS Missions



Status of the RPS Program

- RPS Program Implementation Review recently completed, reaffirming the value of the program
- Funding responsibility for sustainment of RPS operations was transferred from DOE to NASA in FY14
- NASA continues to fund the Plutonium-238 Supply Project to redevelop production capability
- DOE established Pu-238 allotment for NASA planning
    - 35 kg of isotope, 17 kg in-spec, larger than previous planning no.
- ASRG flight development cancelled due to budget
- PSD is developing plans for the next generation power systems

Infrastructure Review

DOE RPS Infrastructure Review

Statement of Task

1. Examine NASA's plans and budget for design and use of radioisotope power systems to define NASA's need for RPS/Pu-238.

2. Comprehensive review of DOE RPS infrastructure (*facilities, staff, capabilities, equipment, and maintenance*).

3. Review plans for Pu-238 supply project (*seek efficiencies*).

4. Provide recommendations for an appropriate level of funding (*identify considerations for new approaches and technologies*).

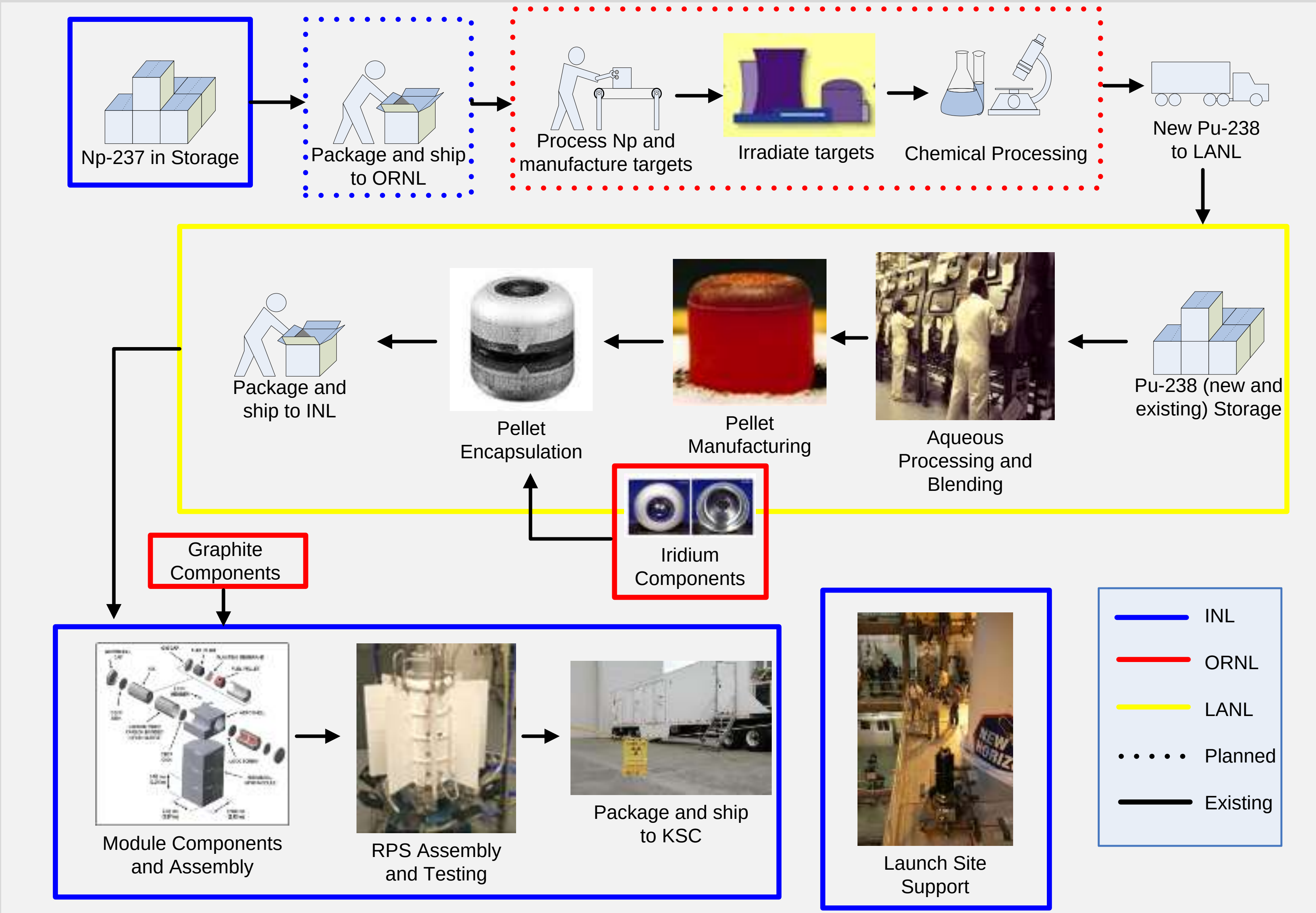
5. Provide recommendations for new governance structure (*transparency, cost constraint, effective oversight, appropriate level of NASA involvement*).

6. Support Agency senior executive review of the recommendations and findings.

DOE RPS Infrastructure Capabilities

- Physical infrastructure
  - Material handling
  - Material storage
  - Safeguards and security
  - Safety
  - Waste management
- Personnel skills
  - Professionals and technicians
  - Corporate knowledge
  - Succession
- Assemble, test and deliver power systems
- Analyze safety and risk of RPS deployment and operations
- Knowledge Bases
  - Safety: in design, production and use for worker safety in production and public safety in application
  - Quality assurance: in production, assembly and testing to assure product quality
  - Program knowledge: the integration of all processes and participant organizations
- Provide launch support and emergency response
- Manage plutonium-238 supply
- Provide international leadership on safe use of space NPS
- Manage customer funded RPS System Integration Contracts

Key Steps in RPS Production



Source: DOE NE-75

Select Observations

Pu-238 is an exceptionally difficult material with which to work.
Disposal of waste products is a significant factor in the process.
The processes observed at the sites did not show excess.
The role of DOE in the process is essential.
RPS's are a critical resource to execute most missions from the National Research Council's National Academy of Science Decadal Survey of Planetary Science for the period 2013-2022.
If the need for plutonium-238 grows beyond the 1.5kg annual production rate currently planned, significant changes will be necessary.
Fine-weave pierced fabric is a critical resource in the production of general-purpose heat source modules.

Select Recommendations (1/2)

Together, NASA and DOE should derive production rates that maintain proficiency across the DOE sites, as well as meet NASA's future mission needs.
Ensure the availability of fine-weave pierced fabric in order to enable general-purpose heat source module production.
Communications between NASA and DOE need to be free and open, while authority needs to be formalized.
Regularly scheduled meetings should be held between the leadership of NASA and DOE at all levels.
NASA participation in DOE technical integration activities is important.

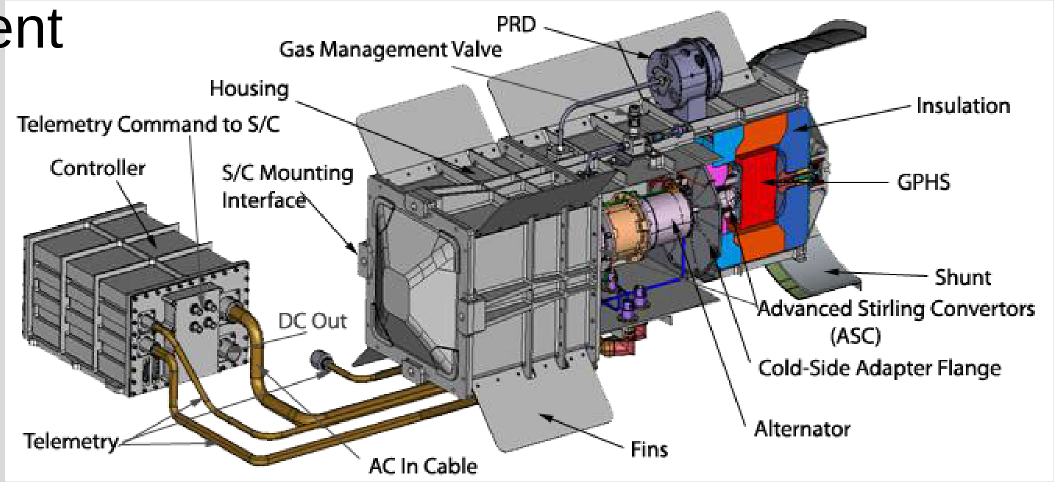
Select Recommendations (2/2)

Though NASA is providing infrastructure funding, the responsibility, accountability, and ownership of these assets should remain with DOE.
NASA should ensure sufficient funding is available to DOE so as to not impact ongoing operations
The investigation of new processes should be considered routinely, coupled with a long-term continuous improvement program.

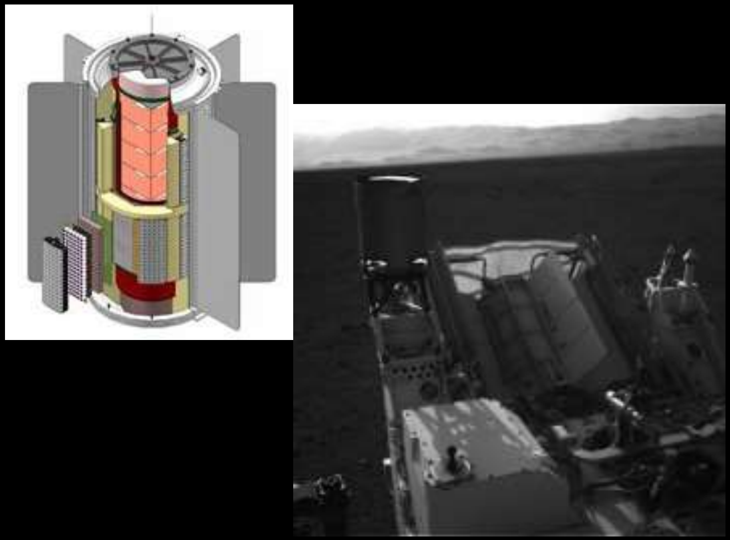
RPS Comparison

Advanced Stirling Radioisotope Generator (ASRG)

- Flight development terminated November 2013 due to budget
- ASRG provides increased efficiency (4X current technology)
- Offered as GFE in Discovery 12
- Highly enabling for new classes of science missions
- Conducted Final Design Review in July 2012
- ASC & System Engineering unit build & test since 2009 have led to reliability database, design improvements, and product maturity
- Qualification unit (QU) component manufacturing in progress
- Hardware being transferred to GRC for continued technology development



Radioisotope Power System Comparison



- **Multi-Mission Radioisotope Thermoelectric Generator**
  - 8 Pu-238 General Purpose Heat Source Modules (GPHS)
  - BOL* 117 Watts/45 kg = 2.8 W/kg
  - EOL* 63 Watts (17 years)
  - Highly successful on Curiosity
  - Planned for Mars 2020

- **Advanced Stirling Radioisotope Generator**
  - 2 Pu-238 GPHS
  - BOL* ~140 Watts/32 kg = 4.5 W/kg
  - EOL* ~118 Watts (17 years)
- **Future Stirling Radioisotope Generator†**
  - 4 Pu-238 GPHS
  - BOL* ~300 Watts/47 kg = 6.4 W/kg
  - EOL* ~250 Watts (17 years)

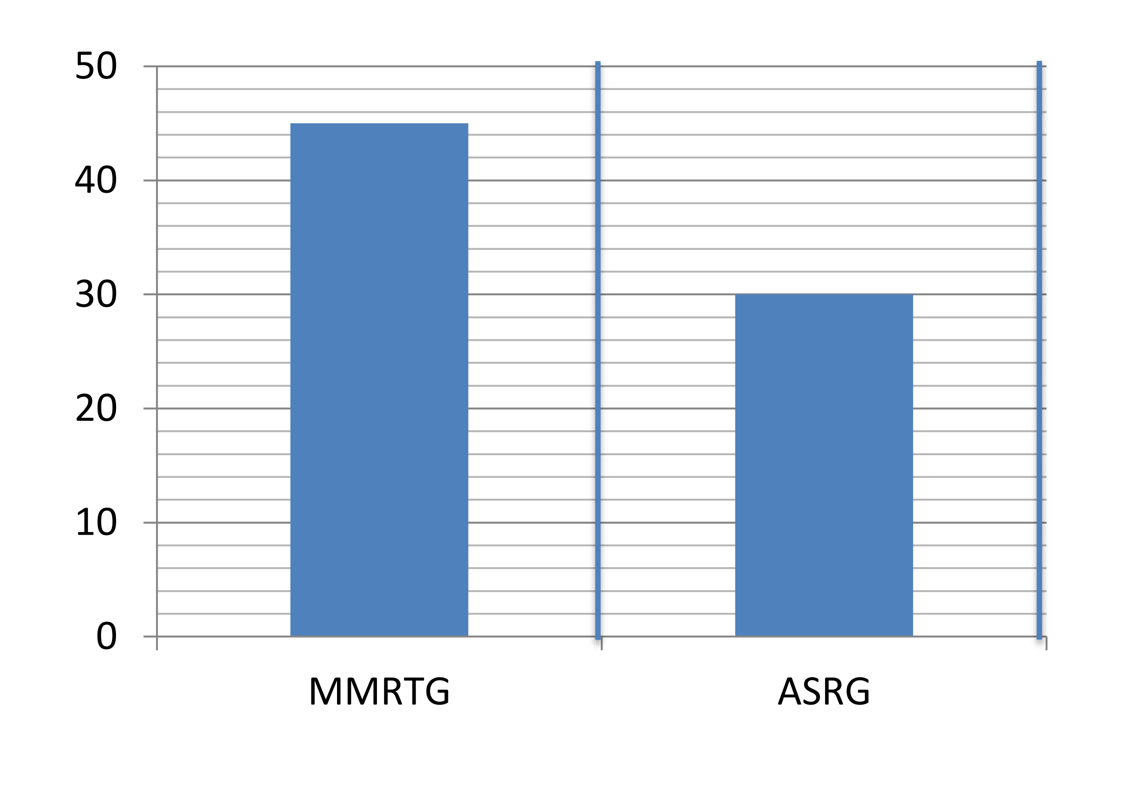
† Potential new technology development

* All power figures are approximate, based on nominal fuel load. Actual power may vary depending on specific mission implementation and environment

RPS Comparisons from a Mission Perspective

MMRTG	ASRG
	

Mass (kg)



RPS Comparisons from a Mission Perspective

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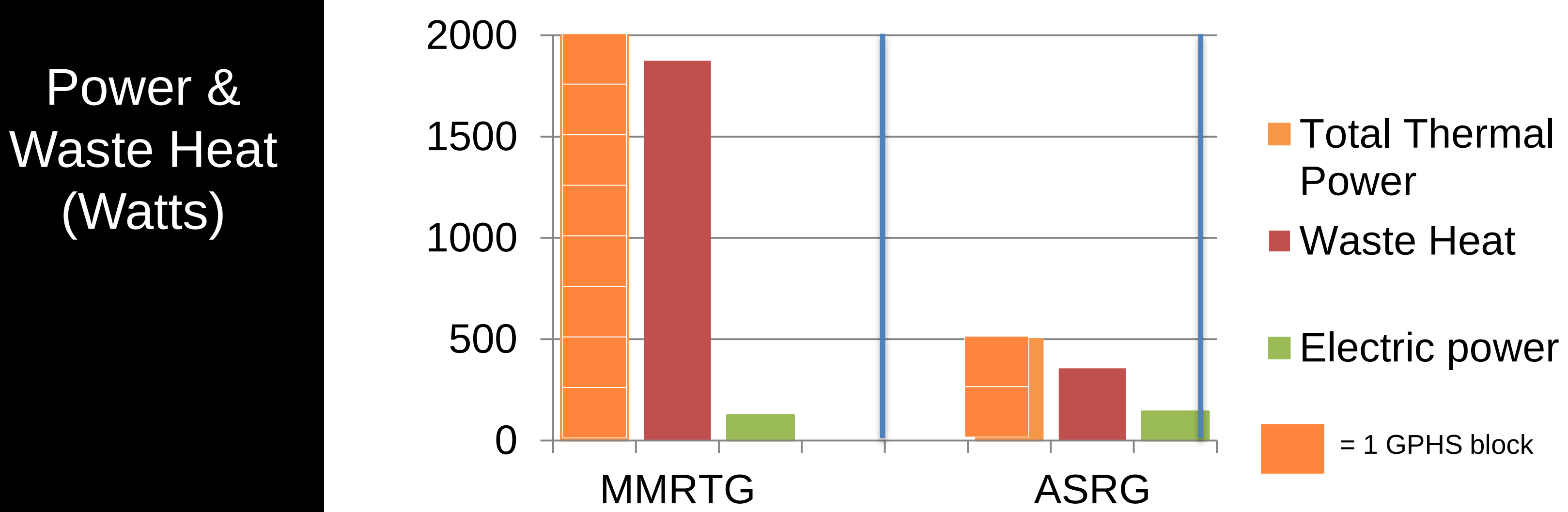


Excess heat at 135-155ºC desirable for S/C heating

Minimal heat at 80ºC desirable for aeroshell integration

Current Plans

Discovery & Radioisotope Power

- ASRG was offered in 2010 AO resulting in 2 step 1 proposal awards and great interest
- NASA FY14 Appropriation directs NASA to mitigate cancellation of ASRG to proposers
- NASA considered Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) for 2014 AO
- DOE planned upgrades to improve reliability of heat source manufacturing operations do not permit supporting a Discovery need date of 2019-2022
- Current U.S. plutonium-238 inventory can support Mars 2020 (1), Europa (4) and (2) more MMRTG for a mission this next decade

Radioisotope Power System Applications in Near Term Planetary Missions

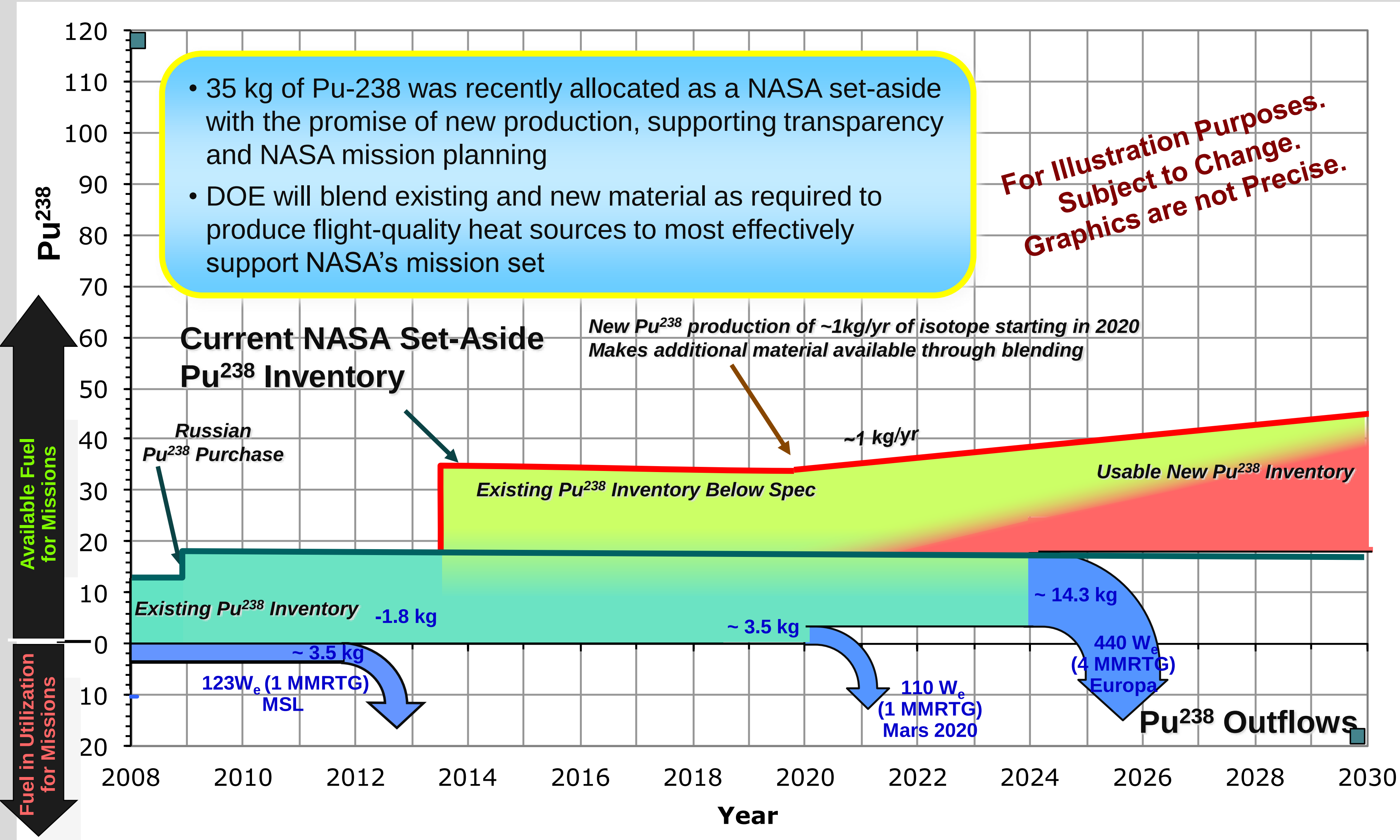
Evolving SMD RPS Mission Planning Set post Decadal Survey

Large Directed / New Frontiers / Discovery / Mars / Lunar / Other	Projected Launch Year	Power Reqmnt (W_e)	RPS Type (Flight + Spare)	Pu-238 Availability
Mars Science Lab *Operational*	2011	100	1 MMRTG	
Juno (New Frontiers 2) *On its way*	2011	No RPS Requirement		
InSight (D12) *In Development*	2016	Non-RPS *(ASRG not selected)*		
Osiris-REX (NF3) *In Development*	2016	Directed non-RPS		
Solar Probe *In Development*	2019	Directed non-RPS *(Originally 3 MMRTG)*		
Discovery *In Planning*	2019 - 22	Directed non-RPS *(MMRTG Unsupportable)*		
Mars 2020 *In Planning*	2020	100 - 150	1 MMRTG + Spare	Existing
Europa† or New Frontiers	2024 - 25	500 - 1000	4-5 MMRTG or 4 eMMRTG*	Existing
Discovery	2023 - 25	300 - 400	3 MMRTG or Next Gen	Exist + New
New Frontiers	2028 - 29	300 - 500	Possible Next Gen Power	+ New

† If funded
** Enhanced*

- 6 year-cadence New Frontier mission opportunities
- Every future Discovery mission opportunity will offer an RPS option
- Radioisotope heater units may be required on these and other missions
- Other science, exploration, and demo missions not yet identified may also require RPS

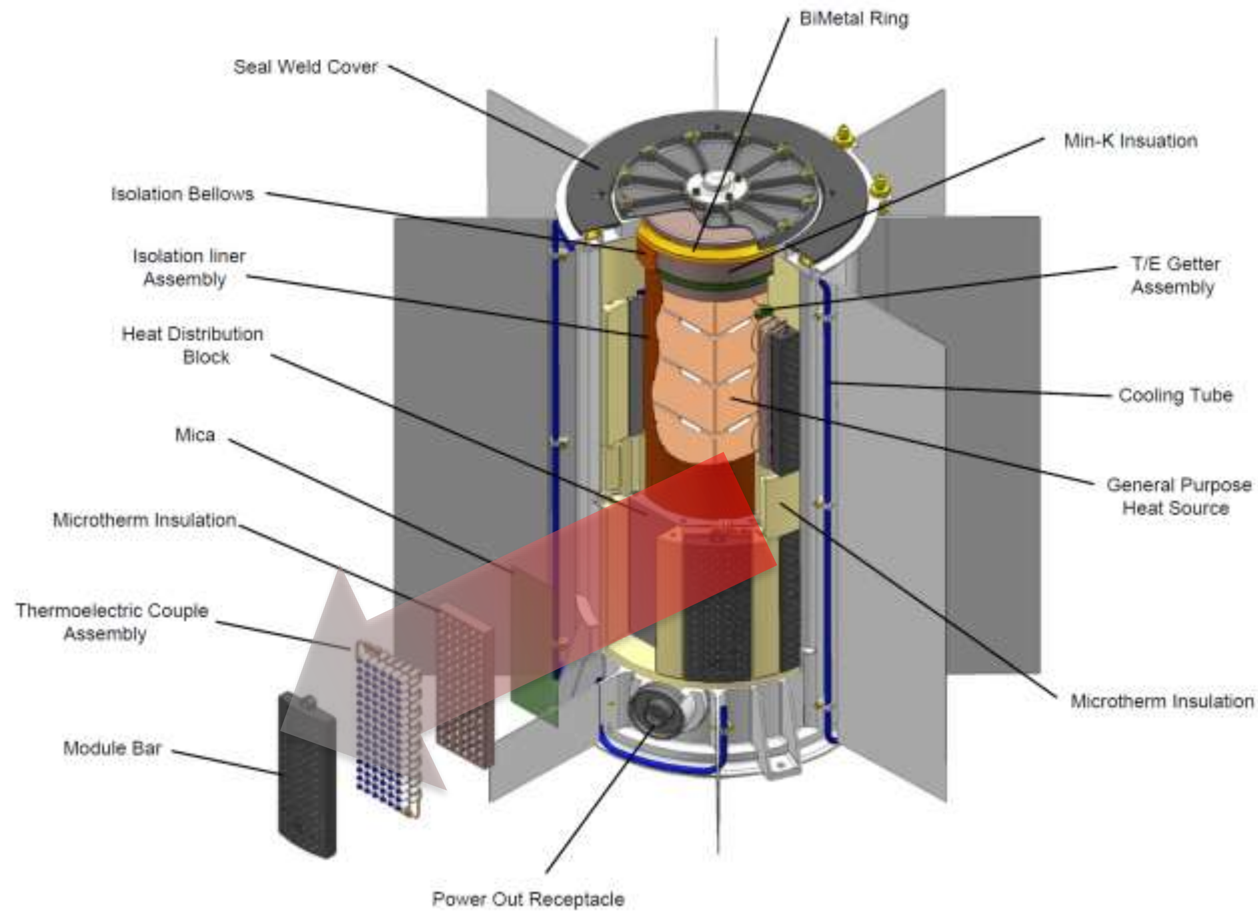
Plutonium Supply vs Current Planetary Requirements
NASA Set-Aside



Looking Ahead

- The 35kg Pu-238 allotment from DoE, with the new Pu-238 production, allows NASA to plan RPS missions into the next decade!
- Radioisotope Heater Units (RHUs) production is also being re-established
- Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) -- working well on Mars -- will be made available for future missions
- Enhancing MMRTG performance is a consideration to improve power for Europa

MMRTG Overview



eMMRTG Boosts Converter Efficiency

Technology Transfer & Maturation + MMRTG design mods = eMMRTG

Skutterudite (SKD) materials

SKD couples

Advanced SKD MMRTG modules

New SKD materials with higher performance and maximum operating temperature than MMRTG TE materials

10% increase in conversion efficiency over MMRTG couples

+

Operating Temperature rises from 520C to 600C

Liner changes boost operating temperature

14% increase in conversion efficiency over MMRTG couples

enhanced MMRTG

24% increase in conversion efficiency over MMRTG

BOL – Beginning of Life, fueling complete

Benefit to BOM & EOM Power

	MMRTG	eMMRTG	delta
Beginning of Life Power *	~117W	~145W	+28W
Degradation to End Of Mission**	3.8%	2.5%	
Power at End Of Mission **	~63W	~94W	+32W

DRAFT CBE Estimates – All statements subject to change

	Number of RTGs	Beginning of Life Power, W	Mass, kg
MMRTG	5	530	225
eMMRTG	4	560	180
For Europa			

Enhanced MMRTG improves end-of-mission power by 50%

Reduces power system mass, mission complexity, and the need for Pu-238

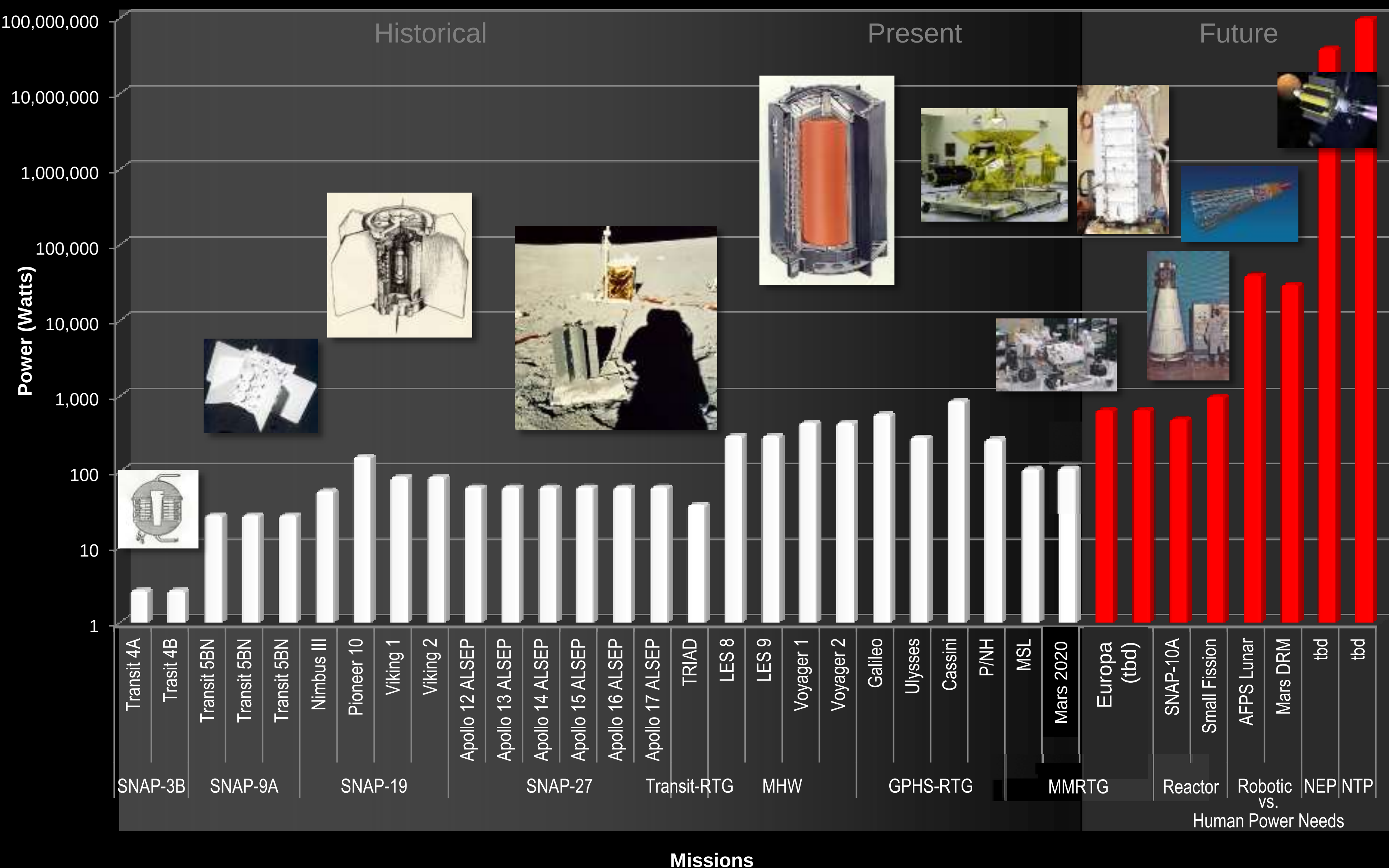
** BOL – Beginning of Life, fueling complete*
*** EOM – End of Mission, 17 years fueled*
Mars hot case assumed for BOL and EOM

Future Planning

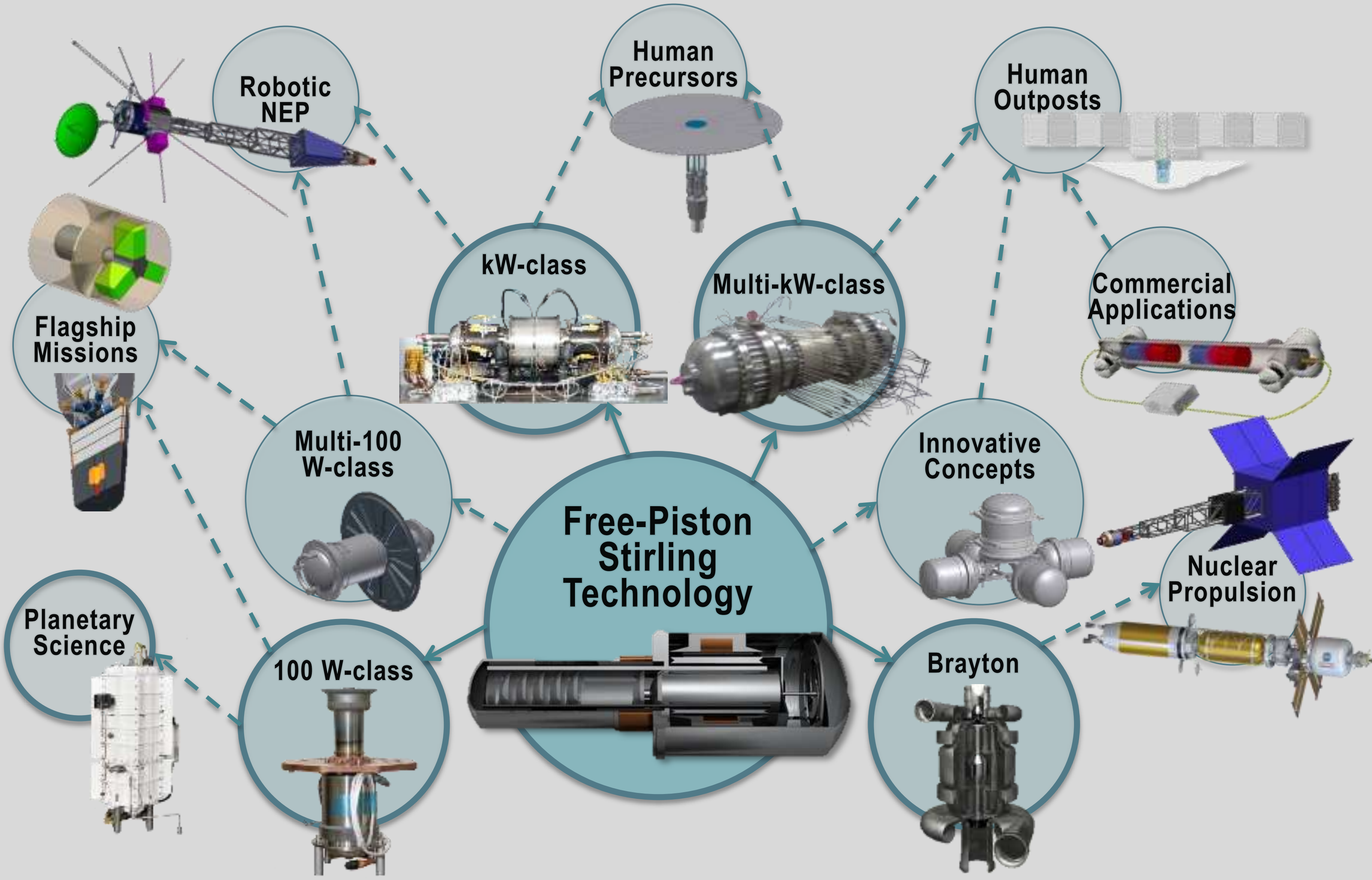
Future Planning

- Stirling technology remains valuable to enabling new capabilities
  - High efficiency offers a means to mitigate Pu-238 supply issues, and enhance performance
  - NASA is continuing technology development
- Small space fission power systems offer a potentially attractive new capability to support higher power planetary missions and an evolvable path for human exploration power
  - Planetary & Human Exploration are investigating

Nuclear Power Enabled Missions



Potential Stirling Applications



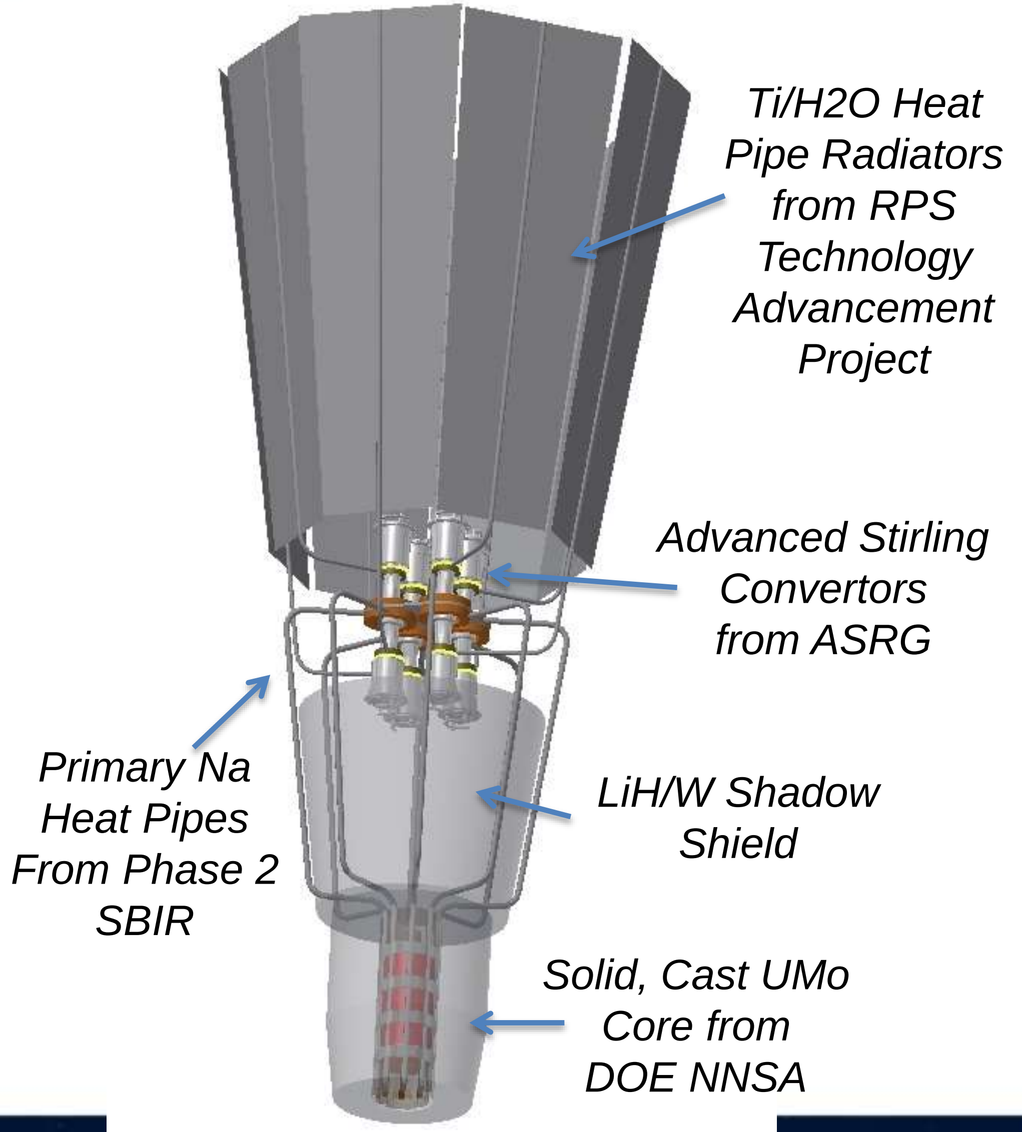
NOTE: Not to scale

Latest Kilopower Concept

National Aeronautics and Space Administration

800 Watt Output
~2.5 m Height
<400 kg Total Mass

- **8X the power of current RPS**
- **Designed to use available components and reactor fuel**
- **Testable in existing DOE facilities**

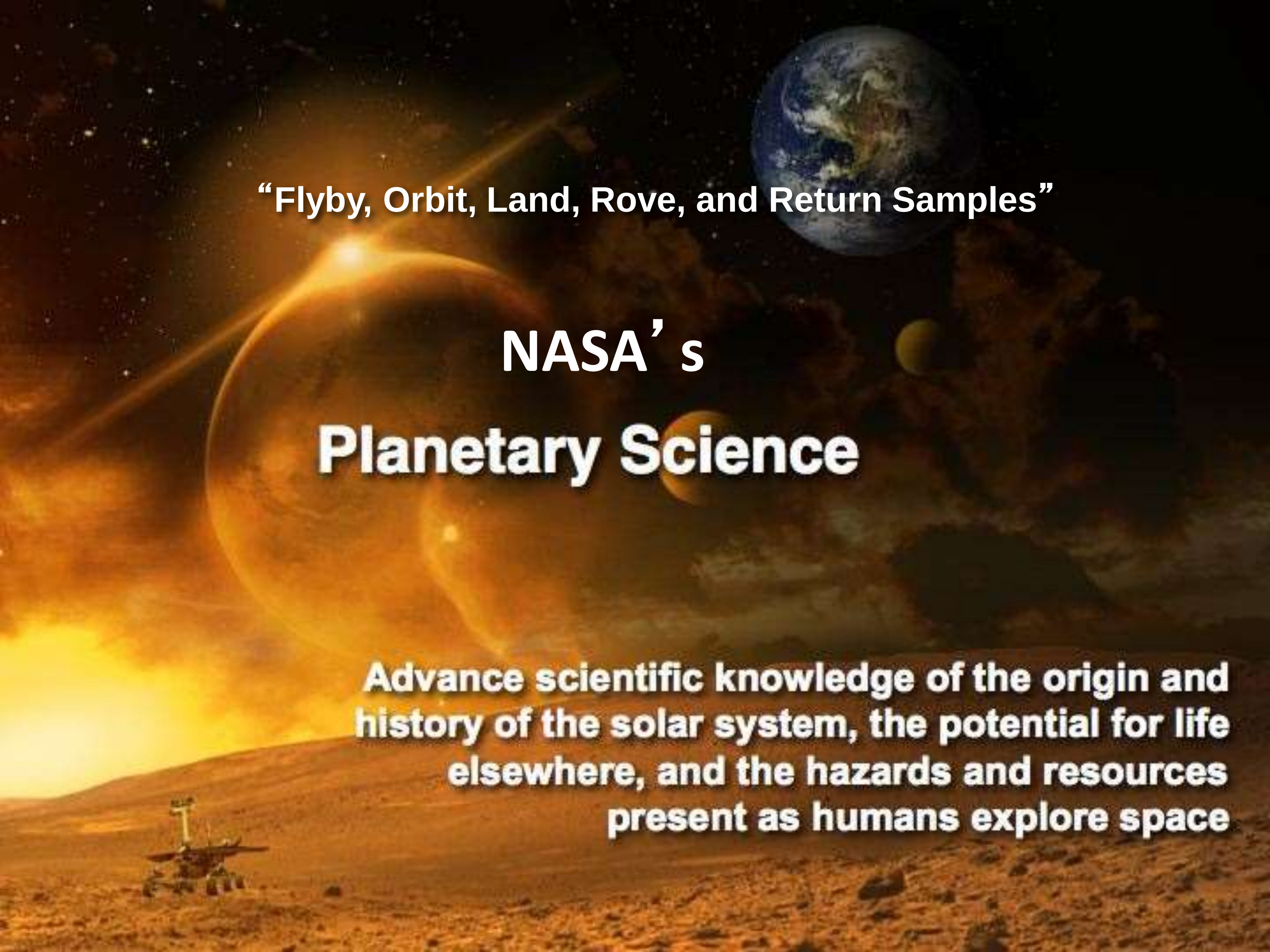


Summary & Conclusion

- Radioisotope power systems represent a unique national capability that NASA will maintain and further
- Pu-238 production and RPS are crucial capabilities for planetary exploration
  - Pu-238 restart project is progressing as planned
- With regards to infrastructure, NASA is getting its fair share
  - Costs seem to be appropriately allocated between customers in shared facilities.
  - No appearance of excess.
  - NASA and DOE are developing an agreed plan for moving forward
- NASA is looking to leverage investments in Stirling and Thermoelectric technology to develop the next generation power systems to mitigate supply issues and provide new capabilities to further exploration

“Flyby, Orbit, Land, Rove, and Return Samples”

NASA’s



Supplemental Material

Review Committee Membership

- NASA Membership
  - **Jim Adams** Chair, NASA Deputy Chief Technologist
  - **David Schurr** NASA PSD Deputy Division Director
  - **Hal Bell** NASA Deputy Chief Engineer
  - **Frank Bellinger** NASA Facilities Engineering & Real Property Director(former); NASA WFF Technical Director
  - **Kevin Gilligan** Committee Executive Secretary; NASA OCFO Program Analyst, Strategic Investments Division
- Non-NASA Consultants
  - **Ralph McNutt** APL, NRC RPS Study Chair
  - **Mark Rokey** The Aerospace Corporation
  - **Tim Frazier** DOE Radioisotope Prog. Director (former); Senior Advisor at DicksteinShapiro LLC
- Ex-Officio Observers
  - **Len Dudzinski** NASA PSD Liaison
  - **Alice Caponiti** DOE NE-75 Liaison

RPS Comparisons from a Mission Perspective

Advantage or Positive: Major (green) / Minor (blue)	**MMRTG** 	**ASRG** 
Flight Heritage	PbTe-TAGS elements were used on RPS missions 1972 to 1975	Same Stirling technology deployed in cell thousands of phone towers
	New generator design first flown on MSL	Cryocoolers have flown with similar technology (RHESSI)
	Experienced in mission implementation and S/C integration	Gas mgmt and some structure components have RTG heritage
Lifetime	Design requirement for 14 year mission after 3 year storage	Design requirement for 14 years after 3 year storage
	BOL=125 W	BOL=144 W
	EOM=68 W (at 17 years)	EOM=110 W (at 17 years)
Reliability	Passive failure modes with series/ parallel/cross-strapping of every TE element w/100s of elements per RTG	Same tech terrestrial Stirling coolers have MTBF >500,000hr, >4000 w/44M cum hrs. 50% power if one converter fails
	Flying on Curiosity	96.9 % Reliability over 17 years, based on test & analysis

RPS Comparisons from a Mission Perspective

Advantage or Positive: Major / Minor	MMRTG 	ASRG 
Radiation Hardness	Materials selected for radiation environments	All controller components rated between 500 kRad and 5 Mrad
	No shielding required to increase radiation tolerance	Standard shielding for higher radiation environments
Electromagnetic	DC only	AC & DC
	EMI needs to be addressed at the spacecraft level. Requirement below 25 nT at 1 meter.	EMI needs to be addressed at the spacecraft level. Requirement below 25 nT at 1 meter. Shielding possible for lower levels.
Vibe	No moving mechanical components	Meets requirement of < 35 N at 102 Hz with large margin
Shock	Meets 0.2 g2/Hz launch vibration requirement	Meets 0.2 g2/Hz requirement. 0.3 g2/Hz goal
Planetary Protection	Hot system is self-sterilizing	Requires VHP sterilization process

Small Nuclear Power Trade Space

National Aeronautics and Space Administration