RADIOISOTOPE POWER SYSTEMS
An Imperative for Maintaining U.S. Leadership in Space Exploration

Space Studies Board
Aeronautics and Space Engineering Board

Radioisotope Power Systems Committee
William Hoover and Ralph McNutt, Co-Chairs

With status update for Satellites Panel, Planetary Science Decadal Survey
Space Studies Board, National Research Council
Arnold and Mabel Beckman Center, 100 Academy, Irvine, CA 92617
8:45 AM 21 September 2009

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National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

Agenda

- Committee membership
- Statement of Task
- Study Schedule and Process

New Horizons spacecraft

- Findings and Recommendations

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Committee Membership

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FRANK B. McDONALD, University of Maryland, College Park
ALAN R. NEWHOUSE, Independent Consultant
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SPENCER R. TITLEY, University of Arizona, Tucson
EMANUEL TWARD, Northrop Grumman Space Technology
EARL WAHLQUIST, U.S. Department of Energy (retired)

View of Jupiter from the New Horizons spacecraft

Statement of Task

Address the following issues regarding the development and use of RPSs for NASA space missions:

- **Technical readiness and programmatic balance of NASA's RPS technology portfolio to support NASA near- and long-term mission plans**

- **Effectiveness and ability of U.S. Government agency management structures, including participating organizations, roles and responsibilities, to meet stated goals and objectives of U.S. programs for RPS capabilities within the current statutory and policy framework**

Surface of Mars from the Viking 1 lander

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Statement of Task (continued)

- Importance to the national interest of maintaining and/or re-establishing needed infrastructure at field centers, laboratories, and the private sector R&D base, given the recent curtailment of RPS program content and ambitious national goals in space exploration;
- Strategies for re-establishment of 238Pu domestic production versus the likelihood of continued procurement of Russian-produced material in view of potential competition for 238Pu fuel from other space-faring nations and the critical shortage of U.S.-owned inventory
- Identification of any actions that could be taken in the context of the overall RPS program to meet stated science and exploration goals.

Study Schedule and Process

7/1/08 Contract start date
8/11/08 Committee membership approved
9/18/08 First Meeting, Washington, D.C.
10/10/08 Site Visit to Glenn Research Center
10/15/08 Site Visit to Idaho National Laboratory
10/27/08 Second Meeting, JPL
11/13/08 Site Visit to Oak Ridge National Laboratory
12/11/08 Third Meeting, Washington, D.C.
1/12/09 Fourth Meeting, NRC Beckman Center, Irvine
1/22/09 Development of Consensus Draft
3/2/09 Report Sent to External Review
4/20/09 Report Review Complete
4/23/09 Report Delivered to Sponsor (actual)
7/1/09 Report Delivered to Sponsor (scheduled)

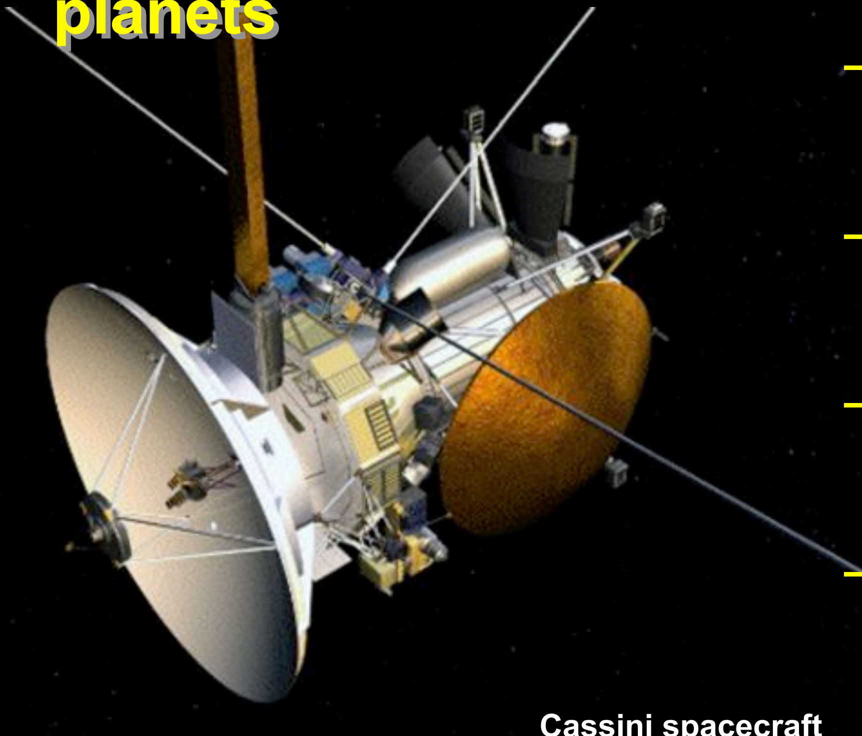
Overview

- Space exploration is important
- RPSs are vital to U.S. leadership in space exploration
- ^{238}Pu is the only viable fuel for RPSs
- ^{238}Pu is no longer being manufactured anywhere in the world
- NASA will soon use all available ^{238}Pu
- Meeting NASA's future needs will require (1) immediate action by DOE to restart production and (2) timely development and flight testing of advanced RPSs by DOE and NASA

Launch of Voyager spacecraft

Why Space Exploration?

- Enhance life on Earth
- Understand the solar system and beyond: the context of the Earth in relation to the Sun and planets
  - How and why Earth is an abode of life
  - Potential for life elsewhere
  - Origins and history of the solar system
  - Sustainable long-term human presence on the Moon and Mars



Cassini spacecraft

Why Radioisotope Power Systems?

RPSs are a core technology that has enabled U.S. leadership in space exploration

- Power for multi-year missions where sunlight is either lacking or unreliable (outer planets and the surface of the Moon and Mars)
- Enable spacecraft to operate complex instruments with high data rates for decades

Conventional RPSs use thermocouples to convert thermal energy from ^{238}Pu to electricity

- Compact, rugged, and extraordinarily reliable
- Static system (no moving parts)
- Low conversion efficiency (~6 percent)

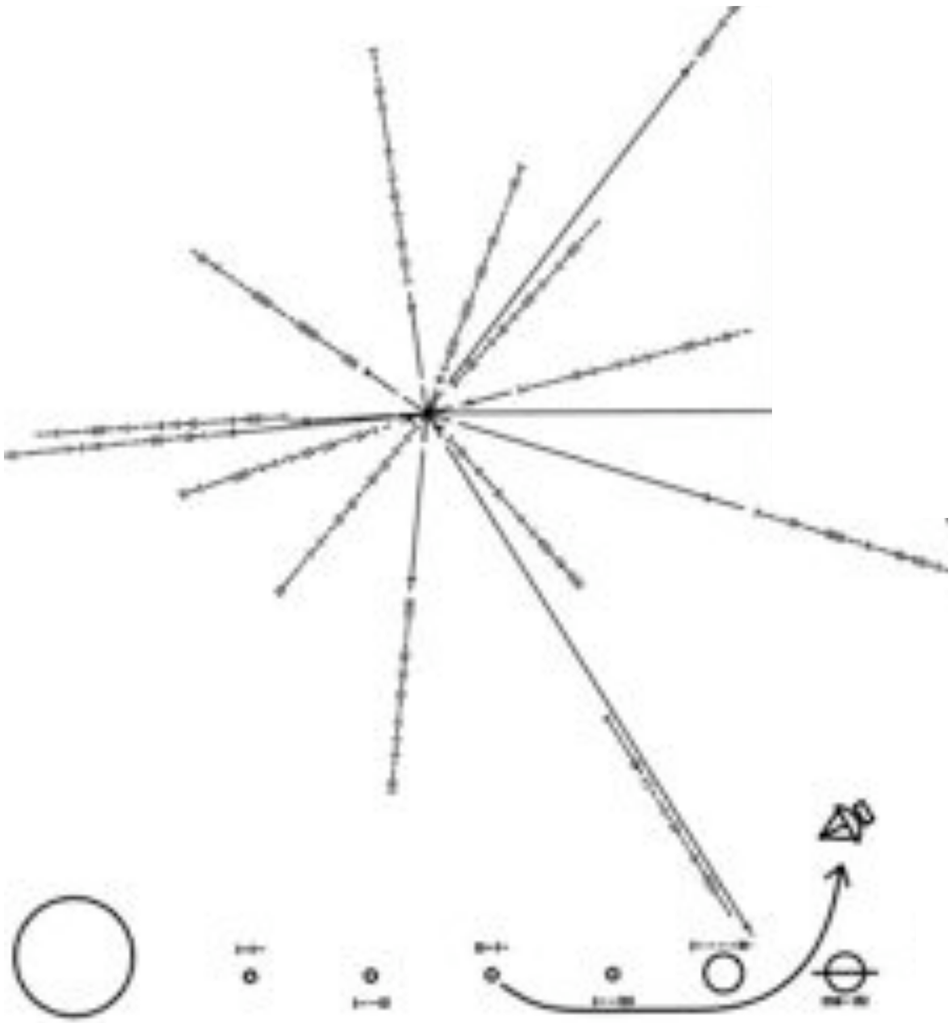
Advanced Stirling Radioisotope Generators (ASRGs)

- Not yet operated in space (reliability TBD, though technology traceable to reliable, flight-proven cryocoolers)
- Dynamic system (moving parts)
- Much more efficiency (~29 percent) means ASRGs need 1/4 as much ^{238}Pu fuel as conventional Radioisotope Thermoelectric Generators

Jupiter and four inner moons

Finding

Importance of RPSs



RPSs have been, are now, and will continue to be essential to the U.S. space science and exploration program.

Detail of plate on Pioneer 10 spacecraft

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Plutonium 238

^{238}Pu does not occur in nature

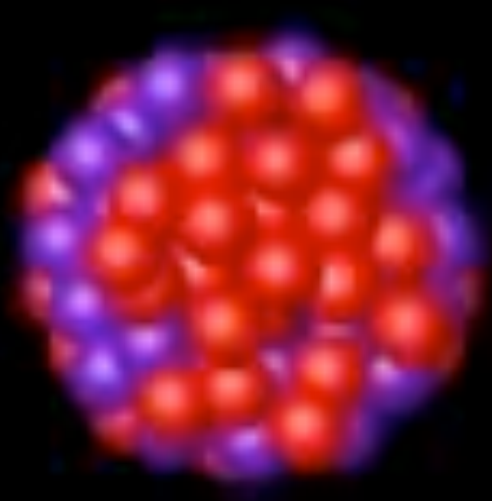
It is created by irradiating ^{237}Np in a nuclear reactor.

Unlike ^{239}Pu, ^{238}Pu CANNOT be used to produce nuclear weapons.

Pu oxide fuel pellet

Finding
^{238}Pu Supply

^{238}Pu is the only isotope suitable as an RPS fuel for long-duration missions because of its half-life, emissions, power density, specific power, fuel form, availability, and cost.



An assured supply of ^{238}Pu is required to sustain the U.S. space science and exploration program.

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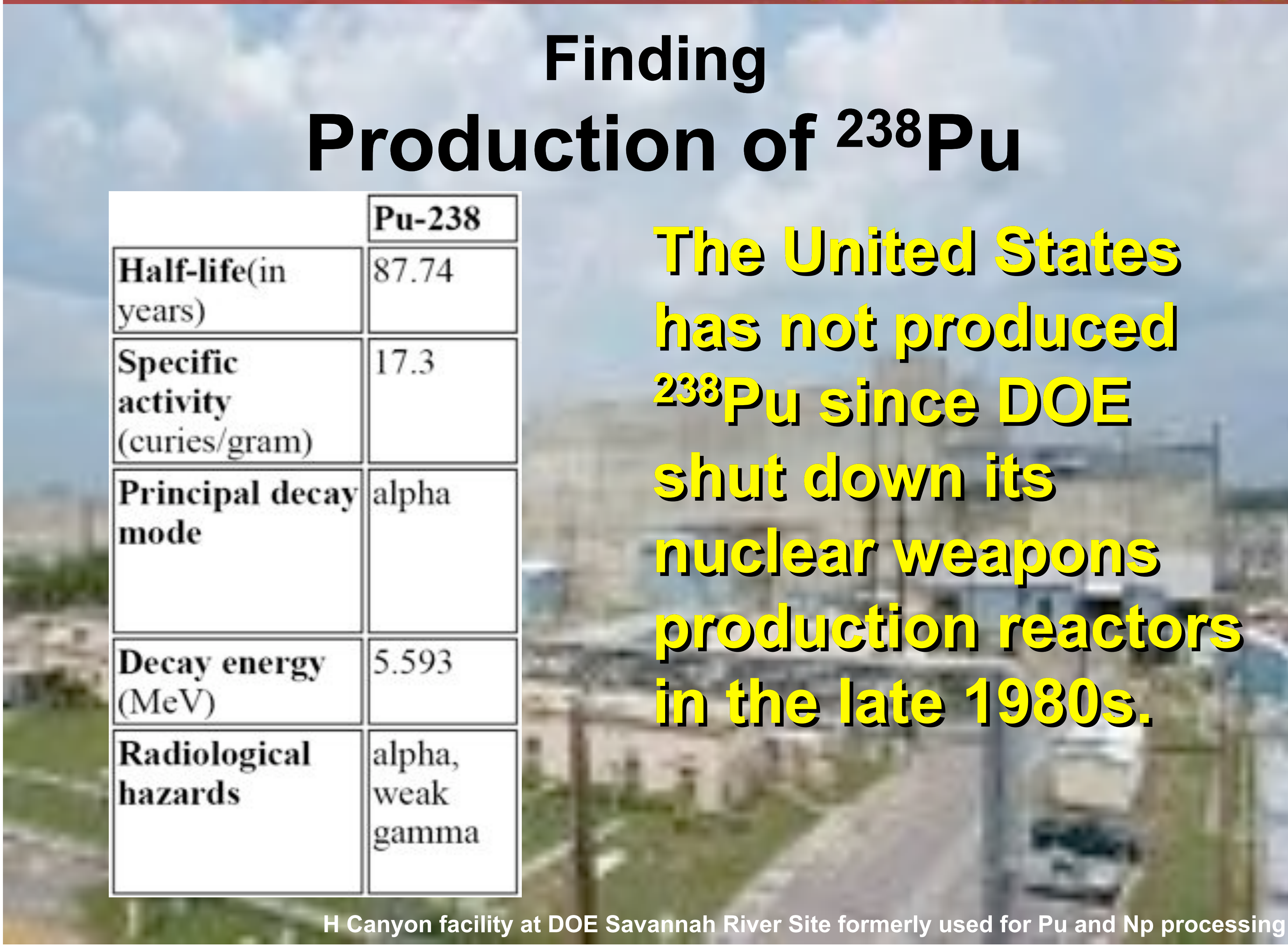
Finding

Production of ^{238}Pu

	Pu-238
Half-life(in years)	87.74
Specific activity (curies/gram)	17.3
Principal decay mode	alpha
Decay energy (MeV)	5.593
Radiological hazards	alpha, weak gamma

The United States has not produced ^{238}Pu since DOE shut down its nuclear weapons production reactors in the late 1980s.



H Canyon facility at DOE Savannah River Site formerly used for Pu and Np processing

Finding

Roles and Responsibilities

Roles and responsibilities as currently allocated between NASA and DOE are appropriate, and it is possible to address outstanding issues related to the short supply of ^{238}Pu and advanced flight-qualified RPS technology under the existing organizational structures and allocation of roles and responsibilities.

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Launch of Cassini

Finding

RPS Nuclear Safety

The U.S. flight safety review and launch approval process for nuclear systems comprehensively addresses public safety, but it introduces schedule requirements that must be considered early in the RPS system development and mission planning process.

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Finding Foreign Sources of ^{238}Pu

No significant amounts of ^{238}Pu are available in Russia or elsewhere in the world, except for the ^{238}Pu that Russia has already agreed to sell to the U.S. Procuring ^{238}Pu from Russia or other foreign nations is not a viable option.

Earth from Apollo 17

Finding

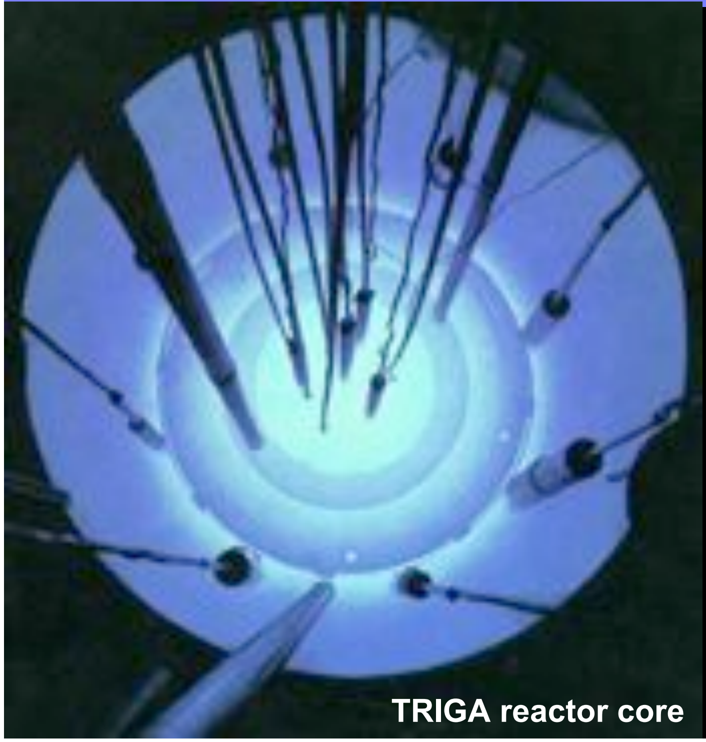
Domestic Production of ^{238}Pu

There are two viable approaches for reestablishing production of ^{238}Pu, both of which would use facilities at Idaho National Laboratory and Oak Ridge National Laboratory. These are the best options, in terms of cost, schedule, and risk, for producing ^{238}Pu in time to minimize the disruption in NASA's space science and exploration missions powered by RPSs.

Finding

Alternate Fuels & Innovative Concepts

Relying on fuels other than ^{238}Pu and/or innovative concepts for producing ^{238}Pu as the baseline for reestablishing domestic production of ^{238}Pu would increase technical risk and substantially delay the production schedule. Nevertheless, research into innovative concepts for producing ^{238}Pu, such as the use of a commercial light water reactor, may be a worthwhile investment in the long-term future of RPSs.



TRIGA reactor core

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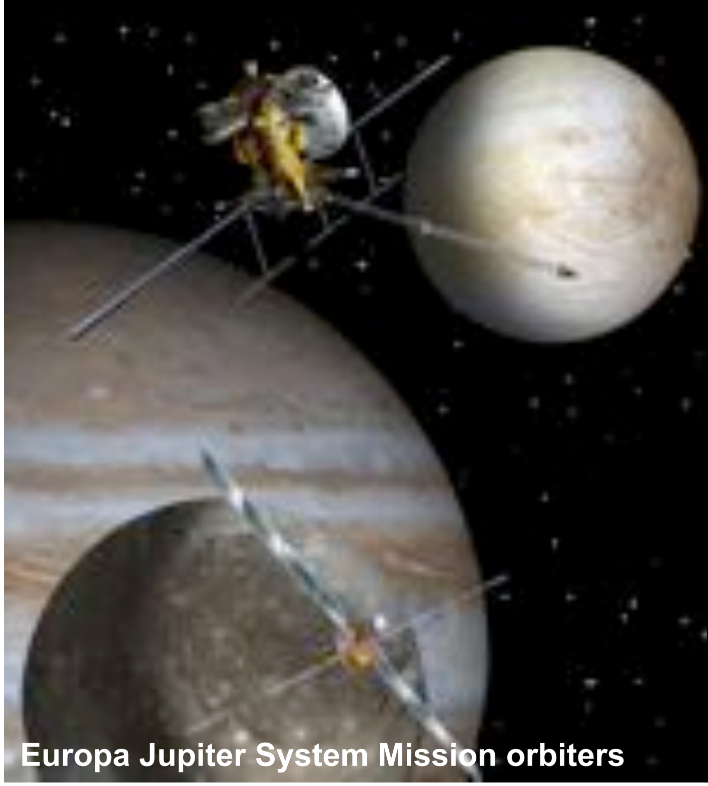
Finding

Current Impact

NASA has already been making mission-limiting decisions based on the short supply of ^{238}Pu.

Future Demand

On April 29, 2008, the NASA administrator sent a letter to the secretary of energy with an estimate of NASA's future demand for ^{238}Pu. The committee has chosen to use this letter as a conservative reference point for determining the future need for RPSs. However, the findings and recommendations in this report are not contingent on any particular set of mission needs or launch dates. Rather, they are based on a conservative estimate of future needs based on various future mission scenarios.



Europa Jupiter System Mission orbiters

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NASA's demand for ^{238}Pu, 2009-2028 (as of April 2008)

Pu (kg)	Mission	Launch Date	Watts	Type of RPS
3.5	Mars Science Laboratory	2009[a]	100	MMRTG
1.8	Discovery 12/Scout	2014	250	ASRG
24.6	Outer Planets Flagship 1	2017	600-850	MMRTG
3.5	Discovery 14	2020	500	ASRG
5.3	New Frontiers 4	2021	800	ASRG
14	Pressurized Rover 1	2022	2000	High Performance SRG [b]
14	ATHLETE Rover	2024	2000	High Performance SRG
1.8-5.3	New Frontiers 5	2026	250-800	ASRG
3.5	Discovery 16	2026	500	ASRG
14	Pressurized Rover 2	2026	2000	High Performance SRG
5.3-6.2	Outer Planets Flagship 2	2027	700-850	ASRG
14	Pressurized Rover 3	2028	2000	High Performance SRG
105-110	Total demand for Pu, 2009-2028 (kg)			
5.3-5.5	Annual demand (20-year average in kg/year)			

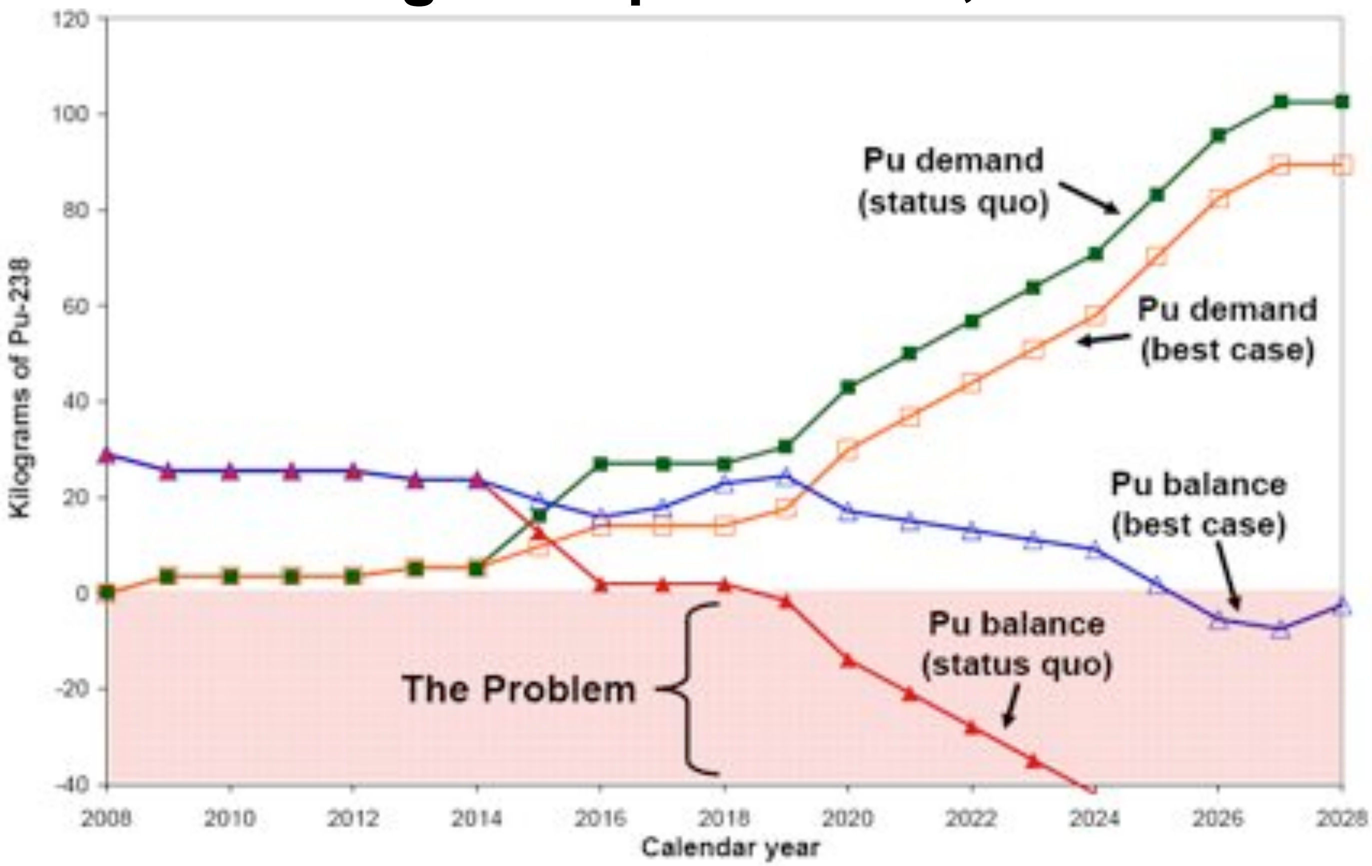
[a]The launch date for the Mars Science Laboratory mission is currently 2011.

Best-Case Estimate of ^{238}Pu Shortfall through 2028: ^{238}Pu Demand Versus Supply Subsequent to OPF 1

Mission	Pu (kg)	
Discovery 14	3.5	
New Frontiers 4	5.3	
Pressurized Rover 1	14.0	
ATHLETE Rover	14.0	
New Frontiers 5	1.8-5.3	
Discovery 16	3.5	
Pressurized Rover 2	14.0	
Outer Planets Flagship 2	5.3-6.2	
Pressurized Rover 3	14.0	
	75.4-79.8	Total ^{238}Pu demand subsequent to OPF 1
	-13.0	Remaining inventory of ^{238}Pu after OPF 1 (with ASRGs)
	62.4-66.8	Best case estimate of ^{238}Pu production needed
	-58.0	Total ^{238}Pu production if work starts in FY 2010
	4.4-8.8	Best case estimate of ^{238}Pu shortfall

Finding
Urgency

Even if the DOE budget for FY 2010 includes funds for reestablishing ^{238}Pu production, some of NASA's future demand for ^{238}Pu will not be met. Continued delays will increase the shortfall.



HIGH-PRIORITY RECOMMENDATION
^{238}Pu Production

The FY 2010 federal budget should fund the DOE to reestablish production of ^{238}Pu.

- **As soon as possible, the DOE and the OMB should request–and Congress should provide–adequate funds to produce 5 kg of ^{238}Pu per year.**
- **NASA should issue annual letters to the DOE defining future demand for ^{238}Pu.**

INL Materials and Fuels Complex

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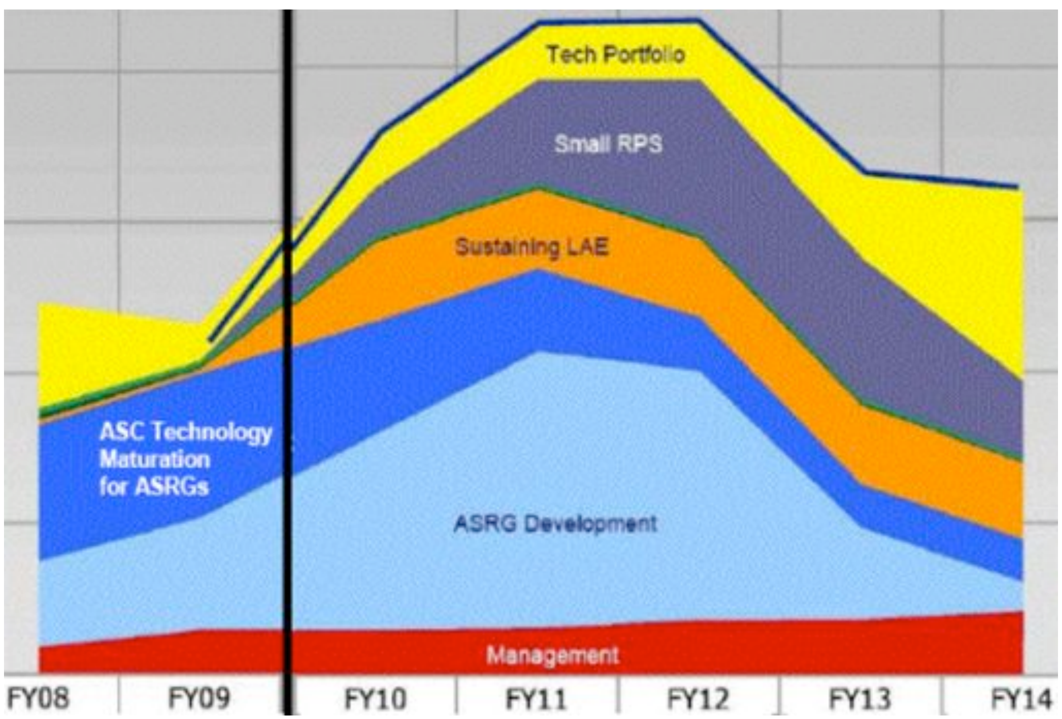
Finding

Programmatic Balance

Balance within NASA's RPS program is impossible given the current (FY 2009) budget and the focus on development of flight-ready ASRG technology. However, NASA is moving the ASRG project forward, albeit at the expense of other RPS technologies.



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Finding

Multi-Mission RTGs

It is important to the national interest to maintain the capability to produce MMRTGs, given that proven replacements do not now exist.

MMRTG for MSL at INL

Recommendation

Multi-Mission RTGs

NASA and/or the DOE should maintain the ability to produce MMRTGs.

MSL Rover

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Finding

Flight Readiness

NASA does not have a broadly accepted set of requirements and processes for demonstrating that new technology is flight ready and for committing to its use.


Small Pressurized Rover concept vehicle

Recommendation
Flight Readiness

The RPS program and mission planners should jointly develop a set of flight readiness requirements for RPSs in general and Advanced Stirling Radioisotope Generators in particular, as well as a plan and a timetable for meeting the requirements.

Recommendation

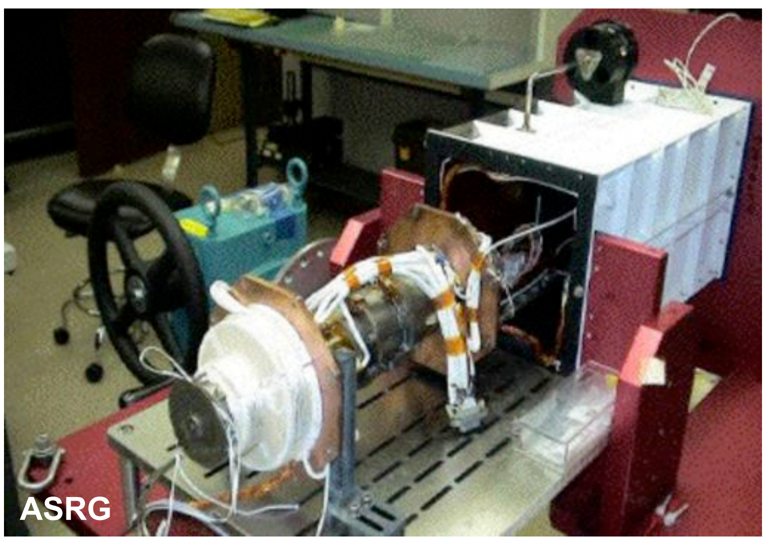
Technology Plan

NASA should develop and implement a comprehensive RPS technology plan that meets NASA's mission requirements for RPSs while minimizing NASA's demand for ^{238}Pu. This plan should include, for example:

- **A prioritized set of program goals.**
- **A prioritized list of technologies.**
- **A list of critical facilities and skills.**
- **A plan for documenting and archiving knowledge base.**
- **A plan for maturing technology in key areas, such as reliability, power, power degradation, electrical interfaces between the RPS and the spacecraft, thermal interfaces, and verification and validation.**
- **A plan for assessing and mitigating technical and schedule risk.**

HIGH-PRIORITY RECOMMENDATION
ASRG Development

NASA and DOE should complete the development of the ASRG with all deliberate speed, with the goal of demonstrating that ASRGs are a viable option for the Outer Planets Flagship 1 mission. As part of this effort, NASA and the DOE should put final design ASRGs on life test as soon as possible (to demonstrate reliability on the ground) and pursue an early opportunity for operating an ASRG in space (e.g., on Discovery 12).



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Bottom Line

- ^{238}Pu is essential for space exploration
- All available ^{238}Pu will be consumed ~2020
- It will take so long to reestablish ^{238}Pu production, and production rates will be so limited, that immediate action is required by DOE to meet NASA's needs thru 2028
  - Even so, NASA's future needs will not be met without concurrent, timely completion of ASRG development and deployment


HFIR fuel core at ORNL

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The Day of Reckoning Has Arrived

Update: Status of H.R. 3183

5 May - NRC study co-chairs briefed staff of NASA, DOE, Congress, OMB, and OSTP

7 May - NRC Report released to public

7 May - Administration FY2010 budget proposes $30M for restart of domestic ^{238}Pu production

9 July - Calendar No. 104 Report SENATE 111-045

Plutonium-238 Production Restart.- The Committee recommends no funding for this program at this time.

12 July - Congressional mandated report from OSTP on domestic ^{238}Pu due

13 July - HOUSE OF REPRESENTATIVES Report 111-203

Plutonium-238 Production Restart…. The Committee recommends $10,000,000 for Pu-238 production start-up and directs the Department to provide its start-up plan, including the role and contribution of users, within 90 days of enactment of this Act.

27 July - STATEMENT OF ADMINISTRATION POLICY on H.R. 3183 *…* *Office of Nuclear Energy*. … In addition, the Administration strongly urges the Congress to restore funding to re-establish a domestic Pu-238 production capability, which is essential to make sure Pu-238 will be available when needed for planned NASA missions as well as future national security applications

29 July - Senate notifies House of its action in insisting on amendments and appoints conferees - Pu-238 funding is one of many items in play for conference

Briefings to Date

- 5 May 2009
  - Congressional staff
  - NASA and DOE staff
  - OMB and OSTP staff
- 10 July 2009
  - NASA Planetary Science Subcommittee
- 4 August 2009
  - (abridged) 7th International Energy Conversion Engineering Conference (IECEC)
    - Plenary Session: The Future of Radioisotope Power Systems for Space Exploration and Space Science
    - http://www.aiaa.org/agenda.cfm?lumeetingid=1894&dateget=04-Aug-09#session12001
- 16 September 2009
  - (abridged) AIAA Space 2009 Conference & Exposition