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

Agenda

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

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
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
• 238Pu is the only viable fuel for RPSs
• 238Pu is no longer being manufactured anywhere in the world
• NASA will soon use all available 238Pu
• 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

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
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 $^{238}\text{Pu}$ 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 $^{238}\text{Pu}$ fuel as conventional Radioisotope Thermoelectric Generators

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

Plutonium 238
$^{238}\text{Pu}$ does not occur in nature.
It is created by irradiating $^{237}\text{Np}$ in a nuclear reactor.
Unlike $^{239}\text{Pu}$, $^{238}\text{Pu}$ CANNOT be used to produce nuclear weapons.

$^{238}\text{Pu}$ Supply
$^{238}\text{Pu}$ 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 $^{238}\text{Pu}$ is required to sustain the U.S. space science and exploration program.
Finding Production of $^{238}$Pu

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

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half-life (in years)</td>
<td>87.74</td>
</tr>
<tr>
<td>Specific activity</td>
<td>17.3</td>
</tr>
<tr>
<td>Principal decay mode</td>
<td>alpha</td>
</tr>
<tr>
<td>Decay energy (MeV)</td>
<td>5.593</td>
</tr>
<tr>
<td>Radiological hazards</td>
<td>alpha, weak gamma</td>
</tr>
</tbody>
</table>

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.

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.

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.
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.

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.
### NASA’s demand for $^{238}\text{Pu}$, 2009-2028 (as of April 2008)

<table>
<thead>
<tr>
<th>Pu (kg)</th>
<th>Mission</th>
<th>Launch Date</th>
<th>Watts</th>
<th>Type of RPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>Mars Science Laboratory</td>
<td>2009</td>
<td>100</td>
<td>MMRTG</td>
</tr>
<tr>
<td>1.8</td>
<td>Discovery 12/Scout</td>
<td>2014</td>
<td>250</td>
<td>ASRG</td>
</tr>
<tr>
<td>24.6</td>
<td>Outer Planets Flagship 1</td>
<td>2017</td>
<td>600-850</td>
<td>MMRTG</td>
</tr>
<tr>
<td>3.5</td>
<td>Discovery 14</td>
<td>2020</td>
<td>500</td>
<td>ASRG</td>
</tr>
<tr>
<td>5.3</td>
<td>New Frontiers 4</td>
<td>2021</td>
<td>800</td>
<td>ASRG</td>
</tr>
<tr>
<td>14</td>
<td>Pressurized Rover 1</td>
<td>2022</td>
<td>2000</td>
<td>High Performance SRG</td>
</tr>
<tr>
<td>14</td>
<td>ATHLETE Rover</td>
<td>2024</td>
<td>2000</td>
<td>High Performance SRG</td>
</tr>
<tr>
<td>1.8-5.3</td>
<td>New Frontiers 5</td>
<td>2026</td>
<td>250-800</td>
<td>ASRG</td>
</tr>
<tr>
<td>3.5</td>
<td>Discovery 16</td>
<td>2026</td>
<td>500</td>
<td>ASRG</td>
</tr>
<tr>
<td>14</td>
<td>Pressurized Rover 2</td>
<td>2026</td>
<td>2000</td>
<td>ASRG</td>
</tr>
<tr>
<td>5.3-6.2</td>
<td>Outer Planets Flagship 2</td>
<td>2027</td>
<td>700-850</td>
<td>ASRG</td>
</tr>
<tr>
<td>14</td>
<td>Pressurized Rover 3</td>
<td>2028</td>
<td>2000</td>
<td>ASRG</td>
</tr>
</tbody>
</table>

**105-110** Total demand for Pu, 2009-2028 (kg)

**5.3-5.5** Annual demand (20-year average in kg/year)

*The launch date for the Mars Science Laboratory mission is currently 2011.*

### Best-Case Estimate of $^{238}\text{Pu}$ Shortfall through 2028:

#### $^{238}\text{Pu}$ Demand Versus Supply Subsequent to OPF 1

<table>
<thead>
<tr>
<th>Mission</th>
<th>Pu (kg)</th>
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<tbody>
<tr>
<td>Discovery 14</td>
<td>3.5</td>
</tr>
<tr>
<td>New Frontiers 4</td>
<td>5.3</td>
</tr>
<tr>
<td>Pressurized Rover 1</td>
<td>14.0</td>
</tr>
<tr>
<td>ATHLETE Rover</td>
<td>14.0</td>
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<tr>
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<tr>
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<td>5.3-6.2</td>
</tr>
<tr>
<td>Pressurized Rover 3</td>
<td>14.0</td>
</tr>
</tbody>
</table>

75.4-79.8 Total $^{238}\text{Pu}$ demand subsequent to OPF 1

-13.0 Remaining inventory of $^{238}\text{Pu}$ after OPF 1 (with ASRGs)

62.4-66.8 Best case estimate of $^{238}\text{Pu}$ production needed

-58.0 Total $^{238}\text{Pu}$ production if work starts in FY 2010

4.4-8.8 Best case estimate of $^{238}\text{Pu}$ shortfall

### Finding Urgency

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

### HIGH-PRIORITY RECOMMENDATION

**$^{238}\text{Pu}$ Production**

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

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

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.

Recommendation Multi-Mission RTGs
NASA and/or the DOE should maintain the ability to produce MMRTGs.

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.
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 $^{238}\text{Pu}$. 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).

Bottom Line

- $^{238}\text{Pu}$ is essential for space exploration
- All available $^{238}\text{Pu}$ will be consumed ~2020
- It will take so long to reestablish $^{238}\text{Pu}$ 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
RADIOISOTOPE POWER SYSTEMS
The Day of Reckoning Has Arrived