Free Executive Summary

Radioisotope Power Systems: An Imperative for Maintaining U.S. Leadership in Space Exploration

Radioisotope Power Systems Committee, National Research Council

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Summary

For nearly 50 years, the United States has led the world in the scientific exploration of space. U.S. spacecraft have circled Earth, landed on the Moon and Mars, orbited Jupiter and Saturn, and traveled beyond the orbit of Pluto and out of the ecliptic. These spacecraft have sent back to Earth images and data that have greatly expanded human knowledge, though many important questions remain unanswered.

Spacecraft require electrical energy. This energy must be available in the outer reaches of the solar system where sunlight is very faint. It must be available through lunar nights that last for 14 days, through long periods of dark and cold at the higher latitudes on Mars, and in high-radiation fields such as those around Jupiter. Radioisotope power systems (RPSs) are the only available power source that can operate unconstrained in these environments for the long periods of time needed to accomplish many missions, and plutonium-238 (^{238}Pu) is the only practical isotope for fueling them. The success of historic missions such as Viking and Voyager, and more recent missions such as Cassini and New Horizons, clearly show that RPSs—and an assured supply of ^{238}Pu—have been, are now, and will continue to be essential to the U.S. space science and exploration program.

Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs) are the only RPS currently available. MMRTGs convert thermal energy released by the natural radioactive decay of ^{238}Pu to electricity using thermocouples. This is a proven, highly reliable technology with no moving parts.

The Advanced Stirling Radioisotope Generator (ASRG) is a new type of RPS, and it is still being developed. An ASRG uses a Stirling engine (with moving parts) to convert thermal energy to electricity. Stirling engine converters are much more efficient than thermocouples. As a result, ASRGs produce more electricity than MMRTGs, even though they require only one-fourth as much ^{238}Pu. It remains to be seen, however, when development of a flight-qualified ASRG will be completed.

THE PROBLEM

Plutonium-238 does not occur in nature. Unlike ^{239}Pu, it is unsuitable for use in nuclear weapons. Plutonium-238 has been produced in quantity only for the purpose of fueling RPSs. In the past, the United States had an adequate supply of ^{238}Pu, which was produced in facilities that existed to support the U.S. nuclear weapons program. The problem is that no ^{238}Pu has been produced in the United States since the Department of Energy (DOE) shut down those facilities in the late 1980s. Since then, the U.S. space program has had to rely on the inventory of ^{238}Pu that existed at that time, supplemented by the purchase of ^{238}Pu from Russia. However, Russian facilities to produce ^{238}Pu were also shut down many years ago, and the DOE will soon take delivery of its last shipment of ^{238}Pu from Russia. The committee does not believe that there is any additional ^{238}Pu (or any operational ^{238}Pu production facilities) available anywhere in the world. The total amount of ^{238}Pu available for NASA is fixed, and essentially all of it is already dedicated to support several pending missions—the Mars Science Laboratory, Discovery 12, the Outer Planets Flagship 1 (OPF 1), and (perhaps) a small number of additional missions with a very small demand for ^{238}Pu. If the status quo persists, the United States will not be able to provide RPSs for any subsequent missions.

Reestablishing domestic production of ^{238}Pu will be expensive (the cost will likely exceed $150 million). Previous proposals to make this investment have not been enacted, and cost seems to be the major impediment. However, regardless of why these proposals have been rejected, the day of reckoning has arrived. NASA is already making mission-limiting decisions based on the short supply of ^{238}Pu.

NASA is stretching out the pace of RPS-powered missions by eliminating RPSs as an option for some missions and delaying other missions that require RPSs until more ^{238}Pu becomes available. Procuring ^{238}Pu from Russia or other foreign nations is not a viable option because of schedule and national security considerations. Fortunately, there are two viable approaches for reestablishing production of ^{238}Pu in the United States. Both of these approaches would use existing reactors at DOE facilities at Idaho National Laboratory and Oak Ridge National Laboratory with minimal modification, but a large capital investment in processing facilities would still be needed. Nonetheless, 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.

IMMEDIATE ACTION IS REQUIRED

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.[1] 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. The estimate of future demand for ^{238}Pu (which is about 5 kg/year) is also consistent with historic precedent.

The orange line [hollow square data points] in Figure S-1 shows NASA's cumulative future demand for ^{238}Pu in a best-case scenario (which is to say, a scenario in which NASA's future RPS-mission set is limited to those missions listed in the NASA administrator's letter of April 2008, the ^{238}Pu required by each mission is the smallest amount listed in that letter, and ASRGs are used to power OPF 1). The green line [solid square data points] shows NASA's future demand if the status quo persists (which is to say, if OPF 1 uses MMRTGs.)

Once the DOE is funded to reestablish production of ^{238}Pu, it will take about 8 years to begin full production of 5 kg/year. The red and blue lines [triangular data points] in Figure S-1 show the range of future possibilities for ^{238}Pu balance (supply minus demand). A continuation of the status quo, with MMRTGs used for OPF 1 and no production of ^{238}Pu, leads to the largest shortfall, and the balance curve drops off the bottom of the chart. The best-case scenario, which assumes that OPF 1 uses ASRGs and DOE receives funding in fiscal year (FY) 2010 to begin reestablishing its ability to produce ^{238}Pu, yields the smallest shortfall (as little as 4.4 kg). However, it seems unlikely that all of the assumptions that are built into the best-case scenario will come to pass. MMRTGs are still baselined for OPF 1, there remains no clear path to fight qualification of ASRGs, and FY 2010 funding for ^{238}Pu production remains more a hope than an expectation. Thus, the actual shortfall is likely to be somewhere between the best-case curve and the status-quo curve in Figure S-1, and it could easily be 20 kg or more over the next 15 to 20 years.

It has long been recognized that the United States would need to restart domestic production of ^{238}Pu in order to continue producing RPSs and maintain U.S. leadership in the exploration of the solar system. The problem is that the United States has delayed taking action to the point that the situation has become critical. Continued inaction will exacerbate the magnitude and the impact of future ^{238}Pu shortfalls, and it will force NASA to make additional, difficult decisions to reduce the science return of some missions and to postpone or eliminate other missions until a source of ^{238}Pu is available.

The schedule for reestablishing ^{238}Pu production will have to take into account many factors, such as construction of DOE facilities, compliance with safety and environmental procedures, and basic physics. This schedule cannot be easily or substantially accelerated, even if much larger appropriations are made available in future years in an attempt to overcome the effects of ongoing delays. The need is real, and there is no substitute for immediate action.

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[1] Letter from the NASA Administrator Michael D. Griffin to Secretary of Energy Samuel D. Bodman, April 29, 2008 (reprinted in Appendix C).

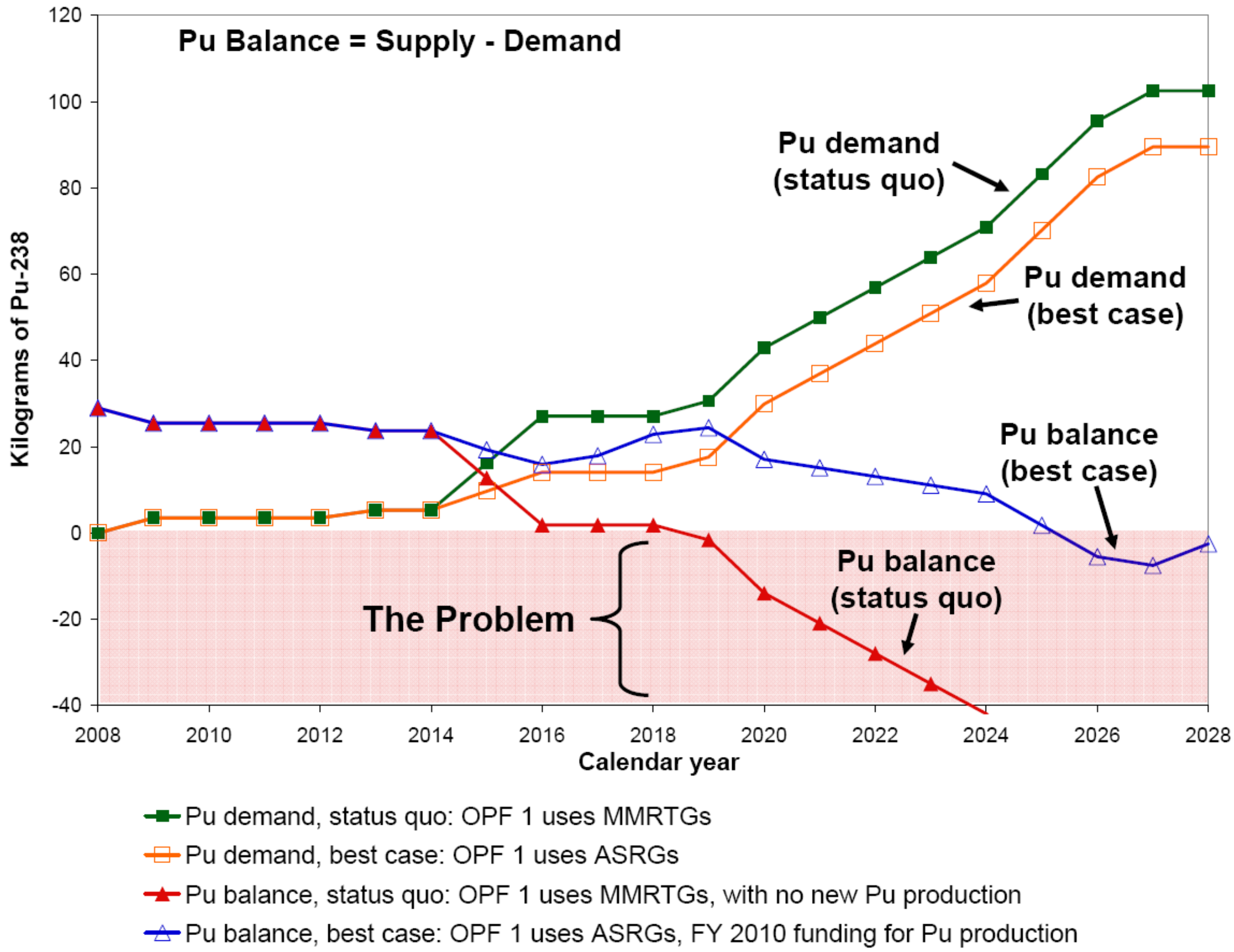

FIGURE S-1 Potential ^{238}Pu demand and net balance, 2008 through 2028.

HIGH-PRIORITY RECOMMENDATION. Plutonium-238 Production. The fiscal year 2010 federal budget should fund the Department of Energy (DOE) to reestablish production of ^{238}Pu.

- As soon as possible, the DOE and the Office of Management and Budget 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 the future demand for ^{238}Pu.

DEVELOPMENT OF A FLIGHT-READY ASRG

Advanced RPSs are required to support future space missions while making the most out of whatever ^{238}Pu is available. Until 2007, the RPS program was a technology development effort. At that time, the focus shifted to development of a flight-ready ASRG, and that remains the current focus of the RPS program. The program received no additional funds to support this new tasking, so funding for several other important RPS technologies was eliminated, and the budget for the remaining RPS technologies was cut. As a result, the RPS program is not well balanced. Indeed, balance is impossible given the current (FY 2009) budget and the focus on development of flight-ready ASRG technology. However, the focus on ASRG development is well aligned with the central, and more pressing, issue that threatens the future of RPS-powered missions: the limited supply of ^{238}Pu. The RPS program should continue to support NASA's mission requirements for RPSs while minimizing NASA's demand for ^{238}Pu. NASA should continue to move the ASRG project forward, even though this has come at the expense of other RPS technologies.

Demonstrating the reliability of ASRGs for a long-life mission is critical—but has yet to be achieved. The next major milestones in the advancement of ASRGs are to freeze the design of the ASRG, to conduct system testing that verifies that all credible life-limiting mechanisms have been identified and assessed, and to demonstrate that ASRGs are ready for flight. In lieu of any formal guidance or requirements concerning what constitutes flight readiness, ongoing efforts to advance ASRG technology and demonstrate that it is flight ready are being guided by experience gained from past programs and researchers' best estimates about the needs and expectations of project managers for future missions. While this approach has enabled progress, the establishment of formal guidance for flight certification of RPSs in general and ASRGs in particular would facilitate the acceptance of ASRGs as a viable option for deep-space missions and reduce the impact that the limited supply of ^{238}Pu will have on NASA's ability to complete important space missions.

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 the 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.

RECOMMENDATION. Multi-Mission RTGs. NASA and/or the Department of Energy should maintain the ability to produce Multi-Mission Radioisotope Thermoelectric Generators.

HIGH-PRIORITY RECOMMENDATION. ASRG Development. NASA and the Department of Energy (DOE) should complete the development of the Advanced Stirling Radioisotope Generator (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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Radioisotope Power Systems

An Imperative for Maintaining U.S. Leadership in Space Exploration

Radioisotope Power Systems Committee
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Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences
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Preface

Radioisotope power systems (RPSs) such as radioisotope thermoelectric generators provide electrical power for spacecraft and planetary probes that cannot rely on solar energy. To support the continued availability of the RPSs required to power NASA space missions, Congress and NASA requested that the National Research Council (NRC) undertake a study of RPS technologies and systems.

The NRC formed the Radioisotope Power Systems Committee to produce this report in response to House Report 110-240 on the Commerce, Justice, Science, and Related Agencies Appropriations Bill, 2008. This report assesses the technical readiness and programmatic balance of NASA's radioisotope power systems technology portfolio in terms of its ability to support NASA's near- and long-term mission plans. In addition, the report discusses related infrastructure, the effectiveness of other federal agencies involved in relevant research and development, and strategies for re-establishing domestic production of ^{238}Pu, which serves as the fuel for RPSs. To put the discussion of RPSs in context, the report includes some information regarding other options (i.e., solar power and space nuclear power reactors), but a detailed assessment of these alternatives is beyond the scope of the statement of task. A complete copy of the statement of task appears in Appendix A.

The Radioisotope Power Systems Committee met four times between September 2008 and January 2009 at NRC facilities in Washington, D.C., and Irvine, California, and at the Jet Propulsion Laboratory in Pasadena, California. In addition, small delegations of committee members and staff visited NASA's Glenn Research Center and the Department of Energy's Idaho National Laboratory and Oak Ridge National Laboratory.

RPS technology has been a critical element in establishing and maintaining U.S. leadership in the exploration of the solar system. Continued attention to and investment in radioisotope power systems will enable the success of historic missions such as Viking and Voyager, and more recent missions such as Cassini and New Horizons, to be carried forward into the future.

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Ralph L. McNutt, Jr.
Co-Chairs, Radioisotope Power Systems Committee

Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council (NRC). The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

William B. Adkins, Adkins Strategies, LLC,
Carl A. Alexander, Battelle Memorial Institute,
Jimmy L. Allison, Boeing Company (technical fellow),
Mohamed S. El-Genk, University of New Mexico,
Kathleen F. Harer, NASA and DOE (retired),
Anthony K. Hyder, University of Notre Dame,
E. Philip Muntz, University of Southern California,
Zack T. Pate, World Association of Nuclear Operations (chairman emeritus), and
John Spencer, Southwest Research Institute.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Louis J. Lanzerotti, New Jersey Institute of Technology. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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