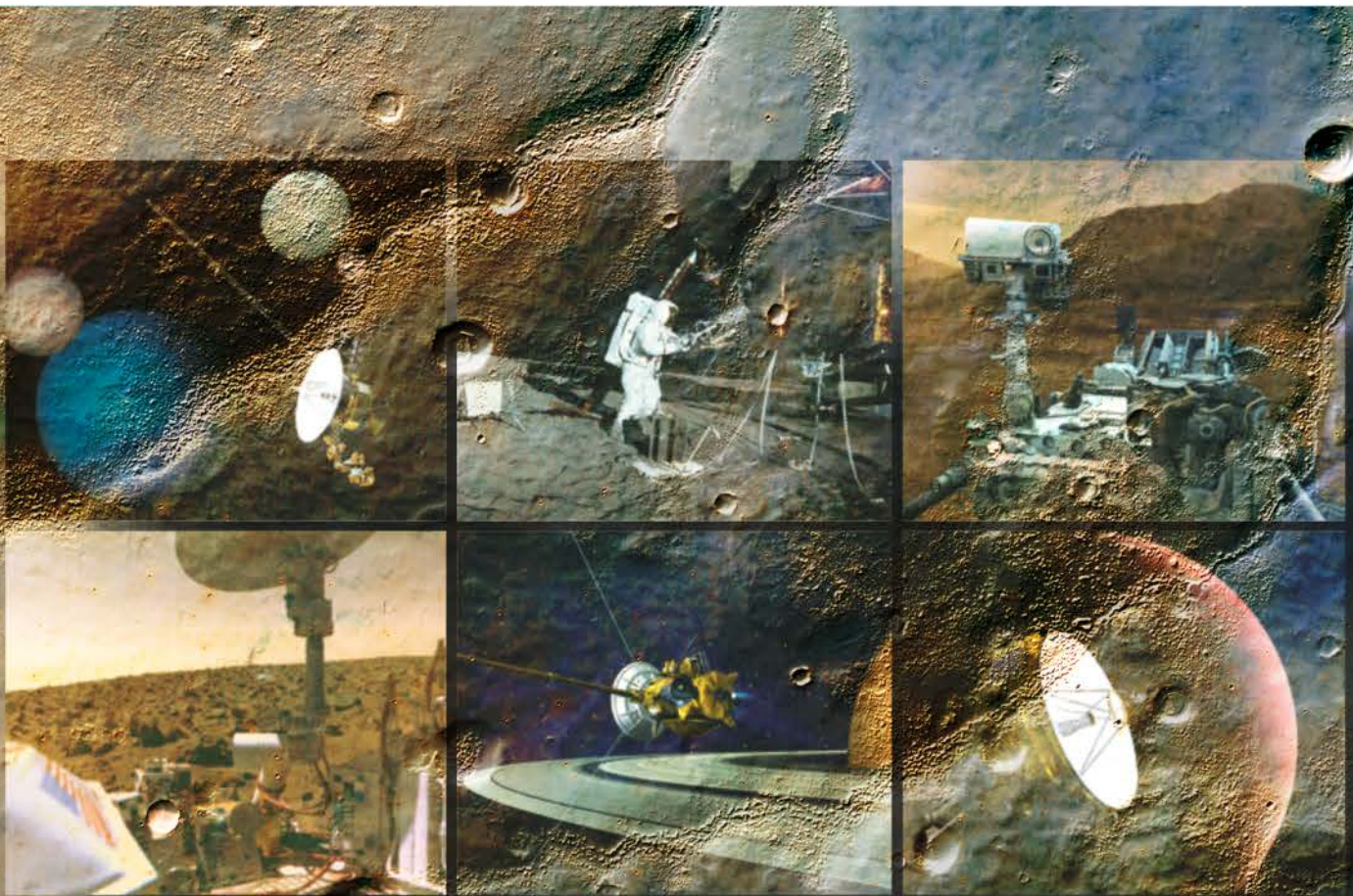




RADIOISOTOPE POWER SYSTEMS PROGRAM OFFICE

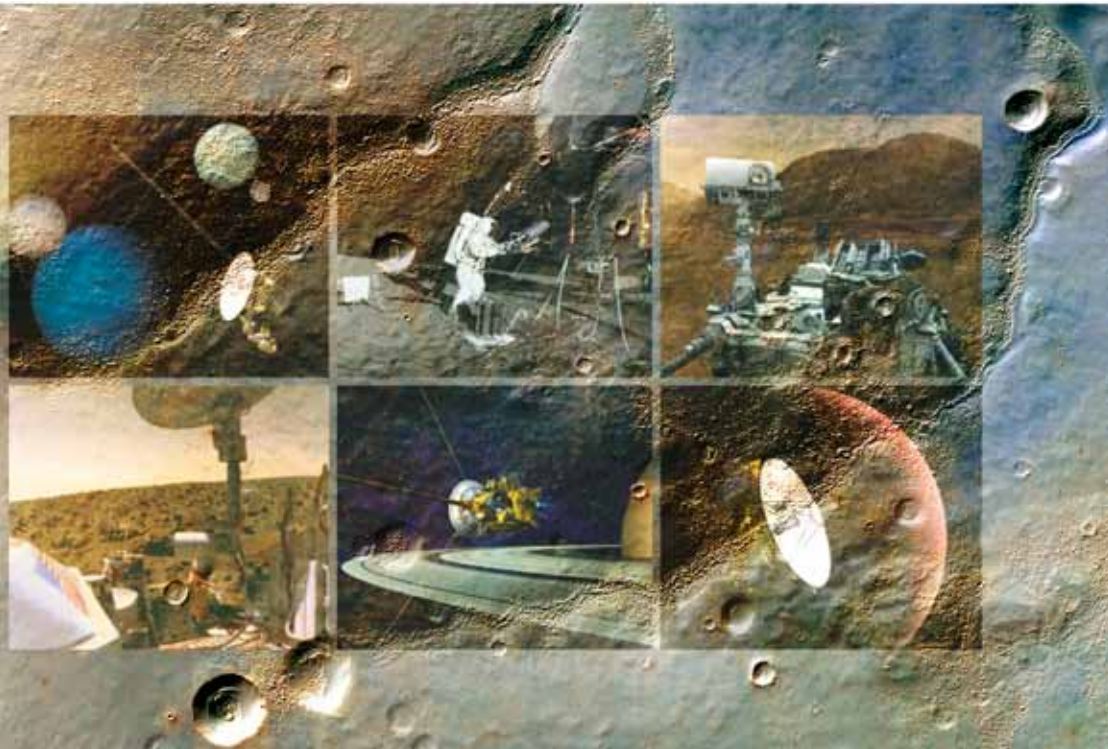


FISCAL YEAR 2012 FINAL REPORT

TABLE OF CONTENTS

Program Executive Foreword	2
Program Manager Foreword	3
The Radioisotope Power Systems Program	
Mission Success	4
Mars Science Laboratory (Curiosity)	4
Radioisotope Power Systems Program Team	
Department of Energy	5
NASA Glenn Research Center	5
Applied Physics Laboratory	5
Jet Propulsion Laboratory	5
Radioisotope Power Systems Program Content	
Program Control	6
Program Planning and Assessment	6
Multi-Mission Launch Approval Engineering	8
Education and Public Outreach	10
Radioisotope Power Systems Projects Content	
Advanced Stirling Radioisotope Generator	12
Technology Advancement Project	15
M1 Project	18
The Future of Radioisotope Power Systems	19

On the front cover: A mosaic of images representing the vast history in space of Radioisotope Power Systems: (left to right and top to bottom) artist's concept of Voyager; Apollo Lunar Surface Experiment Package (ALSEP) Mission, which is powered by a Radioisotope Thermoelectric Generator; artist's concept of the Mars Science Laboratory, "Curiosity"; Viking Lander image on Mars; artist's concept of Cassini; artist's concept of New Horizons.



PROGRAM EXECUTIVE FOREWORD



LEONARD DUDZINSKI

Planetary Science Division

Program Executive, Radioisotope Power Systems Program Office

Fiscal year 2012 (FY12) was a strong year for the Radioisotope Power Systems (RPS) Program. I was impressed by the perseverance and tenacity of the team in solving technical, programmatic, and procedural challenges to advance the development of the Advanced Stirling Radioisotope Generator (ASRG), the availability of RPS, and the state of technology for future systems. At the same time, we were all inspired by the image of the first new RPS in more than two decades powering the Mars Science Laboratory—the Nation’s latest triumph on Mars. The United States remains the leader in deep space exploration because of our ability to develop and fly RPS.

The ASRG project is proving a new technology for more efficient power in space through countless hours of research, development, and testing. Significant technical challenges were identified, studied, and successfully resolved in FY12. We are pressing forward to complete the ASRG for a flight before 2020. We view this success as critical to enabling a wide array of new and more frequent missions to revolutionize the exploration of our solar system.

The RPS Program team is working hard to expand the reaches of future exploration by always looking for innovative ways to enhance the already proven RPS technologies. The Technology Advancement Project continues to push the refinement of current technology while discovering new ways to power spacecraft to reach challenging destinations in our solar system and beyond. More capable, more efficient RPS will result from the hard work done in this area.

Hand in hand with these efforts, the program is laying the groundwork for future successes by building on the past and the present. We are gathering a knowledge base from those experienced in using RPS and enhancing processes so that future missions can gain approval, integrate, and fly RPS more efficiently. This year NASA and the Department of Energy (DOE) celebrated the profound success of the Multi-Mission Radioisotope Thermoelectric Generator on the Mars Science Laboratory and, with this opportunity, reached the public through education and outreach efforts with the message of the value of RPS.

What is most important about what we do is the potential we have to benefit every life through discoveries powered by RPS. As you look through this report, I hope that, like me, you can appreciate the value of the hard work put forward by our team.

PROGRAM MANAGER FOREWORD



JOHN HAMLEY

Program Manager, Radioisotope Power Systems Program Office

It is a pleasure to share with you the FY12 report for the RPS Program. This report highlights some of the key accomplishments in the program office as well as in the project areas.

The ASRG project made outstanding accomplishments throughout the fiscal year that were crucial to the development of flight hardware. Technical and scheduling issues identified in the ASRG Final Design Review will be mitigated in early FY13. The fabrication of flight hardware has begun, and the schedule relief provided by uncoupling the ASRG delivery date from a launch schedule will be used to further mitigate risk.

The Technology Advancement Project is a world leader in technological breakthroughs and keeps the RPS Program at the front of RPS development. The RPS Program continues to develop thermoelectric energy conversion technologies at higher efficiency levels with new materials because thermoelectrics are expected to continue to have challenging mission applications.

Unfortunately, none of the missions proposing to utilize the ASRG were selected for flight in the recent Discovery 12 procurement. The ASRG was prepared to support these missions and will continue to drive toward the completion of flight hardware. The program has initiated a project called “M1” that will act as a surrogate mission—supporting the completion of a fueled and tested qualification unit and two unfueled flight units in 2016, subject to adequate funding and support, as if it were a planetary science mission. The qualification unit will remain on extended test, and the flight units will be stored at a Department of Energy national laboratory.

The RPS Program and projects continue to foster excellent working relationships with the DOE, the Jet Propulsion Laboratory, the John Hopkins University Applied Physics Laboratory, and our industrial and academic partners. Their expertise has been crucial to the advancement of RPS and related technologies.

I am very proud of the team we have assembled, and their accomplishments are detailed in this report.

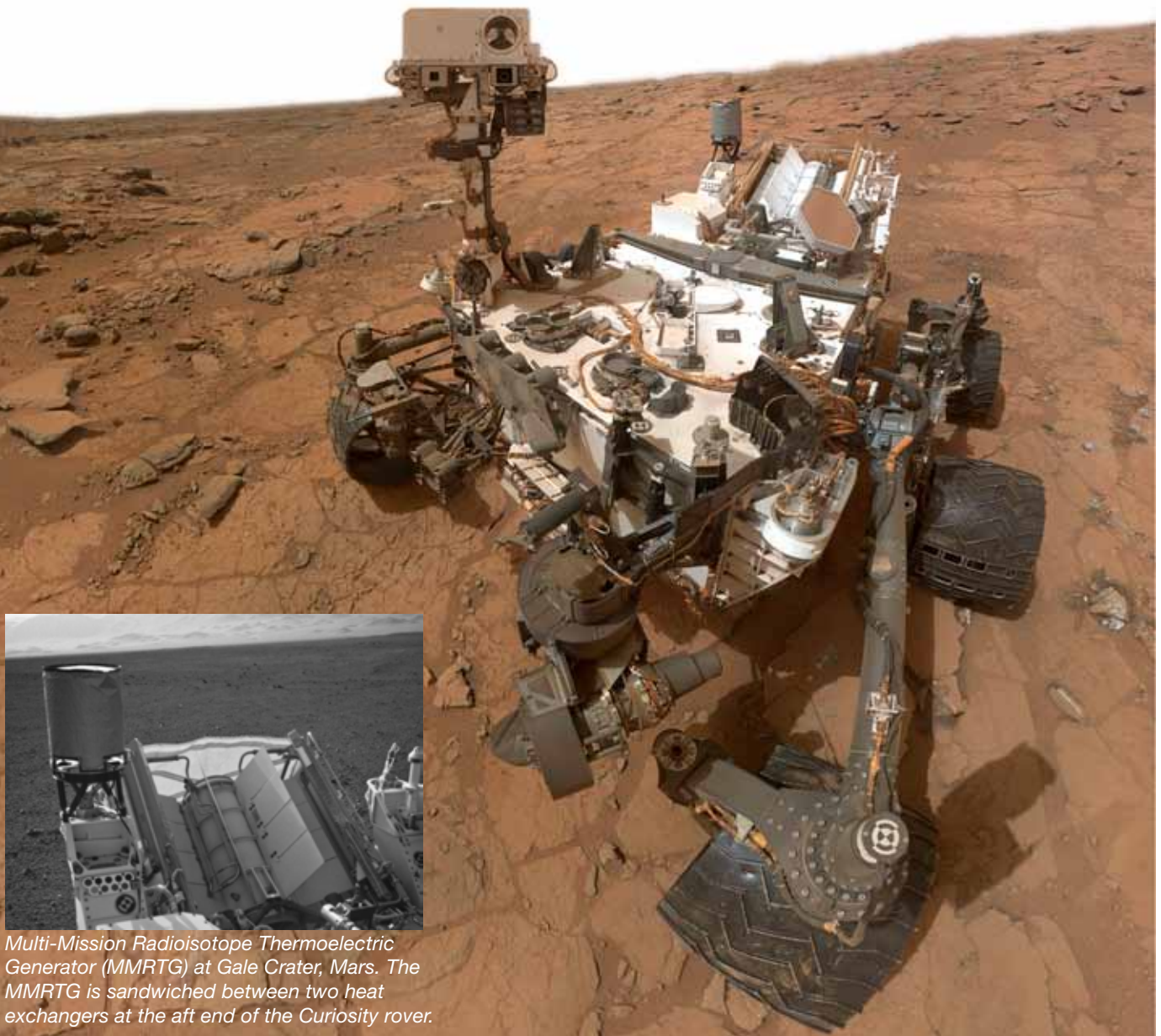
RADIOISOTOPE POWER SYSTEMS PROGRAM

MISSION SUCCESS

MARS SCIENCE LABORATORY (CURIOSITY)

The Mars Science Laboratory landed on the planet Mars on August 6, 2012. Radioisotope Power Systems are at the heart of operations for the Curiosity rover via use of a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), which was developed for flight by the DOE. RPS Program partner the Jet Propulsion Laboratory operates and manages the Mars Science Laboratory and is the lead center for this mission. Electrical power and thermal stability via waste heat are supplied to the rover and its subsystems through the use of an MMRTG. This type of power supply will give the mission an operating lifespan on Mars' surface of at least a full Martian year (687 Earth days).

More regions of Mars are opened up to exploration, via use of the MMRTG, giving mission managers more choices as the planet is explored. Lessons learned from the use of an RPS in Curiosity are already being presented and reviewed in the RPS Program to better construct future missions.



Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) at Gale Crater, Mars. The MMRTG is sandwiched between two heat exchangers at the aft end of the Curiosity rover.

RADIOISOTOPE POWER SYSTEMS PROGRAM

RADIOISOTOPE POWER SYSTEMS PROGRAM TEAM

DEPARTMENT OF ENERGY

The Department of Energy (DOE) is responsible for the design, manufacture, and fueling of the ASRG and Multi-Mission Thermoelectric Generators (MMRTGs). A Memorandum of Understanding (MOU) signed by NASA and DOE in 1991 established the productive, ongoing partnership between the two agencies in developing and operating RPS for space exploration.



NASA GLENN RESEARCH CENTER

The NASA Glenn Research Center is host to the RPS Program and its projects. The RPS Program office and projects are managed within the Space Flight Systems Directorate and rely on matrix participation of the Engineering, Safety and Mission Assurance, and Research and Technology directorates to perform its content. Program leadership areas include Program Control, Program Planning and Assessment, and System Engineering.



The projects hosted at Glenn are the ASRG (supports the DOE ASRG project), the Technology Advancement Project (TAP), and the M1 project (currently in formulation). Other activities at Glenn include support to Education and Public Outreach as well as local support service contracting aiding in program and project implementation.

APPLIED PHYSICS LABORATORY

Recognizing the rich history of the Johns Hopkins University Applied Physics Laboratory (JHU APL) in implementing RPS missions, its systems engineering expertise, and its understanding of the ASRG stemming from a decade of mission concept studies hosting the ASRG, the RPS Program employs JHU APL to assist in systems and mission analyses. JHU APL provides leadership in RPS reliability and life certification, supports modeling of the ASRG, and provides historical information on the integration and performance of operational systems. When warranted for specific improvements to core system technologies, the RPS Program selectively uses JHU APL as a source of development capabilities for systems technologies.



JET PROPULSION LABORATORY

The NASA-Caltech Jet Propulsion Laboratory (JPL) assists the RPS Program in its implementation of missions based on RPS. JPL provides lead functions in Multi-Mission Launch Approval Engineering and Education and Public Outreach. Critical expertise at JPL in thermoelectric energy conversion supports the Technology Advancement Project, while further assistance is provided in the areas of mission analysis and being a part of the Government management team for ASRG.



RADIOISOTOPE POWER SYSTEMS PROGRAM CONTENT

PROGRAM CONTROL

Program Control executes the RPS Program's responsibilities for financial operations and is responsible for the following programmatic activities:

- Scheduling
- Configuration management
- Risk management (in conjunction with the Safety and Mission Assurance Technology Advancement Project)
- Graphics and general office support

Highlights of Fiscal Year 2012 Accomplishments

It was a very challenging yet successful year in the Program Control area of the RPS Program. Work began early in FY12 to establish a single tool to enable the reporting of RPS data at all levels with official numbers. This project management tool developed by the NASA Ames Research Center greatly increased the efficiency of reporting program information. Program Control improved the Planning, Programming, Budgeting, and Execution (PPBE) process by incorporating new tools to ensure that the input from all projects and areas was accurately captured and tracked. Consequently, PPBE data ensured that the RPS Program's top priorities were adequately funded to stay on schedule and were delivered to the Planetary Science Division. The configuration management area was significantly strengthened with the addition of new personnel. The configuration management plan also was updated to incorporate best practices, and these were flowed down into the RPS projects.

Key Events and Milestones

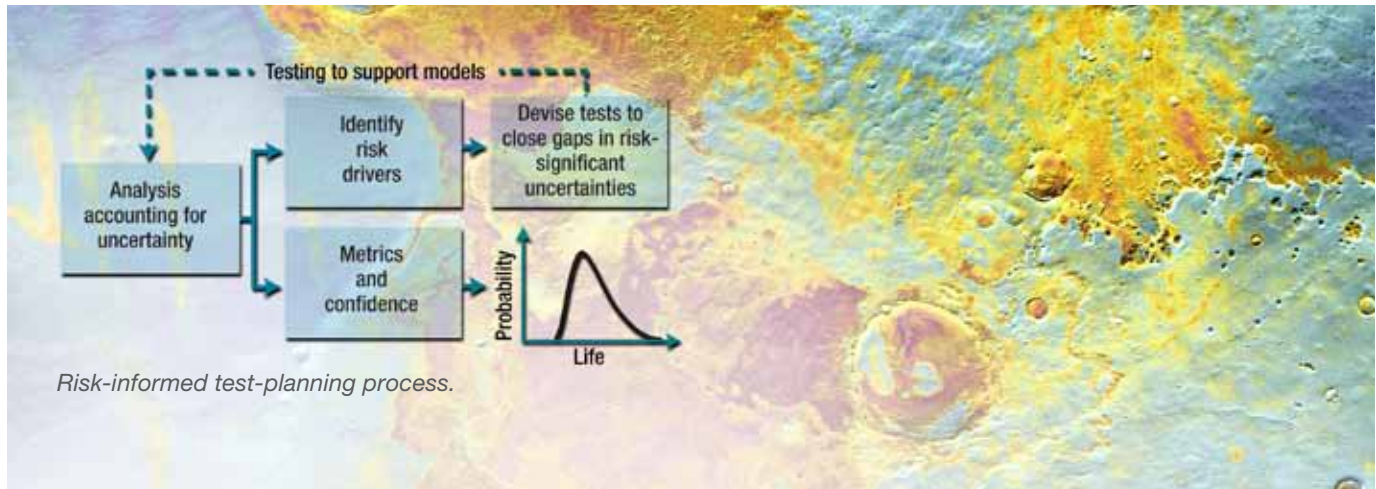
- Delivered the Project Management Tool Work Breakdown Structure to the NASA Ames Research Center to allow for automated reports; the structure was used to improve the RPS PPBE process.
- Ended FY12 with over 99 percent of FY12 New Operating Authority obligated, meeting NASA requirements

PROGRAM PLANNING AND ASSESSMENT

The Program Planning and Assessment (PP&A) Element is responsible for developing and maintaining the implementation strategy of the RPS Program to meet the requirements and expectations of planetary science stakeholders. This crosscutting area ensures that the flow of research and technology development is responsive to the future needs of missions by performing mission studies that drive RPS-level capabilities and determine mission-imposed requirements and subsequent system studies that drive generator design requirements. PP&A identifies the tactical approach that the program uses to implement the requirements across the various program and project areas. The work within PP&A is executed by a joint team across NASA, APL, and JPL and is directly supported by the RPS Program's Systems Engineering and Integration (SE&I) team.



RADIOISOTOPE POWER SYSTEMS PROGRAM



Highlights of Fiscal Year 2012 Accomplishments

PP&A and SE&I developed a number of program-guiding documents, including both life and flight certification standards. These standards establish analysis and test guidelines for RPS flight and lifetime qualifications and develop a set of relevant flight-readiness requirements for any RPS. The Goal Based Testing approach to life verification also was developed. This approach, which recommended the adoption of the risk-informed testing/analysis framework, forces an early agreement for the understanding of what the lifetime requirements are and how to confirm them among all stakeholders. Models developed to analyze and predict system life with respect to the lifetime requirements will focus the testing program on understanding and reducing the uncertainties in risk-significant failure mechanisms. Reliability analysis and testing will be integrated in a mutually supportive manner. Finally, the process encourages the inclusion of all heritage and test data regardless of source and type.

PP&A also conducted a number of studies and activities focused on determining the future RPS needs of the planetary mission stakeholder community, including several mission studies

- To determine the breakpoint between 100-watt-class RPS and larger power class systems
- To understand at what power level mission architectures could benefit more from a fission conversion power system than from a large RPS
- To determine areas where ASRG robustness and mission usability should be increased

System studies for both thermoelectric and Stirling generators were conducted to improve the capability to predict system power. Continuation of the testing of the MMRTG couples allowed the life prediction software to be updated on the basis of empirical data. The Stirling degradation mechanisms were analyzed, and initial elements of the life prediction software were developed.

A synopsis of one of the studies conducted by PP&A in 2012 follows. More detailed information on any of the PP&A topics can be obtained by contacting the RPS Program.

Large RPS Breakpoint Study

This Breakpoint Study analyzed the need for and appropriate power of higher power versions of the current 100-watt-class radioisotope power sources, the ASRG, and the MMRTG. The study focused on outer planet mission concepts where solar power is not a suitable option. The mission utility of higher power RPS was assessed considering notional mission instruments, high-performance attitude control, high-rate data communications, electric propulsion, space vehicle RPS accommodations, and launch site RPS integration. The following observations were made concerning the power and energy needs of the missions:

RADIOISOTOPE POWER SYSTEMS PROGRAM

- Many missions may require only 150- to 400-watt average power, but outer planet missions could require from 600 to greater than 1,000 watts.
- Both the spacecraft bus and science payload could benefit if power was less constrained. Hundreds of watts would enable the use of sensors like penetrating radars or Light Detection and Ranging Systems (LIDARS) and the use of reaction wheels instead of thrusters for attitude control.
- Telecommunication could readily utilize higher power, 500 to 1,000 watts, with higher power amplifiers enabling higher data rates.
- Electric propulsion, particularly Hall effect thrusters, is usable at powers above 600 watts, with performance improving at higher powers.

A large RPS on the order of 650 to 700 watts would benefit the outer planet mission community. A larger RPS would enable consideration of a radioisotope electric propulsion mission, with propellant mass savings allowing smaller launch vehicles and/or additional instruments with higher power demands. Communication data rates could benefit from the additional power provided. Missions with larger power demands could use multiple 100-watt-class systems; however challenges with integration and the engineering desire for the greatest simplicity of spacecraft design could drive the need for the availability of higher power RPS.

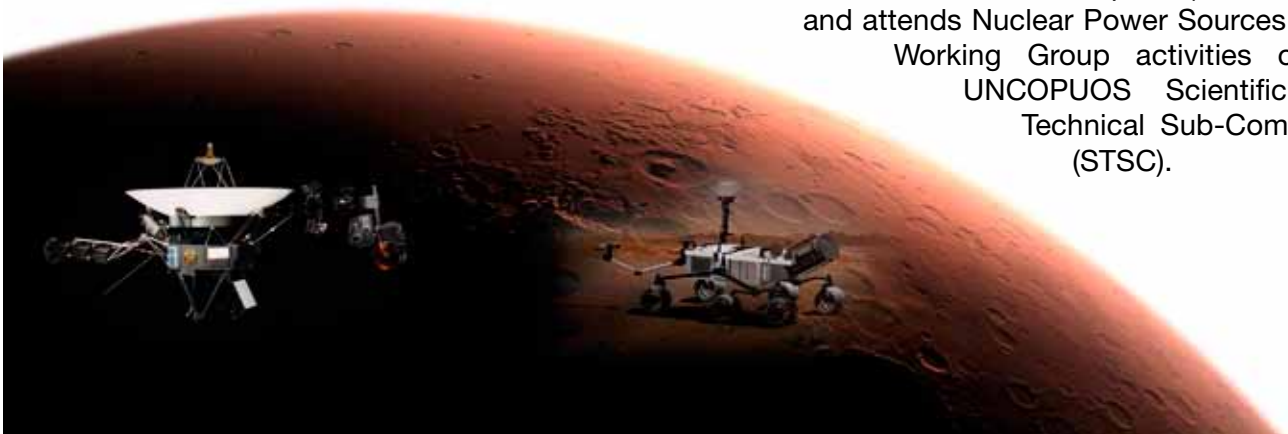
Key Events and Milestones

- First of two unfueled MMRTG flight systems complete on shelf, awaiting mission need
- Life prediction modeling code for both ASRG and MMRTG updated, increasing production capability
- Five major program guidance documents established
- Two mission studies and key mission-enabling questions completed

MULTI-MISSION LAUNCH APPROVAL ENGINEERING

Jet Propulsion Laboratory Launch Approval Engineering Office

The Multi-Mission Launch Approval Engineering (MMLAE) effort supporting the RPS Program leverages the existing JPL Launch Approval Engineering (LAE) Office. This office conducts LAE activities necessary to satisfy national and NASA policies and regulations regarding space nuclear power development and use, including the formal launch approval process. The LAE Office coordinates with, and conducts activities in concert with, NASA Headquarters, the Department of Energy, and other Federal agencies. In addition, the MMLAE Office participates in U.S. Interagency Group meetings of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) and attends Nuclear Power Sources (NPS) Working Group activities of the UNCOPUOS Scientific and Technical Sub-Committee (STSC).



RADIOISOTOPE POWER SYSTEMS PROGRAM

Highlights of Fiscal Year 2012 Accomplishments

In FY12, the MMLAE team provided key contributions to the Science Mission Directorate's RPS Program in four areas: National Environmental Policy Act (NEPA) Compliance; Aerospace Nuclear Safety Engineering (ANSE), Risk Communication, and MMLAE tasks.

The MMLAE team at JPL supported NASA Headquarters' efforts to maintain and work toward implementing an LAE plan to support a potential selection of a Discovery 12 mission that would baseline the use of an RPS. In addition, MMLAE ANSE finalized, and the NASA Kennedy Space Center approved, the baseline Multi-Mission Databook Revision 0, which covers the Atlas V and Falcon 9 launch vehicles that would have supported a Discovery 12 selection of a proposed RPS mission.

MMLAE defined monthly Solid Propellant Fire Test (SPFT) milestones, finalized a subcontract with Sandia National Laboratories (SNL) to support SPFT analysis and modeling, and obtained and delivered—from Kennedy to Alliant Techsystems (ATK)—five excess STAR-37 motors for use in the Solid Motor Drop Test.

MMLAE Risk Communication supported the RPS Program stakeholder communication efforts and finalized, and received approval for, the RPS Program Risk Communication Plan. The plan was implemented during the year with the development of numerous products, including new fact sheets on "What is Plutonium-238?", "Radioisotope Power Systems: Mission Need," and "Safety of Radioisotope Power Systems."

The MMLAE team at JPL has been coordinating with NASA Headquarters in its ongoing activity to update NASA NEPA regulations and NASA policy requirements documentation. During the year, those regulations, and the associated NASA Procedural Requirements (NPRs) for implementing them, were finalized. MMLAE delivered a finalized RPS Environmental Impact Statement template that captures lessons learned from past RPS-related Environmental Impact Statements and that will help keep LAE off the "critical path" schedule for future missions that consider the use of RPS.

Key Events and Milestones

- Prepared a comprehensive Discovery-baseline LAE plan until a non-RPS-baselined mission was selected for Discovery 12
- Conducted upwards and downwards burn tests at SNL using STAR-48 solid propellant
- Presented "United States Preparedness and Response Activities for Space Exploration Missions Involving Nuclear Power Sources" at the February 2012 UNCOPUOS NPS Working Group Safety Framework Workshop
- Developed and delivered several new stakeholder information products, in close collaboration with DOE and the RPS Education and Public Outreach team.



*MSL showing its MMRTG at Gale Crater, Mars.
The rim of Gale Crater is in the distance.*

RADIOISOTOPE POWER SYSTEMS PROGRAM

EDUCATION AND PUBLIC OUTREACH

The Education and Public Outreach (EPO) team develops communications products for the RPS Program. These include videos and animations; Web sites; physical models; exhibits and displays; printed products like fact sheets, lithographs, and posters; activities and lessons for use by informal and formal educators; and 3D visualizations. The team also supports an RPS presence, as exhibitors, at several relevant professional conferences. The focus during FY12 was on producing a portfolio of such products, particularly Web and video products. The EPO team coordinates all communications with NASA Risk Communications officers at JPL, NASA Headquarters, and DOE to ensure that appropriate messages are communicated.

Highlights of Fiscal Year 2012 Accomplishments

In FY12, the EPO team demonstrated several successes in its efforts to make information and resources about NASA's use of radioisotope power more accessible to the public and the space science community. On February 9, the team launched a Web site for the general public (<http://rps.nasa.gov>). It is the first focused NASA resource for information about the Agency's use of RPS for exploring our solar system.

On July 10 the team published an RPS-focused module in NASA's "EYES on the SOLAR SYSTEM" 3D interactive Web site (<http://eyes.nasa.gov>). "Eyes" provides an engaging, interactive way to learn about RPS and the types of missions that the technology enables NASA to undertake.



RPS Web site.



EPO products.



RADIOISOTOPE POWER SYSTEMS PROGRAM

In late July, NASA eClips published three educational videos about RPS on the NASA Web site and YouTube. The videos focus on the history and safety of RPS, along with the role of radioactive half-life in producing long-lived, reliable power systems.

Finally, several times during the fiscal year, members of the RPS Program made educational outreach visits to schools in Northeast Ohio to talk about RPS and other important NASA technologies.

Key Events and Milestones

- The EPO team was the proud recipient of a 2012 NASA Group Achievement Award.
- The EPO team published an initial version of the RPS Web site (<http://rps.nasa.gov>) and added content throughout the year. This is a partner site within the NASA Planetary Science Division's Solar System Exploration Web site (<http://solarsystem.nasa.gov>).
- Under contract to the JPL, the eClips team at the National Institute of Aerospace published three videos. The videos are available on the RPS Web site (<http://solarsystem.nasa.gov/rps/videos.cfm>).
- The "EYES on the SOLAR SYSTEM" 3D interactive visualization launched at <http://eyes.nasa.gov>. This interactive site introduces the extreme environments that RPS enable NASA to explore and describes RPS and the missions that they enable.
- The EPO team exhibited at two major science conferences (the American Geophysical Union, and the Lunar and Planetary Science Conference/Nuclear and Emerging Technologies for Space (LPSC/NETS)) and one important technical meeting (the Joint Propulsion Conference/International Energy Conversion Engineering Conference).
- The team produced 3D animations of RPS technology that are to be published in FY13 for the general purpose heat source, MMRTG, ASRG, and radioisotope heater unit.
- Outreach events
 - May 14 to 15: Cedar Point's Math and Science Week
 - May 16: Norwayne Elementary School in Creston, Ohio
 - May 22: Summit Academy in Akron, Ohio
 - Aug. 12: Curiosity rover booth at the John Williams Tribute Concert at Blossom Music Center in Cuyahoga Falls, Ohio



Scenes from NASA eClips educational videos featuring RPS published in 2012.

RADIOISOTOPE POWER SYSTEMS PROJECTS CONTENT

ADVANCED STIRLING RADIOISOTOPE GENERATOR

The ASRG project is a joint effort between DOE and NASA. The ASRG project was initiated in 2002 as the SRG-110 project using a Stirling convertor design from a different vendor than currently baselined; this convertor switch occurred in 2007, with a nomenclature change to ASRG. The ASRG project was proceeding on a flight systems development path to maintain the option of producing two flight-worthy generators in time for potential use by a mission user in the 2015 to 2016 timeframe. With the Discovery 12 announcement in August 2012 that the next mission would be baselined using a solar energy power supply, the ASRG project has made adjustments to deliver two non-fueled, but flight-ready, generators to protected storage by October 2016.

The ASRG is a joint team led by DOE consisting of members from DOE, Glenn, Idaho National Laboratory (INL), Oak Ridge National Laboratory (ORNL), Lockheed Martin (LM), Sunpower, and others. Sunpower, a key subcontract supplier to LM, will provide a pair of Advanced Stirling Convertors (ASCs) as the energy conversion components of the generator.

Highlights of Fiscal Year 2012 Accomplishments

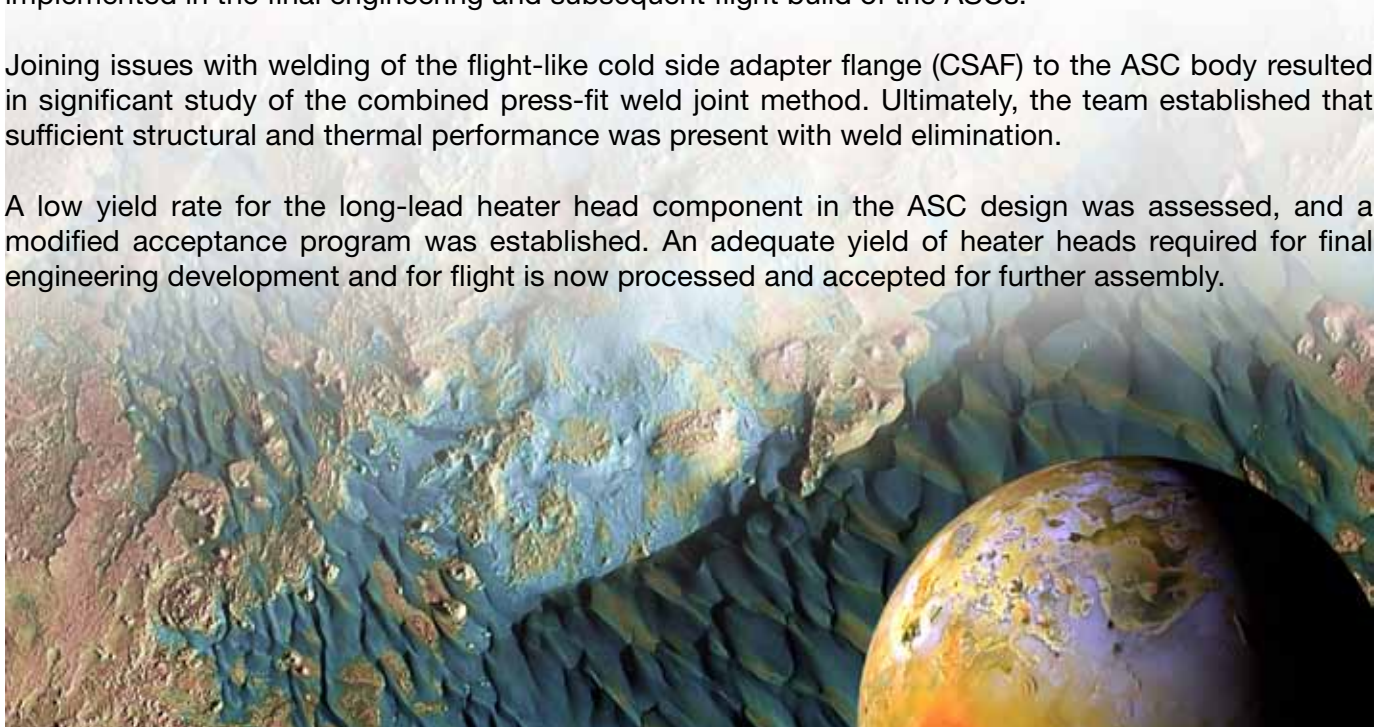
The ASRG project achieved several major milestones in FY12. These were both organizational and technological. Organizationally, a joint ASRG project office was established between DOE and NASA. The joint project office is creating greater efficiencies between both agencies as ASRGs are developed.

Technical milestones passed during the year included the flight ASC Final Design Review (FDR) Closeout in February 2012 and the ASC Control Unit (ACU) FDR Closeout in May 2012.

The project team has now overcome the series of technical hurdles encountered near FDR. A series of power fluctuations were observed in the engineering test set of ASCs. A team was established to investigate and has resolved the issues through a series of corrective and preventative actions being implemented in the final engineering and subsequent flight build of the ASCs.

Joining issues with welding of the flight-like cold side adapter flange (CSAF) to the ASC body resulted in significant study of the combined press-fit weld joint method. Ultimately, the team established that sufficient structural and thermal performance was present with weld elimination.

A low yield rate for the long-lead heater head component in the ASC design was assessed, and a modified acceptance program was established. An adequate yield of heater heads required for final engineering development and for flight is now processed and accepted for further assembly.



RADIOISOTOPE POWER SYSTEMS PROGRAM



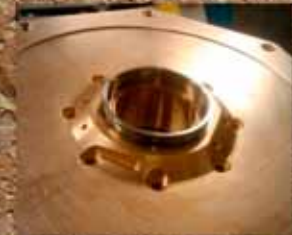
Completed ASC-E3 heater head.



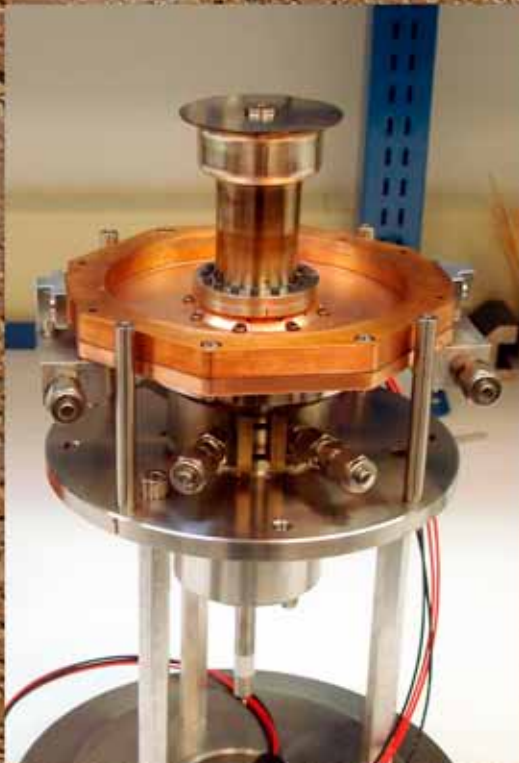
Case Western Reserve University centrifugal test rig.



High-temperature heater head leak test rig.



First E3 production cold side adapter flange (CSAF) press.



ASC-E3 #2 preparation for initial operation.



MarM-247 Kb bar specimens.



ASC-E2 #7 and #8 in Lockheed Martin Coherent Technologies controller testing.

RADIOISOTOPE POWER SYSTEMS PROGRAM

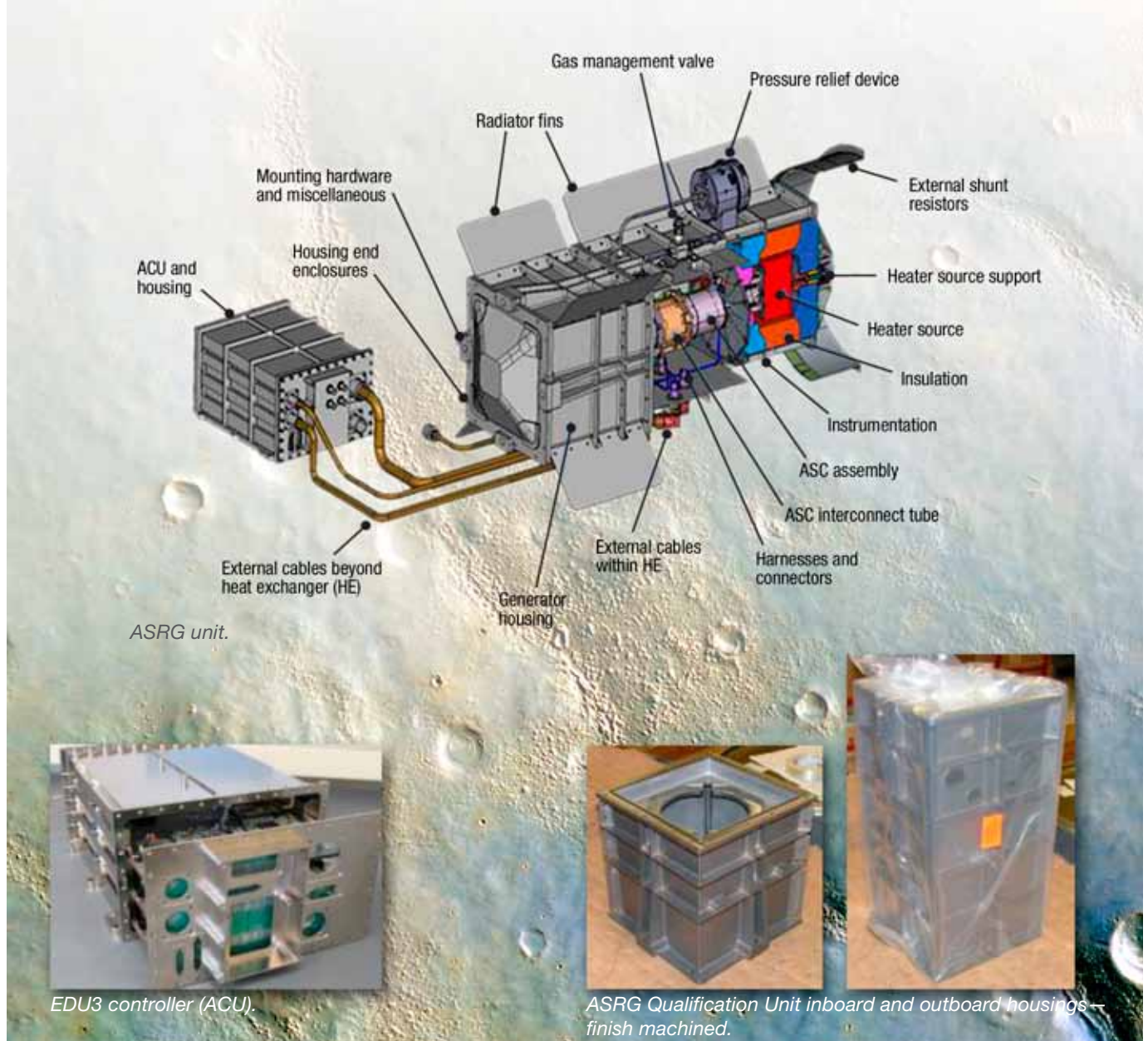
The ACU design was found to lack sufficient control authority to protect the ACU internal piston from overstroke during simulated launch vibration. The design team assessed and implemented a set of design changes that were shown to now protect the ASC during vibration exposure.

The balance of the ASRG system proceeded through long-lead component fabrication and component test checkouts. The first flight generator housing assembly was machined, proof-pressure tested, and painted. In addition, the first in a series of system ground support equipment racks were completed and initiated their checkout process.

Other Key Events and Milestones Achieved by the ASRG Project

Project Office/Organizational Events and Milestones

- An Integrated ASRG Project Office was established with integrated NASA support on January 18, 2012.



RADIOISOTOPE POWER SYSTEMS PROGRAM

Technical Events and Milestones

- Engineering Design Unit 3 (EDU3) #1 Open Box Testing was successfully completed at Lockheed Martin Coherent Technologies (LMCT) in December 2011.
- A NASA/DOE-chartered Red Team completed its investigation into ASC power fluctuations identified on ASC-E2 hardware. Power fluctuations were resolved with design modifications to the E3 and flight configurations.
- NASA materials testing of MarM-247 Kb bar samples and fracture analysis revealed the presence of oxide inclusions in test specimens that led to revised acceptance procedures for thin-wall heater head components.
- ASC-E3 Pair 1 delivery and operation:
 - #2 first operation was on March 13, 2012; #1 first operation was on April 12, 2012.
 - Convertors were hermetically sealed, and the workmanship vibe test was completed.

System-Level Events and Milestones

- Ongoing extended operation of convertors with nominal performance at Glenn (as of Sept. 30, 2012):
 - Total ASC operating time at Glenn is greater than 233,000 hours.
 - Leading unit ASC-0 #3 has greater than 32,000 hours.
 - The ASRG Engineering Unit (EU) (with a pair of ASC-E) has achieved greater than 28,000 hours.
- *Steady-State Model*: A steady-state model of the ASRG was developed by JPL to support the telemetry analysis, allowing fault injections into the system and assessment of received telemetry effects.
- *Telemetry Analysis*: JPL provided a preliminary sensitivity analysis of ASRG faults to ASRG telemetry.
- *Master Logic Diagram*: A master logic diagram was developed by JPL. A master logic diagram is the basis for fault protection work, facilitating the fault protection effort as requirements are assessed across all environments and all possible faults.

TECHNOLOGY ADVANCEMENT PROJECT

The Technology Advancement Project (TAP) supports the RPS Program's strategic objectives of providing RPS capabilities for potential future NASA space science mission requirements and sustaining current and future RPS capabilities and the necessary support functions. TAP provides the overall management of technology advancement activities for RPS power conversion and relevant subsystems.

Highlights of Fiscal Year 2012 Accomplishments

TAP is on the cutting edge of technical achievements that enhance the future development of RPS. The Small RPS project achieved a significant milestone with the delivery of the Single Convertor Controller (SCC), which was designed and built by APL, and



Two Single Convertor Controllers.

RADIOISOTOPE POWER SYSTEMS PROGRAM

the awarding of a contract for the Dual Convertor Controller (DCC) to APL. In the JPL-led Advanced Thermoelectrics area, many breakthroughs were made in the research and testing of various materials, including Zintl and lanthanum telluride (LaTe), and in the demonstration of the long-term stability of Zintl/LaTe/skutterudite thermoelectric properties. Toward the end of the fiscal year, the first annual review of TAP took place, reaffirming the content and research goals, and measuring progress made on the content.

TAP also managed investments in readying future systems for flight integration via the RPS System Integration Laboratory (RSIL).

Key Events and Milestones

RSIL was started in FY12, and a team was formed. The team developed a Phase 1 design that was focused on the ASRG and its initial mission. A System Requirements Document was developed and approved, the Phase 1 design was approved, and hardware purchases were initiated. One significant purchase was an Advanced Stirling Convertor Simulator (for an ASRG) that was designed and built by APL. This simulator allows Stirling controllers to be tested without being connected to an actual Stirling convertor.

The Small RPS project made some significant accomplishments in FY12. The SCC was delivered to NASA Glenn from APL, where it was successfully operated at full power with an ASC and demonstrated fault-tolerance capabilities. ASC-Lunar (ASC-L) was reworked, and the passive balancer was adjusted at Sunpower. ASC-L was installed on the lunar test stand and was run with the SCC. In addition, temperature performance mapping was completed.

The Small RPS project also awarded a contract to APL to develop a DCC. The DCC, which will operate a pair of ASCs, is based on the SCC design and is a fully redundant system consisting



Electronic load bank.

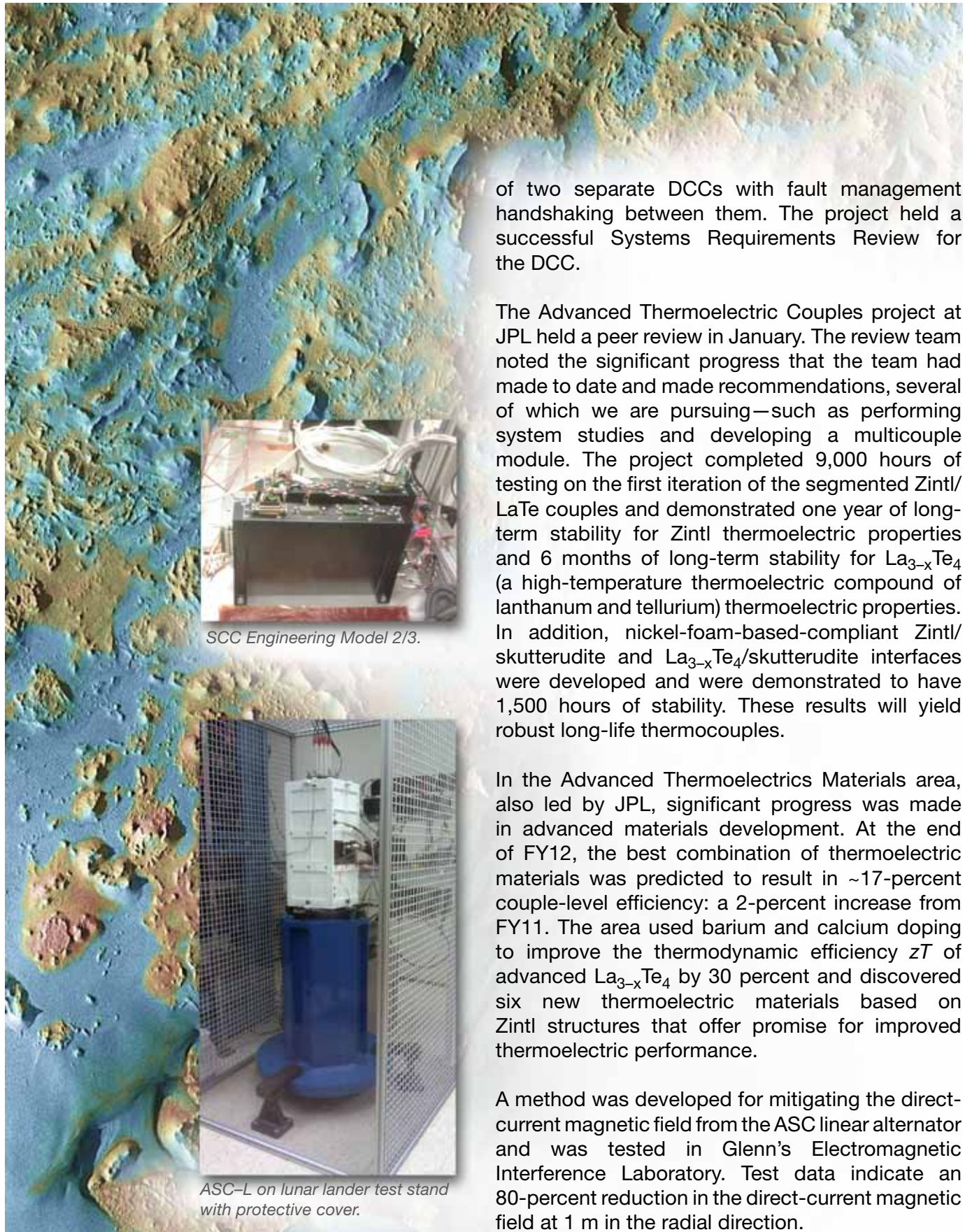


Battery unit (Ares 1).



16-channel solid-state power controller.

RADIOISOTOPE POWER SYSTEMS PROGRAM



SCC Engineering Model 2/3.



ASC-L on lunar lander test stand with protective cover.

of two separate DCCs with fault management handshaking between them. The project held a successful Systems Requirements Review for the DCC.

The Advanced Thermoelectric Couples project at JPL held a peer review in January. The review team noted the significant progress that the team had made to date and made recommendations, several of which we are pursuing—such as performing system studies and developing a multicouple module. The project completed 9,000 hours of testing on the first iteration of the segmented Zintl/LaTe couples and demonstrated one year of long-term stability for Zintl thermoelectric properties and 6 months of long-term stability for $\text{La}_{3-x}\text{Te}_4$ (a high-temperature thermoelectric compound of lanthanum and tellurium) thermoelectric properties. In addition, nickel-foam-based-compliant Zintl/skutterudite and $\text{La}_{3-x}\text{Te}_4$ /skutterudite interfaces were developed and were demonstrated to have 1,500 hours of stability. These results will yield robust long-life thermocouples.

In the Advanced Thermoelectrics Materials area, also led by JPL, significant progress was made in advanced materials development. At the end of FY12, the best combination of thermoelectric materials was predicted to result in ~17-percent couple-level efficiency: a 2-percent increase from FY11. The area used barium and calcium doping to improve the thermodynamic efficiency zT of advanced $\text{La}_{3-x}\text{Te}_4$ by 30 percent and discovered six new thermoelectric materials based on Zintl structures that offer promise for improved thermoelectric performance.

A method was developed for mitigating the direct-current magnetic field from the ASC linear alternator and was tested in Glenn's Electromagnetic Interference Laboratory. Test data indicate an 80-percent reduction in the direct-current magnetic field at 1 m in the radial direction.

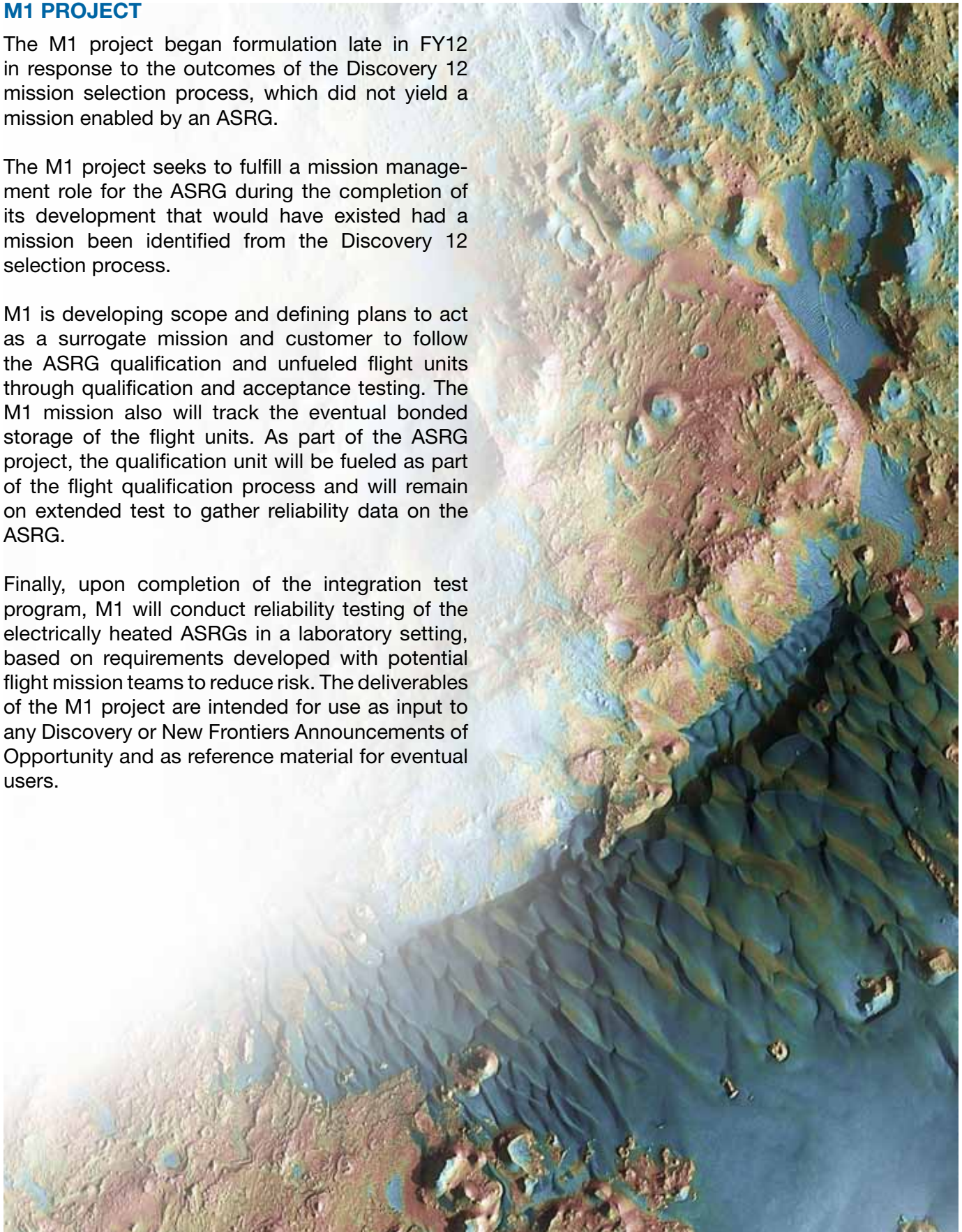
M1 PROJECT

The M1 project began formulation late in FY12 in response to the outcomes of the Discovery 12 mission selection process, which did not yield a mission enabled by an ASRG.

The M1 project seeks to fulfill a mission management role for the ASRG during the completion of its development that would have existed had a mission been identified from the Discovery 12 selection process.

M1 is developing scope and defining plans to act as a surrogate mission and customer to follow the ASRG qualification and unfueled flight units through qualification and acceptance testing. The M1 mission also will track the eventual bonded storage of the flight units. As part of the ASRG project, the qualification unit will be fueled as part of the flight qualification process and will remain on extended test to gather reliability data on the ASRG.

Finally, upon completion of the integration test program, M1 will conduct reliability testing of the electrically heated ASRGs in a laboratory setting, based on requirements developed with potential flight mission teams to reduce risk. The deliverables of the M1 project are intended for use as input to any Discovery or New Frontiers Announcements of Opportunity and as reference material for eventual users.



RADIOISOTOPE POWER SYSTEMS PROGRAM

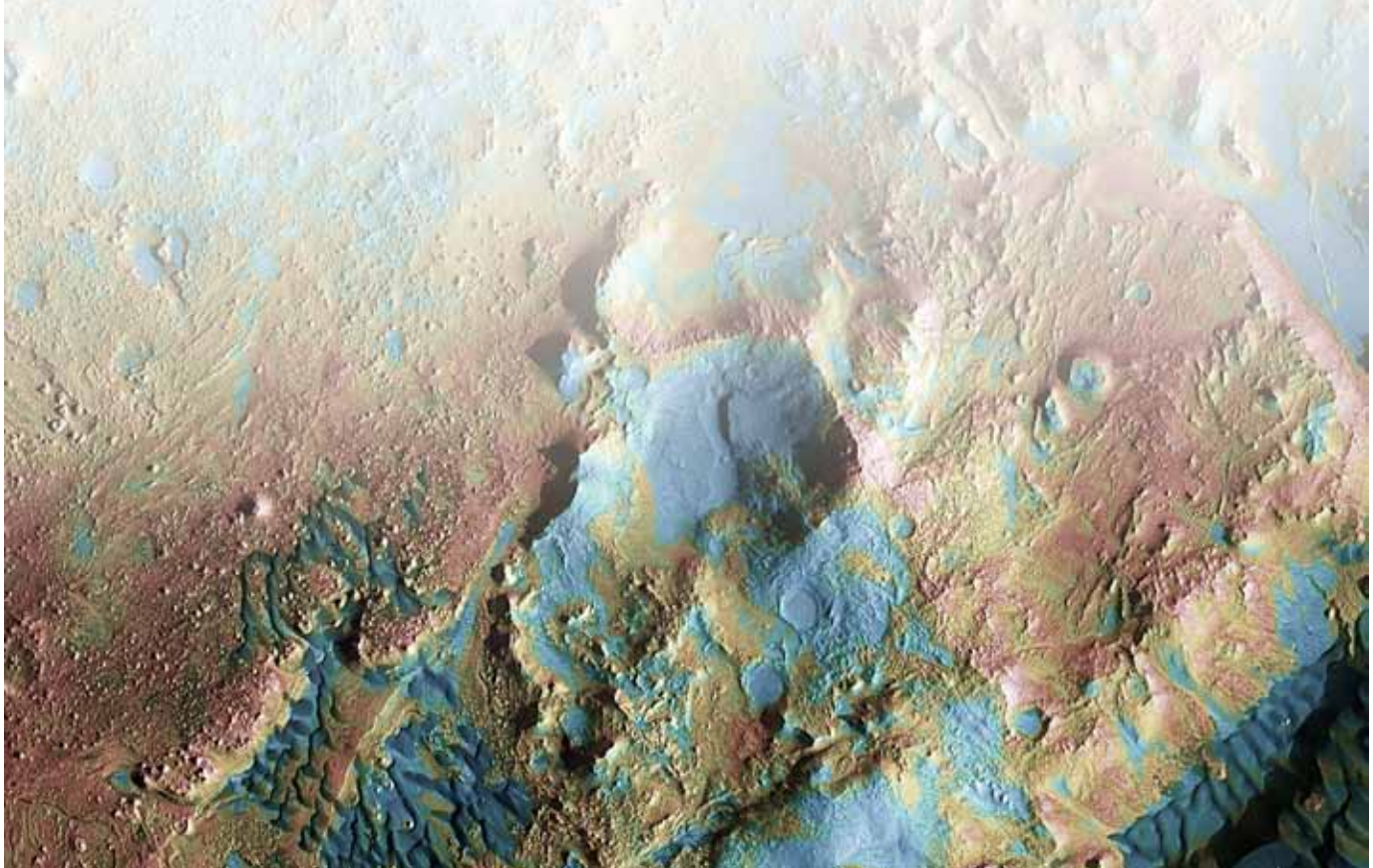
THE FUTURE OF RADIOISOTOPE POWER SYSTEMS

The RPS Program has been in existence formally for three years. In those three short years, the ASRG has reached a final design stage and initiated flight hardware fabrication, technologies for improved system capabilities and reliability are maturing, and significant efficiencies in launch approval engineering processes have been established. The RPS Program has crafted a top-notch education and public outreach program and continues to engage its stakeholder community: the missions and the scientists for whom the RPS enable exploration throughout the solar system. The program successfully supported a Principal-Investigator-led mission call for proposals in which two Government-furnished ASRG systems were offered to proposers, yielding many high-quality scientific proposals. Two of the three final proposals, in fact, were uniquely enabled by the use of RPS.

The RPS Program continues to advance the state of power systems for planetary exploration. The ASRG will be completed in the near term, allowing demonstrations both on the ground and in an eventual flight mission that will verify that the design is sound and ready for acceptance by the broad user community. The RPS Program will continue to support future mission proposal processes, through smart investments like the M1 project, to enable effective mission designs leading to selection for flight.

Continued investments in thermoelectric energy conversion will be made, based largely on predicted performance improvements becoming a reality in the lab. The investment in preparing two additional flight MMRTGs through the program's sustaining capability approach may enable a straightforward reflight of another Curiosity-style Mars rover in the 2020 timeframe.

Finally, the program's investments in cutting-edge studies of missions and system configurations will result in further enhancements to the future RPS for deep space exploration. Radioisotope power systems will continue to provide the power to explore.





<http://rps.nasa.gov>