A Program Overview
Prepared for the 2016 NETS Conference

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Radioisotope Power Systems

- Enable and enhance missions by providing electrical power to explore remote and challenging environments where solar power is unavailable
  - Spacecraft operation
  - Instrumentation
- Converts heat from a Radioisotope into electricity
  - Heat is the product of the natural decay process of the isotope
Over 50 years of RPS Missions
Flight Systems for Current Missions

General Purpose Heat Source - Radioisotope Thermoelectric Generator (GPHS-RTG)

Multi-Hundred Watt - Radioisotope Thermoelectric Generator (MHW-RTG)

Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)
Operational Missions

- **Voyager 1 & 2 – Extended Operations**
  - Launched: August 20, 1977 & September 5, 1977
  - Science Mission duration: 35+ yr science
  - Power Source:
    - Three MHW-RTG
    - 474 $W_e$ BOM

- **Cassini – Extended Operations**
  - Launched: October 15, 1997
  - Arrival at destination: July 2004
  - Science Mission duration: 7 yr cruise, ~8+ yr science
  - Power Source:
    - Three GPHS-RTG
    - ~885 $W_e$ BOM
Operational Missions (cont’d)

- **Pluto/New-Horizons – Operational**
  - Launched: January 19, 2006
  - Closest Approach / Flyby: July 14, 2015
  - Science Mission duration: 9.5 yr cruise, 5 yr science
  - Power Source:
    - One GPHS-RTG
    - $243 \, W_e \, \text{BOM}; \, \sim 200 \, W_e \, \text{at arrival}$

- **Mars Science Laboratory – Extended Operations**
  - Launched: November 26, 2011
  - Gale Crater: August 6, 2012
  - Science Mission duration: ~ 2 yr
  - Power Source:
    - One MMRTG
    - $\sim 110 \, W_e \, \text{BOM}; \, \sim 105 \, W_e \, \text{at arrival}$
Curiosity – Extended Mission
Pluto: Higher Resolution...

A cosmic shoreline is pictured here, where the vast icy plain informally named Sputnik Planum borders rugged mountains made of water ice blocks standing up to 1.5 miles tall.
A Partnership with the Department of Energy

**NASA**
- Program Management
- Program Control (cost/schedule/risks)
- Program Planning and Assessment
- Launch Approval Engineering
- Education and Public Outreach
- Technology Projects
- DOE Insight

**DOE**
- Systems Acquisition
- Flight system deployment to missions (e.g. Mars 2020)
- Maintain/Augment capabilities
  - Operations and Analysis
  - Plutonium-238 Supply Project
Program With DOE Content

- Production Operations*
- Mars Rover 2020 Mission Support*
- Future Systems Development*
- Pu-238 Supply Project
- Un-fueled RPS Production
- Program Planning and Assessment
- DOE Insight
- Program Control
- Launch Approval Engineering
- Education and Public Outreach
- Thermoelectric Technology Development
- Stirling Cycle Technology Development

* NASA-funded DOE activities with unique Inter Agency Agreement
Oak Ridge National Laboratory is the lead to re-establish domestic production of $^{238}\text{Pu}$

Specific tasks:
- Develop qualified irradiation targets for both the INL Advanced Test Reactor and the ORNL High Flux Isotope Reactor
- Establish target fabrication capability
- Establish chemical processing to recover and purify both neptunium and plutonium
- Establish capabilities for all shipment of nuclear materials

50g of new material produced
Program Planning and Assessment

• Develops requirements and sustainment strategy
  – eMMRTG
    • Improves EODL power by > 50% compared to MMRTG
  – SRG
    • Higher power, robust, reliable

• Assesses State of Art for RPS technologies
  – RFI for Stirling

• Mission Studies to inform system needs to support planetary science
  – CubeSat and SmallSat

• Customer / User engagement
  – Missions – Mars 2020, NF
  – Assessment Groups (OPAG, SBAG, etc.)
  – Developing User’s Guide for MMRTG – See LPSC peripheral session & RPS website

• Performs as the Surrogate Mission
  – Cross Flight Center with DOE Mission Team

• Developing life performance prediction models
  – MMRTG LPPM
  – SRG Risk Informed Life Models and Prediction Models
Thermoelectric Technology Development Project

• Sustain industry capability to manufacture and test thermoelectric converters
  – Manufacture Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs) and components at Teledyne Energy Systems (TESI)

• Sustain NASA (JPL) workforce of thermoelectric technologists
  – Continue testing at JPL thermoelectrics labs
  – Leverage investments in technology/component development for transition to flight
  – Actively transition advanced technologies to industry
Future Work- Thermoelectrics (FY16)

- Enhanced Multi-Mission Radioisotope Thermoelectric Generator (eMMRTG) Concept
  - Retrofit the MMRTG with new thermoelectric (TE) couples
    - Substitution of current MMRTG PbTe/TAGS couples with skutterudite (SKD) couples
    - Technology developed with NASA support at the Jet Propulsion Laboratory over the last 20 years
    - Key industry partners include Teledyne Energy Systems and Aerojet/Rocketdyne
  - Addition of a surface oxidation layer to the heat source liner inner surface to allow for increased hot junction temperatures

<table>
<thead>
<tr>
<th></th>
<th>MMRTG</th>
<th>eMMRTG</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of GPHS Modules</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>TE Type</td>
<td>PbTe/TAGS</td>
<td>SKD</td>
</tr>
<tr>
<td>No. of Couples</td>
<td>768</td>
<td></td>
</tr>
<tr>
<td>Beginning of Life (BOL) Power (W)**</td>
<td>121</td>
<td>140.8</td>
</tr>
<tr>
<td>BOL System Efficiency**</td>
<td>6.0%</td>
<td>7.0%</td>
</tr>
<tr>
<td>BOL Specific Power (W/kg)**</td>
<td>2.7</td>
<td>3.1</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>Mission Usage</td>
<td>Multi-mission</td>
<td></td>
</tr>
<tr>
<td>Development Time</td>
<td>In Use</td>
<td>~5 years</td>
</tr>
<tr>
<td>Potential Future Missions</td>
<td>MSL, Mars 2020</td>
<td>Future Discovery and New Frontiers missions, Mars missions</td>
</tr>
</tbody>
</table>

**BOL is defined as fueling complete; for consistency between the power estimates the following conditions were applied: thermal inventory = 250W/ht per GPHS; \( V_{\text{Load}} = 32V \); thermal sink = 4K
Stirling Cycle Technology Development Project

- Reassess Stirling Technology industry capability
- Manufactured Advanced Stirling Converters at Sunpower through end of CY15
- Sustain NASA workforce of Stirling technologists
  - Continue testing at GRC Stirling Labs
  - Leverage investments in technology/component development for transition to flight
  - Assess state of readiness of technology for flight
  - Develop requirements for flight system
Future Work- Stirling (FY16)

- Focus on fault tolerance and robust architectures
- Develop requirements for flight system based on mission pull and technology availability
  - Power level
  - Efficiency
  - Lifetime
- Eventual transition to flight system to support missions
- With DOE, develop qualification unit prior to inclusion in a flight opportunity announcement
Launch Approval Engineering

- Activities which support the nuclear safety process compliant with Presidential Directive/NSC-25 (PD/NSC-25) and the Interagency Nuclear Safety Review Panel (INSRP) process that are not mission specific
  - Launch vehicle data books
  - Systems simulations
  - Systems and vehicle component destructive tests
  - Accident investigations and analysis
  - Site environmental sensors
  - Risk communications
## RPS Mission Planning

<table>
<thead>
<tr>
<th>Mission</th>
<th>Status</th>
<th>Launch Year</th>
<th>Power Reqmnt ($W_e$)</th>
<th>RPS Type (Flight + Spare)</th>
<th>Pu-238 Availability</th>
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</thead>
<tbody>
<tr>
<td>Mars Science Lab</td>
<td>Operational</td>
<td>2011</td>
<td>100</td>
<td>1 MMRTG</td>
<td>Yes</td>
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<tr>
<td>Mars 2020</td>
<td>In Development</td>
<td>2020</td>
<td>120</td>
<td>1 MMRTG</td>
<td>Yes</td>
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<td>New Frontiers 4</td>
<td>In Planning</td>
<td>2025*</td>
<td>~300</td>
<td>Up to 3 MMRTG/eMMRTG</td>
<td>Yes</td>
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<td>New Frontiers 5</td>
<td>Notional</td>
<td>2030</td>
<td>~300</td>
<td>TBD</td>
<td>Yes</td>
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</table>

- **Potential 5-6 year-cadence for New Frontier mission opportunities**
  - RPS not required for all mission concepts
- **Radioisotope heater units may be used on missions not requiring RPS**
- **Strategic missions often require RPS; 2 highest priority strategic missions in current decadal (Mars 2020 and Europa) are already in work**
  - Mars 2020 will use an MMRTG
  - Europa mission will be solar powered

*Nuclear launches are in 2025*
Summary

• RPS Program provides NASA a robust, end-to-end program capability
  – Customer engagement
    • Missions, ‘AGs, other Stakeholders
  – DOE systems acquisition (MMRTGs)
  – DOE partnership/sustained capabilities

• Ongoing capability enhancements
  – Systems (eMMRTG)
  – Missions (Mars 2020, potential NF-4)
  – Infrastructure (Plutonium Supply Project)