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
Program With DOE Content

RPS

Production Operations*
- Operations and Analysis
- Pu-238 Supply Project
- Un-fueled RPS Production

Mars Rover 2020 Mission Support*

Future Systems Development*
- Program Planning and Assessment
- DOE Insight
- Thermoelectric Technology Development
- Stirling Cycle Technology Development

RPS Program
- Program Control
- Launch Approval Engineering
- Education and Public Outreach

DOE

NASA

* NASA-funded DOE activities with unique Inter Agency Agreement
The DOE Role

- Np-237 in Storage
  - Package and ship to ORNL
  - Process Np and manufacture targets
  - Irradiate targets
  - Chemical Processing
  - New Pu-238 to LANL

- Pu-238 (new and existing) Storage
  - Aqueous Processing and Blending

- Graphite Components
- Iridium Components
- Module Components and Assembly
- RPS Assembly and Testing
- Package and ship to KSC
- Launch Site Support

- Plotted:
  - INL
  - ORNL
  - LANL
  - Planned
  - Existing
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)
Flight Systems

• **Voyager 1 & 2** – *Extended Operations*
  – Launched: August 20, 1977 & September 5, 1977
  – Science Mission duration: 37+ yr science
  – Power Source:
    • Three MHW-RTG
    • 474 W\textsubscript{e} BOM

• **Cassini** – *Extended Operations*
  – Launched: October 15, 1997
  – Arrival at destination: July 2004
  – Science Mission duration: 7 yr cruise, ~ 11+ yr science
  – Power Source:
    • Three GPHS-RTG
    • ~885 W\textsubscript{e} BOM
Operational Missions

• 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 \( W_e \) BOM; \(~200 W_e\) at arrival

• Mars Science Laboratory – *Extended Operations*
  – Launched: November 26, 2011
  – Gale Crater: August 6, 2012
  – Science Mission duration: \(~3+ yr\)
  – Power Source:
    • One MMRTG
    • \(~110 W_e\) BOM; \(~105 W_e\) at arrival
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
Path to Possible Future eMMRTG

- **Enhanced Multi-Mission Radioisotope Thermoelectric Generator (e-MMRTG) 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>
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<tbody>
<tr>
<td>No. of GPHS Modules</td>
<td>8</td>
<td></td>
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<tr>
<td>TE Type</td>
<td>PbTe/TAGS</td>
<td>SKD</td>
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<tr>
<td>No. of Couples</td>
<td>766</td>
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<tr>
<td>Hot Junction Temperature (°C)</td>
<td>530</td>
<td>600</td>
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<tr>
<td>Cold Junction Temperature (°C)</td>
<td>200</td>
<td></td>
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<tr>
<td>Beginning of Mission Power (W)</td>
<td>110</td>
<td>~145</td>
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<tr>
<td>Est. EOM Power (W) at 14 years*</td>
<td>60</td>
<td>&gt;90</td>
</tr>
<tr>
<td>BOL System Efficiency</td>
<td>6%</td>
<td>8%</td>
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<tr>
<td>BOL Specific Power (W/kg)</td>
<td>2.8</td>
<td>&gt;3.6</td>
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<tr>
<td>Mission Usage</td>
<td>Multi-Mission</td>
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<tr>
<td>Development Time</td>
<td>In Use</td>
<td>~5 years</td>
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<td>Potential Future Missions</td>
<td>MSL, Mars 2020</td>
<td>Europe, future Discovery and New Frontiers</td>
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</tbody>
</table>

*17 years total including 3-year storage
The eMMRTG: What is being enhanced?

- **Engineering:**
  - emissivity change to liner,
  - substitute insulation

- **Changes needed to MMRTG**

- **New Technology:** Substitute SKD thermoelectric couples
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 flight
  - Develop requirements for flight system

ASRG EU2 on extended testing at GRC

Completed ASC-E3 Prior to Delivery
Systems Formulation and Mission Integration
(Program Planning and Assessment)

- **Studies and Analysis**
  - Mission-RPS accommodation studies (Team X, COMPASS, ACES, etc.)
  - Nuclear Power Assessment Study

- **Customer / User engagement**
  - Assessment Groups (OPAG, SBAG, etc.)
  - Future Missions – Mars 2020, New Frontiers, Ice Giants
  - Developing User’s Guide for MMRTG – LPSC peripheral session & RPS website
Nuclear Power Assessment Study

• Study Objective
  – “Identify opportunities and challenges of a sustainable RPS and FPS provisioning strategy for safe, reliable, and affordable nuclear power systems that enable NASA Science Mission Directorate (SMD) missions and are extensible to Human Exploration and Operations Mission Directorate (HEOMD) needs in the next 20 years.”

• Planetary Science budget reductions forced a cancellation of the ASRG, but the long-term need to develop more efficient systems remains

• Study was intended to identify opportunities and challenges of a sustainable, incremental development strategy for nuclear power systems to support SMD and initial fission capabilities for HEO
RPS Mission Planning

- 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

<table>
<thead>
<tr>
<th></th>
<th>Projected Launch Year</th>
<th>Power Reqmnt (W&lt;sub&gt;e&lt;/sub&gt;)</th>
<th>RPS Type (Flight + Spare)</th>
<th>Pu-238 Availability</th>
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<tbody>
<tr>
<td>Mars Science Lab</td>
<td>Operational</td>
<td>100</td>
<td>1 MMRTG</td>
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<tr>
<td>Mars 2020</td>
<td>In Development</td>
<td>120</td>
<td>1 MMRTG + Spare</td>
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<td>New Frontiers 4</td>
<td>In Planning</td>
<td>~300</td>
<td>Up to 3 MMRTG/eMMRTG</td>
<td>Yes</td>
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<tr>
<td>New Frontiers 5</td>
<td>Notional</td>
<td>~300</td>
<td>TBD</td>
<td>Requires new</td>
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</tbody>
</table>

Courtesy J. Green (HQ)
New Frontiers #4 Focused Missions

COMET SURFACE SAMPLE RETURN

LUNAR SOUTH POLE AITKEN BASIN SAMPLE RETURN

TROJAN TOUR & RENDEZVOUS

SATURN PROBES

OCEAN WORLDS (TITAN AND ENCELADUS)

VENUS IN-SITU EXPLORER

Courtesy J. Green (HQ); Cassini images
MMRTG Primer

The Multi-Mission Radioisotope Thermoelectric Generator, or MMRTG, is powering Curiosity and is the baseline power system for M2020 rover.

- Converts heat produced from the decay of plutonium dioxide into DC power
- Power at launch is >110W DC, quiet
- Mass is ~45kg
- Operates in vacuum and planetary atmospheres
- Roughly speaking the generator envelope is a 60 cm diameter cylinder x 60 cm long
- It mounts using a 4-bolt interface
- Thermal output is ~1880Wth, BOL
- Cooling tubes are optional
- Can be painted in black or white
  - White paint matches optical properties of MMRTG on Curiosity
- Design is rugged and passive
- Series-parallel electrical circuit for increased reliability
- Does not require in-flight commanding; nor in-flight maintenance
- The environmental requirements include qualification to ATLAS and DELTA LV levels (0.2g^2/Hz.)
- Nuclear Launch Safety basis was established by MSL

As Measured
F1 MMRTG Mass = 44.79 kg
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)
  – Technologies (thermoelectrics and Stirling)
  – Infrastructure & Plutonium Supply Project

• Service to Missions
  – Operational (Voyager, Cassini, New Horizons, Curiosity)
  – Future (Mars 2020, potential NF-4)
Important RPS Contact Information

- **RPS Website**
  - [http://rps.nasa.gov](http://rps.nasa.gov)

- **NASA RPS Program**
  - [rps@nasa.gov](mailto:rps@nasa.gov)

- **RPS DOE Info**
  - [http://www.energy.gov/ne/nuclear-reactor-technologies/space-power-systems](http://www.energy.gov/ne/nuclear-reactor-technologies/space-power-systems)

- **AO links**
  - New Frontiers: [http://newfrontiers.larc.nasa.gov](http://newfrontiers.larc.nasa.gov)
  - Discovery: [http://discovery.larc.nasa.gov](http://discovery.larc.nasa.gov)

- **OPAG**
  - [http://www.lpi.usra.edu/opag/](http://www.lpi.usra.edu/opag/)

- **SBAG**
  - [http://www.lpi.usra.edu/sbag/](http://www.lpi.usra.edu/sbag/)