Mission Analysis for a Potential Next-Generation Radioisotope Thermoelectric Generator

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Introduction

**Purpose:**
- Identify NASA Planetary Science Division (PSD) mission requirements for a potential Next-Generation Radioisotope Thermoelectric Generator (Next-Gen RTG)
- Examine the existing PSD mission concepts to various destinations across the solar system
  - Priority of National Research Council's (NRC) Decadal Survey missions in response to NASA's Strategic Plan
  - Mission concepts studied by various organizations
  - Missions flown
- Evaluate the mission impacts to a notional Next-Gen RTG power system
- Evaluate Next-Gen RTG's key requirements
- Assess Next-Gen RTG power, generator size/volume, and launch vehicle and in-space operational environments

**Approach:**
- Examined prioritized mission concepts
  - NASA Science Plan 2014
  - 2011 NRC Planetary Science Decadal Survey (PSDS)
  - Ocean Worlds Exploration Program conceptual direction
- Gathered data on Radioisotope Power System (RPS) powered mission concepts and actual missions
  - Studies performed for the PSDS published in 2011
  - Studies performed by the RPS Program Mission Analysis Team
  - 2007 Discovery and Scout Mission Capabilities Expansion (DSMEC) Study
  - Next-Gen Power Assessment Study (NPAS) Study
- Summary provided of GRC COMPASS Team studies
- Summary provided of GSFC Mission Design Lab studies
- Other publically available mission concept studies conducted for NASA
- Flown and in-development missions

**NASA Science Plan**

<table>
<thead>
<tr>
<th>NASA Strategic Objective</th>
<th>Science Goals</th>
<th>Decadal Survey Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Understand the content, origin, and evolution of the solar system and the potential for life elsewhere</td>
<td>1. Build New Worlds—advance the understanding of solar system beginnings (1-2)</td>
<td></td>
</tr>
<tr>
<td>2. Advance the understanding of how the chemical and physical processes in our solar system operate, interact, and evolve</td>
<td>2. Planetary Habitability—search for the requirements for life (2-4)</td>
<td></td>
</tr>
<tr>
<td>3. Explore and find locations where life could have existed or could exist today</td>
<td>3. Habitability of Solar Systems—review planetary processes through time (1, 2, 5)</td>
<td></td>
</tr>
<tr>
<td>4. Inform our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere</td>
<td>4. Workings of Solar Systems—review planetary processes through time (1, 2, 5)</td>
<td></td>
</tr>
</tbody>
</table>

**PSDS Studies – Power Findings**

<table>
<thead>
<tr>
<th>Name</th>
<th>Missions Count</th>
<th>Estimated EOM Power (W)</th>
<th>Power Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triton Flyby</td>
<td>New Frontiers</td>
<td>374</td>
<td>RPS/Solar</td>
</tr>
<tr>
<td>Saturn Probe</td>
<td>New Frontiers</td>
<td>284</td>
<td>RPS</td>
</tr>
<tr>
<td>Europa Geophysical Network</td>
<td>New Frontiers</td>
<td>5</td>
<td>RPS/Solar</td>
</tr>
<tr>
<td>In Observer</td>
<td>New Frontiers</td>
<td>251</td>
<td>RPS/Solar</td>
</tr>
<tr>
<td>Mars 2018 MASC Rover</td>
<td>Flagship</td>
<td>680</td>
<td>Solar</td>
</tr>
<tr>
<td>Titan Europa Orbiter and Probe</td>
<td>Flagship</td>
<td>375</td>
<td>RPS</td>
</tr>
<tr>
<td>Enceladus Orbiter</td>
<td>Flagship</td>
<td>480</td>
<td>RPS</td>
</tr>
<tr>
<td>Venus Climate Orbiter</td>
<td>Flagship</td>
<td>7</td>
<td>Solar</td>
</tr>
<tr>
<td>Titan Saturn System Mission</td>
<td>Flagship</td>
<td>750</td>
<td>RPS</td>
</tr>
<tr>
<td>Neptune System Orbiter and Probe</td>
<td>Flagship</td>
<td>755</td>
<td>RPS</td>
</tr>
</tbody>
</table>

**Ice Giants Studies**

2016 Ice Giants Study Goal: Assess science priorities and affordable mission concepts and options to explore Uranus and/or Neptune in preparation for the next Decadal Survey

<table>
<thead>
<tr>
<th>Name</th>
<th>Missions Count</th>
<th>Estimated EOM Power (W)</th>
<th>Power Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranus</td>
<td>1,756 kg</td>
<td>50 kg</td>
<td>350 We</td>
</tr>
<tr>
<td>Neptune</td>
<td>1,023 kg</td>
<td>50 kg</td>
<td>~325 We</td>
</tr>
</tbody>
</table>

**Ocean Worlds Studies**

**Baseline Next-Gen RTG Requirements**

- Power System Attributes
  - Power Level, Volume, Mass, Efficiency, Degradation Rate, Lifetime and so on
- Environments
  - In-space Operation related: Thermal, Depressurization, Radiation, MMOD
  - Launch Vehicle related: Acoustic, Vibration, Static Load, Pyroshock
  - Destination: Vacuum, Atmosphere, EDL, Surface, Subsurface
- Extreme Environments
  - Overpressuure, Radiation, Thermal, Caustic Chemicals, Fine Particles/Dust, Liquids/Aerosols, Significant Presence of Organics and so on
- Level of Required Planetary Protection
  - S/C Design Complexity
    - Flight System Design, Thermal Design, Mechanical Design and so on
    - Instruments Requiring Accommodation

**Gathered information on past RPS-powered missions**

- Built an understanding of "mission pull" that is crucial to requirements for a next generation of RTGs.
- Developed and harnessed a set of RPS-based mission concepts for a database developed for the Next-Gen RTG study.
- Examined a total of 77 RPS-powered flight systems from mission concept studies
  - These 77 flight systems performed a total of 125 “missions,” where mission is defined as a unique vector of spacecraft, mission type (e.g., lander) /subtype (e.g., rover), and target

**Mission Analysis Results**

- Number of Analyzed Destinations | 125
- Total missions used in this study | 125
- Reviewed flown missions: 124
- Orbiter missions | 128
- Flyby missions | 5
- Surface missions | 4
- Atmospheric probe missions | 8
- orbit mission | 0
- Surface mission | 29
- Sample return mission | 1
- Small sample mission | 3

**Mission Types**

- Flyby
- Orbiter
- Atmospheric Probe
- Aerial
  - Spacecraft: Helicopter
  - Surface: Rocket, Boat
- Subsurface
  - Liquid
  - Soil and Regolith
- Ice
  - Sample Return

**Past Studied Mission Concepts for Ocean Worlds**

<table>
<thead>
<tr>
<th>Name</th>
<th>Mass*</th>
<th>Payload*</th>
<th>Power Level</th>
<th>Volume</th>
<th>Mass</th>
<th>Efficiency</th>
<th>Degradation Rate</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titan</td>
<td>556 kg</td>
<td>50 kg</td>
<td>250 W</td>
<td>~325 W</td>
<td>50 kg</td>
<td>50 We</td>
<td>50 We</td>
<td>50 We</td>
</tr>
<tr>
<td>Jupiter</td>
<td>750 kg</td>
<td>50 kg</td>
<td>400 W</td>
<td>~325 W</td>
<td>50 kg</td>
<td>75 We</td>
<td>75 We</td>
<td>75 We</td>
</tr>
<tr>
<td>Saturn</td>
<td>2,000 kg</td>
<td>50 kg</td>
<td>800 W</td>
<td>~325 W</td>
<td>50 kg</td>
<td>200 We</td>
<td>200 We</td>
<td>200 We</td>
</tr>
<tr>
<td>Mars</td>
<td>2,500 kg</td>
<td>50 kg</td>
<td>1,250 W</td>
<td>~325 W</td>
<td>50 kg</td>
<td>500 We</td>
<td>500 We</td>
<td>500 We</td>
</tr>
<tr>
<td>Earth</td>
<td>3,000 kg</td>
<td>50 kg</td>
<td>1,500 W</td>
<td>~325 W</td>
<td>50 kg</td>
<td>750 We</td>
<td>750 We</td>
<td>750 We</td>
</tr>
</tbody>
</table>

**Summary**

- Gathered 249 missions from flown and studied concepts using RPS, including many with RPS design parameters of interest to a broad community
- Used to determine which potential RPS concepts would be applicable to many future missions
- Missions’ power levels were one of the key inputs for the mission design
- Missions performed for sanity checks on RTG concepts
  - New mission concept study: Cheater Explorer performed by OGF
  - GPLS RTG and MMRTG-determined requirements

- Delivered requirements to Next-Gen RTG study team

**Mission-Specific Requirements**

- Power
  - Mission Length
  - Volumes of Atmosphere
- Other Requirements
  - Atmospheric pressure
  - Temperature
  - Radiation
  - Power
  - Mission length