The Vision for Space Exploration

Outline

- Our Solar System Exploration Vision
- Power Source Classification & Brief Overview of the Options
- Introduction to Radioisotope Power Systems
- Implications of RPS Requirements through Mission Concepts
- Questions

Mars Exploration Strategies

Common Threads

Guiding Principles (MEPAG Goals)
1. Determine if life ever arose on Mars (past/present) (Biological Markers)
2. Determine the climate and connected processes (present/past) (Weather & Environment)
3. Determine the evolution of the surface and interior of Mars (Geology)
4. Prepare for human exploration (Robotic/Human Precursors/Humans)

This decade Next decade Following decades

Mars Program in This Decade

Proposed Mars Program for the Next Decade

Solar System Exploration (Beside Mars)

- Many scientifically interesting targets exist in our Solar System waiting to be explored.
- A systematic exploration strategy could include a succession of orbiter, lander and sample return missions to these destinations.
- A detailed roadmap with a full set of Design Reference Missions is currently under development. From these a set of missions could be selected based on science interest and other relevant considerations (e.g., affordability).

Power Options: Radioisotope Power Systems (RPS)

- The Plutonium-238 fuel used in RPSs is a radioisotope with a half-life of ~87.7 years.
- It produces heat through natural alpha particle decay (an alpha particle is virtually a He nucleus).
- A small portion of the heat is converted to electricity using various conversion technologies (2% to 25%).
- Waste heat is rejected through radiators or utilized for thermal control of spacecraft subsystems or components.

Power Options: Solar Power Generation

- Mercury: 0.054 W/m²
- Venus: 0.71 W/m²
- Earth: 1.00 W/m²
- Mars: 0.86 W/m²
- Jupiter: 1.41 W/m²

Power Source Classification
Comparison of Solar & RPS Power Generation

Solar Irradiation at Mars

Power Options: Fuel Cells, Batteries, Flywheels

Power Options: Beamed Power

U.S. Radioisotope Missions
Building Blocks for Future Small-RPSs

Heat-to-Electric Power Conversion

Conversion Technologies: Static

The Past – GPJHS-RTG

Conversion Technologies: Dynamic

Multi-Mission Radiisotope Power System (MMRTG)
Smell-RPS: Prototypes Built & Tested Around RHUs

Potential power range: 30 to 100 mWe

Predicted Nuclear Power System Availability

RPS available for SSE
Small RPS: potentially available
JIM0 class fission based power generation

Mission Impact of RPS Requirements

Note: the JIM0 fission core will be used in the upcoming planned (2006) Fukushima Daiichi melt down.
**Concept: Triton Lander**

- Triton is the largest moon of Neptune.
- Cool place in the dark side.
- Can fly on a 29-day orbit.
- Small RPS (single GPHS module base).
- Has a secondary battery.
- Soft landing (total ~65 km/s).
- Shielding needs can be significant, limiting mass allocation (314 kg).

**Concept: Europa Surface Science Package**

- Small RPSs could enable the mission.
- Fixed heat load feasible in the WBE.
- Development should address TFE conversion efficiency.

**Mars Mission Concept: NetLander**

- Small RPS (DPSB module).  Small RPSs (single GPHS module based) + a secondary battery.
- Soft landing (total ~65 km/s).
- Shielding needs can be significant, limiting mass allocation (314 kg).

**Radiation Environment for the NetLander Concept**

- Small RPS
- Spot shielding provided between the RPS and the radiation sensor.
Mars Mission Concept: Small-RPS Powered Rover

- Mars Science Drive Orbits to MIT/PAC Mission 1
- Instruments will include: Microscope, LiDAR, Rovers, spectrometers, APXS, Mini-Mars (for Cubs, RAT, TEGA, OCAMS, etc.).
- Drive range up to 3 years on Mars.
- MER use power generation 600W and 600W; small RPS modules up to 90W Bolt; 4 RPS modules up to 240W Bolt.
- EOL power: 2 to 3 kW Bolt (total energy 3000W Bolt; thermal control to as high as 20% by the end of life).
- Each of the 3x2 RPS modules produces 230W thermal power at EOL.
- Waste heat could be stored or sent to space, antennas, skid, etc.
- High power requirements by mobility, vision.

Small-RPS Concept for the Mars Rover

- Power (100W-300W) continuously for 1-2 months
- Drive range up to 3 years
- Driven from Mars
- Cylindrical format
- 2011 Scaur mission
- APR (April 2011) likely to come out soon

Radiation Environment for the Small Rover Concept

- High power systems should be used for high performance and energy maps.
- Thermal environment should be addressed through all mission phases.

Summary

- An active RPS research and development program is in place by NASA / DoD.
- Two systems are under consideration:
  - MMRTG ~110 We Bolt
  - SRG ~210 We Bolt
  - Offered as early as 2009.
- Small-RPS development is under consideration:
  - 200W bolt, small RPS in the 0.5 to 1 We Bolt.
  - Potential as 2011 could be made available as early as 2011, front mission.
  - NERL (not in September 2004) & NRP (likely to come out this month)
- Radiokapet Power Systems (RPS) could enable Solar System Exploration:
  - Long mission duration & continuous power generation
  - Works in void (vacuum) & in atmospheres
  - Independent from solar flux
  - Without ~AAT with high luminosity, it allows access locations on planetary surfaces where solar flux is not available e.g., polar regions
  - Beyond ~AAT for long mission: main power generation requirement: only visible option
  - Power or waste heat could be cycled for thermal management

Mars Mission Concept: Deep Drill

- Deep Drill to 50 m or 50 m in depth
- Key instruments: sample acquisition and processing, meteorology, instruments, etc.
- In addition to MIT/PAC mission 1.
- 300W Bolt could service mission goals with 100W Bolt, generating ~70W Bolt and ~240W Bolt.
- 500W Bolt could service ~2011 mission (~110 We Bolt ~700 We Bolt)
- High power requirements by drilling operations and bores

- Hybrid power system should be used for peak power ranges and energy maps.
- Thermal environment should be addressed through all mission phases.

Small-RPS Concept: Mars Rover

- Power (100W-300W) continuously for 1-2 months
- Drive range up to 3 years
- Driven from Mars
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Thanks for your attention. Any questions?
Power Generation Paradigm

Historical Overview (RPS & Solar)

Past RPS:
- MTRW-RTG
- SNAP-19
- OPUS-RTG

Newer RPS:
- MAREG (~2009)
- PGW (~2009-2010)
- Small-RPS (~2017)

Solar panels:
- Gataa
- GaAs & Si
- Triple junction

Power System Cost Summary

Fission Power and RTG's to Date

Power System Mass Summary

Radiation Exposure: Material Charging
- In radiation environments, high-speed electrons could cause high voltage-potential charged regions
- If grounded, this charge could set up a permanently burned conductive path
- Internal charging could result in catastrophic breakdowns of materials!

Example: Lucite acrylic, exposed to 4.5 MeV electrons, then charged at the location of a ground point (by P.B. Will, JPL)
Radiation Tolerance: Testing vs. Accelerated Testing

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>100°C for 5 minutes</td>
<td></td>
</tr>
<tr>
<td>40°C for 1 week</td>
<td></td>
</tr>
<tr>
<td>70°C for 3 weeks</td>
<td></td>
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</tbody>
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Accelerated testing is only meaningful if the mechanisms to be tested remain consistent through ranges of time, temperature, rate, energy etc.

Therefore, equal "dose" may not result in the same outcome!

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Power System Trade for the Same Amount of Pa²¹³

- Small-RPS with 1 GPHS module
  - 2 small-RPS (1 GPHS each)
  - Pu²³⁹ fuel mass: 2 x 0.5 kg
  - Static conversion (assumed η~5%) → Dynamic conversion (η~75%)
  - Thermal power: 2 x 250W (BOL) → Thermal power: 2 x 500W (BOL)
  - Electric power: 2 x 125W → 250W
  - System mass: 2 x 7.8 kg = 16 kg
  - Dimensions: ~11.5" x 6.0" x 6.0" each
  - Other: g-load tolerance (TBD)
  - Low TRL target 2014 Scout
  - Development program not yet started

- Stirling Radioisotope Generator
  - Small-RPS with 2 GPHS modules
  - Pa²¹³ fuel mass: 2 x 0.5 kg
  - Static conversion (assumed η~75%)
  - Dynamic conversion (η~75%)
  - Thermal power: 2 x 500W (BOL)
  - Electric power: 110 W (BOL)
  - System mass: ~34 kg
  - Dimensions: ~11.5" x 6.11.5" x 3.75"
  - Other: g-load tolerance (TBD)
  - Other: g-load tolerance (TBD)
  - TRL9 target: 2009
  - Development program ongoing

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Note: "Thermal power: 2 x 250W (BOL)" may not be representative of 2 x 500W for small-RPS testing and design.