The Potential Benefits of Nuclear Power on the Surface of Mars: The Robotic Exploration Perspective

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Overview

- **Mars Exploration Program**
  - Objectives and approach
- **Potential future robotic Mars missions** (2011-2024):
  - Approved and candidate Mars exploration missions
- **Power Systems**
  - Power Source Classification
  - Solar Availability and Solar Power Generation
  - Radioisotope Power Systems (SoP, development, future plans)
  - Batteries
  - Special considerations for using RPSs on Mars landed missions
- **Future Mission Concept Examples Utilizing RPSs**
- **Conclusions**

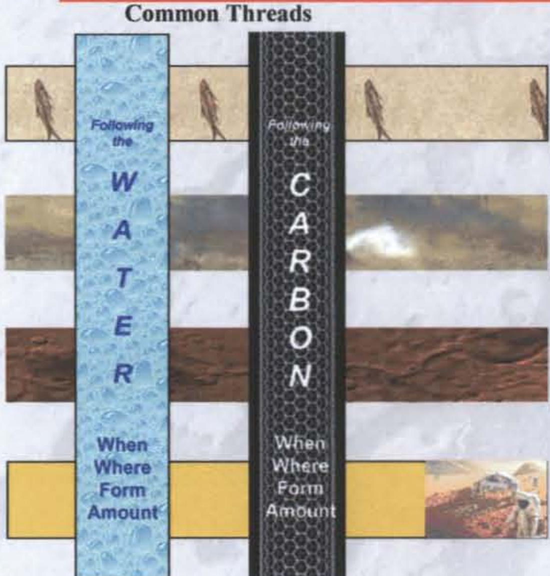
Mars Exploration Program

- Consists of a **science-driven** effort to characterize and understand Mars as a dynamic system. This includes its present and past environment; climate cycles; geology; and biological potential. A key question we are trying to answer is whether life ever arose on Mars.
- Exploration strategy: "**Follow the Water**" (present & early next decade) Search for sites on Mars with evidence of past or present water activity and with materials favorable for preserving either bio-signatures or life-hospitable environments.
- Exploration approach: "**Seek + In-Situ + Sample**" Orbiting and surface-based missions are interlinked to target the best sites for detailed analytical measurements, and for sample return.

Exploration Strategies

Common Threads

Guiding principles (MEPAG Goals)



I: Determine if **life** ever arose on Mars (past/present)
(Biological Markers)

II: Determine the **climate** and connected processes (present/past)
(Weather & Environment)

III: Determine the evolution of the surface and interior of Mars
(Geology)

IV: Prepare for **human exploration**
(Robots/Human Precursors/Humans)

This decade → **Next decade** → Following decades →

MEPAG: Mars Exploration Program Assessment Group

Recent Discoveries

Based on Mars Exploration Rover (MER); Mars Global Surveyor (MGS); Mars Odyssey and Mars Express findings:

- Early Mars was wet and had an active hydrological cycle.
- Groundwater played an important role on early Mars.
- Periodic climate change influenced the hydrological cycle.
- Near subsurface is hydrogen rich at mid-latitudes and poleward.
- Detection (putative) of significant and spatially variable amounts of CH_4 may indicate geologically or biologically active sites
- Evidence of an early dynamo suggests magnetic field could have provided shielding at the surface from solar and cosmic radiation.

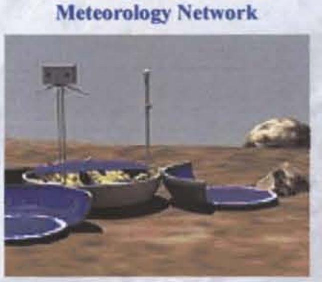
Future Mission Concepts Evaluated

Mars Science Orbiter and Telecom

Midrovers

Astrobiology Field Laboratory (AFL)

Planetary Evolution and Meteorology Network



Mars Sample Return (MSR)

Draft Mars Exploration Architecture (Approval Pending)

2009 - 2024

2009	2011 / 2013	2016	2018	2020	2022	2024
Mars Science Laboratory (MSL)	Scout or Mars Science Orbiter with Telecom	Midrovers or Astrobiology Field Laboratory (AFL)	Scout	Planetary Evolution And Meteorology Network	Mars Sample Return (MSR) Orbiter and Return Capsule	Mars Sample Return (MSR) Mobile
	 OR	 OR				

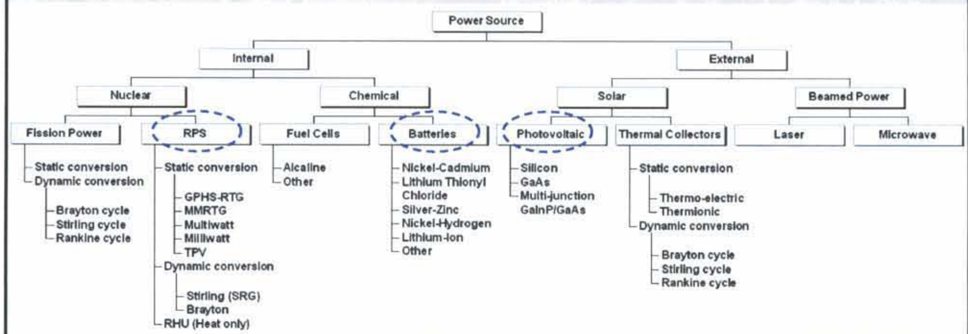
Approved and Candidate Robotic Mars Missions

Selected & Potential Missions	Mission Class	Power System Option(s)
Orbiters (e.g., **MRO**[1])	Moderate/Large	Solar (typical for Mars orbiters)
Phoenix[1]	Scout	Solar selected
Mars Science Laboratory (MSL)[1]	Large	RPS (MMRTG) baselined (solar feasibility study in work)
Scouts (small missions)	Scout	Solar (RPS usage not allowed)
Multi-Lander Network	Moderate/Large	(Small-RPS or Solar)[2]
Astrobiology Field Lab (AFL) rover	Large	(To be determined)[2]
Mars Sample Return (MSR)	Flagship	(Solar or RPS)[2]
MSR Fetch rover (sub-MER class)	Scout-Large	(Small-RPS or Solar)[2]
Deep Drill	Large	(RPS or Solar)[2]

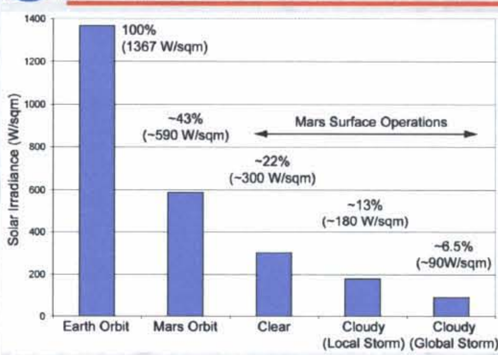
[1] **Funded** missions;

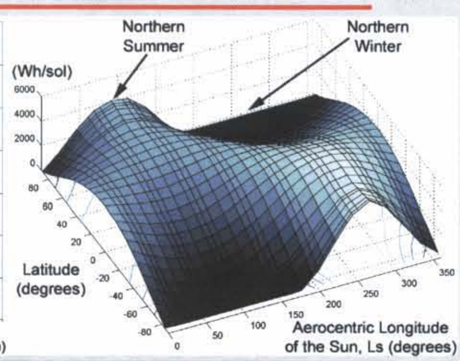
[2] **Everything below Scouts line should be referenced as based upon presumed mission requirements and preliminary power trade studies**

Power Systems: Power Source Classification



Power Systems: Solar Irradiation at Mars

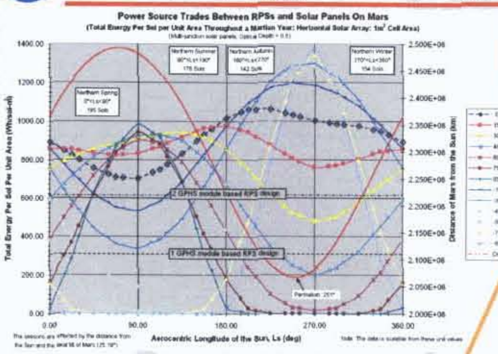




- Insolation at Mars is ~43% of that at Earth / Moon
- Insolation on the surface of Mars is significantly lower than in orbit
- Solar flux on the surface of Mars can be as low as ~6.5% of that at Earth/Moon

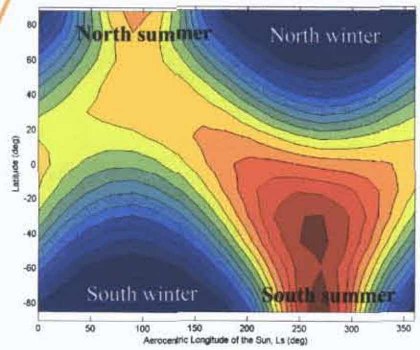
- Solar power generation on Mars is impacted by:
  - Operating latitude
  - Sand storms
  - Eclipses
  - Solar panel degradation – mission duration (dust; thermal cycling)
  - Seasons (Ls, aerocentric longitude of the Sun)
  - Atmospheric conditions
  - Terrain shadowing

Why Consider Using RPS on Mars?



- Comparison of power generated with a 1 m^2 solar panel and small-RPSs utilizing 1 or 2 GPHS modules
- RPS power generation is constant over the Martian year (note: there is an ~1.5% degradation per year)
- Solar power generation is dependent on Aerocentric Longitude of the Sun (L_S), and latitude (among other factors)

- Average insolation over a Martian year
  - Latitude and season dependent
- Polar winters produce permanently dark periods, affecting long lived missions
  - Caused by axial tilt of Mars
- The elliptic orbit of Mars results in
  - Warmer South Pole summers
  - Colder North Pole summers



Pre-decisional – For discussion purposes only

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Advantages of Using RPSs and RHUs on Mars

- RPS enabled surface missions:
  - Are independent from solar flux; shadows and eclipses
  - Could provide significantly longer mission duration and hence longer range of mobility
  - Allows operations at night
- RPSs could provide advantages over solar power generation at all regions of Mars:
  - It allows for continuous year around operation; measured in years
  - Could utilize excess heat from RPS to the Warm Electronics Box (WEB),
    - This allows for tight temperature control, thus minimizing thermal-cycling (note: solar power systems must use batteries to heat components overnight)
  - Tight temperature control could lower the risk of mechanical failures of components (e.g., failure of solder bonds)
  - Keeping battery temperatures at a constant 0°C helps with battery chemistry, hence could increase battery life – thus system and mission lifetime
- Radioisotope Heater Units (RHU) could provide component heating to external components (RHUs were used on both Pathfinder and MER)

Pre-decisional – For discussion purposes only

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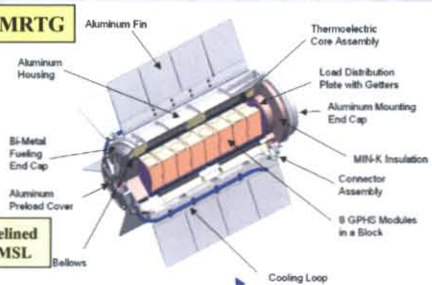
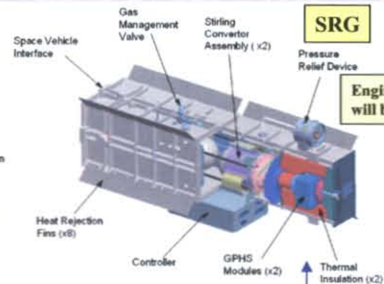
RPSs for Mars: Past, Present and Possibly Future

MMRTG



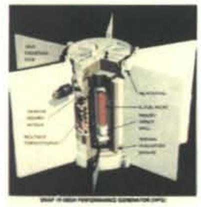
Baselined for MSL

SRG



Engineering Unit will be Developed

Parameter	MMRTG Future:	SNAP-19 (DISCONTINUED) Past:	*SRG* (Development)
Power per Unit (BOM), We	~125	~40.3	*~116*
Mass per Unit, kg	44	13.4	*34*
# of GPHS Modules per Unit	8	N/A	*2*
Thermal Power, Wt	2000	250	*500*
Specific Power, We/kg	2.9	3.0	*3.4*
Conversion type	Static	Static	*Dynamic*
Converter materials	PbTe/TAGS	PbTe/TAGS	*Stirling*
Technical Readiness level	TRL-5	TRL-9	*TRL-3*
Availability	MSL-2009	Discontinued (used on Viking 1 &2)	*2014+*



Present: Radioisotope Heater Unit 1Wt
Used on MPF & MER
(component heating)

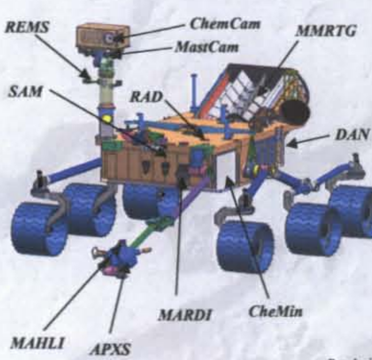
SNAP-19 was on Viking 1 operated for >6 years, spacecraft was shut down

SRGs are only considered as trade options for next decade Mars missions

Mars Science Laboratory (MSL) Mission (2009)

Salient Features

- Mobile Science Laboratory
- One Mars Year nominal surface operational lifetime (669 sols / 687 days)
- Discovery Responsive over wide range of latitudes and altitudes
- Controlled Propulsive Landing
- Precision Landing via Guided Entry
- Baselined with an MMRTG



Remote Sensing (Mast)

ChemCam – Laser Induced Breakdown Spectrometer
MastCam – Color Stereo Imager

Contact Instruments (Arm)

MAHLI – Microscopic Imager
APXS – Proton/X-ray Backscatter Spectrometer

Analytical Laboratory (Front Chassis)

SAM – Gas Chromatograph/Mass Spectrometer/ Tunable Laser Spectrometer (Sample Composition / Organics Detection)
CheMin – X-ray Diffraction / Florescence (Sample Mineralogy)

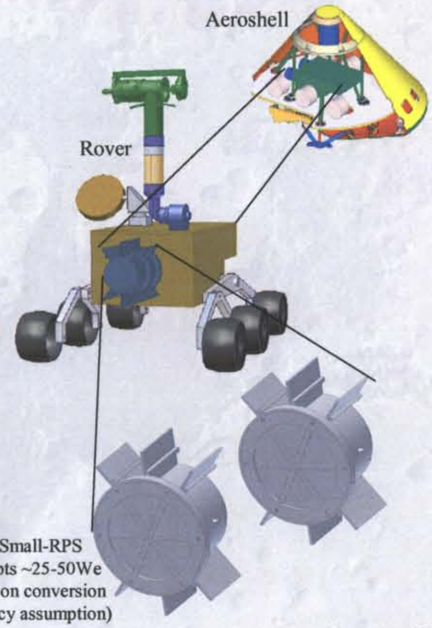
Environmental Characterization (Body-mount)

MARDI – Descent Imager
REMS – Meteorological monitoring
RAD – Surface Radiation Flux Monitor (future human health & safety)
DAN – Neutron Backscatter subsurface hydrogen (water/ice) detection

In current studies, the main difference between MSL and AFL missions would be the science instrument suite and sample processing.

Rovers: MER-Class Rover and AFL Concepts

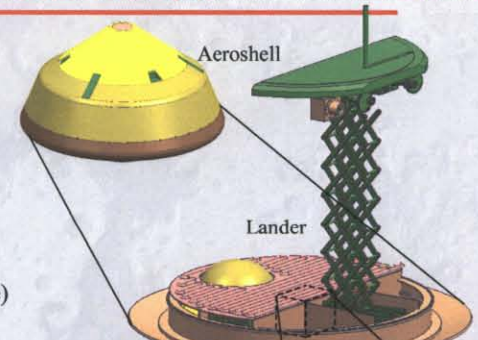
- Astrobiology driven goals to address MEPAG Goals 1 to 3
- Instruments could include: Microscopic imager; Raman spectrometer; APXS; Mini-TES; Pan Cam, RAT; TEGA; GC/MS etc.
- Could operate up to 2-3 years on Mars
- MER solar power generation:
  - ~1000 Wh/sol BOL:
  - ~600 Wh/sol EOL (primary mission);
- Small-RPS enabled mid-rovers with
  - 2 GPHS modules: ~620 Wh/sol BOL;
  - 4 GPHS modules: ~1240 Wh/sol BOL.
- Large MSL heritage rover:
  - MMRTG (8 modules): ~2700 Wh/sol
- Excess heat from RPS could be utilized to heat components, motors, actuators, etc.
- Typical high power operating modes:
  - mobility, telecom,
  - GC/MS, drilling



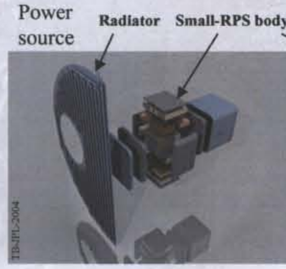
2 x Small-RPS concepts ~25-50We (based on conversion efficiency assumption)

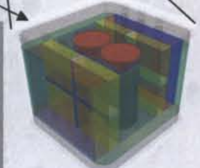
Mars Multi-Lander Network Concept

- Monitor weather & environment
- Address MEPAG Goals 2 to 3
- Instruments could include: seismometer; mini-MS; Pan Cam; meteorology station
- Baseline:
  - 4 landers (up to 10)
  - Solar powered
  - (RPS trades considered – shown here)
- High power requirement by telecom
- Small-RPS based configuration:
  - Long life (up to several years)
  - Independent from solar flux
  - Capable to operate at any location
  - Nominal hard landing requires high g-load tolerant RPS (~2000g, compared to 40g for the MMRTG). This requires significant technology development



Power source

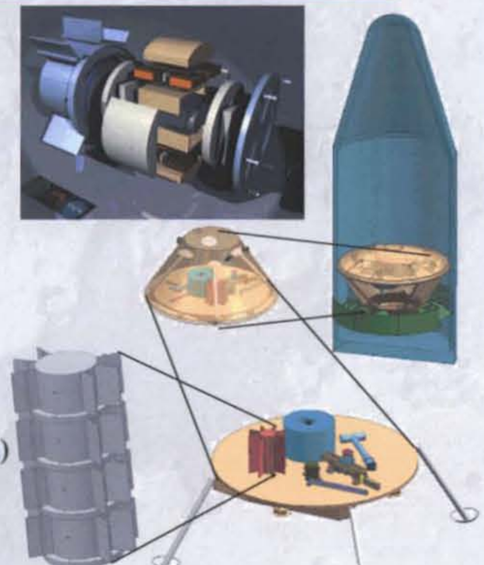




Small-RPS concept ~12.5-25We (based on 5% to 10% conversion efficiency)

Mars Deep Drill Concept

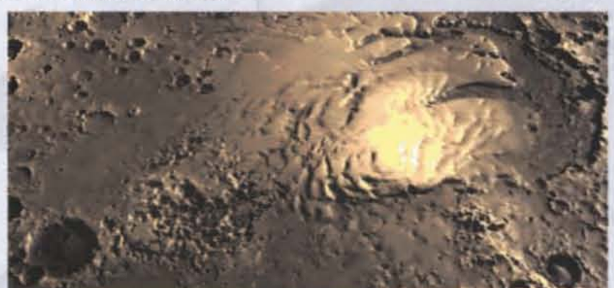
- Deep Drill to 10 m or 50 m depth
- Key instruments: sample acquisition and processing; meteorology instrument; Pan Cam
- To address MEPAG Goals 1 to 3
- 10m drill could achieve mission goals with 4 small-RPSs, generating ~50We and ~1240 Wh/sol
- 50m drill would likely require an MMRTG (~110 We and ~2700 Wh/sol)
- High power requirements for drilling operations and telecom



4 x Small-RPS concepts
~50-100 We (based on conversion efficiency assumptions)

Conclusions

- NASA's post 2010 Mars program is in a pre-planning phase, therefore the listed missions are under study. Final program plan is expected in Summer 2006.
- Mars orbiter missions will likely continue employing solar power generation
- Some landers / rovers could use both RPSs or solar panels. The options depend on mission duration, landing location (latitude, longitude terrain), season, atmospheric conditions and planetary protection constraints
- Next decade landed missions will likely use MSL heritage, but if available then small-RPSs could also be considered
- Radioisotope Heater Units (RHU) will likely continue to provide local component heating on some surface missions



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