Radioisotope Power Systems (RPS) for Discovery 2010 Missions

Presented to the Discovery Pre-Proposal Conference

July 1, 2010

Residence Inn DC/Capitol
Washington, DC

Presented by

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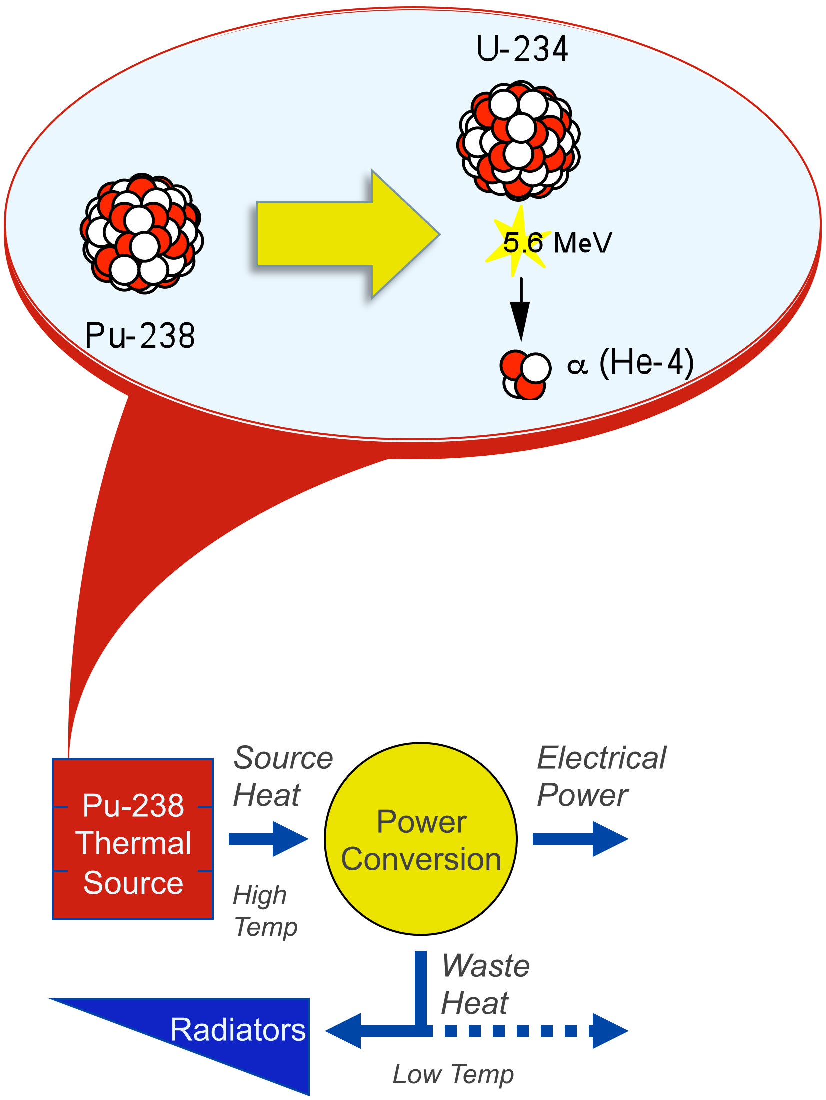
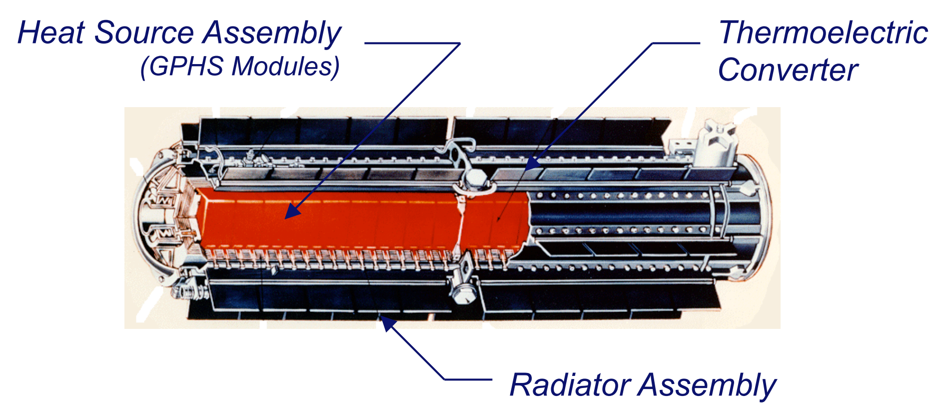
Radioisotope Power Systems (RPS)

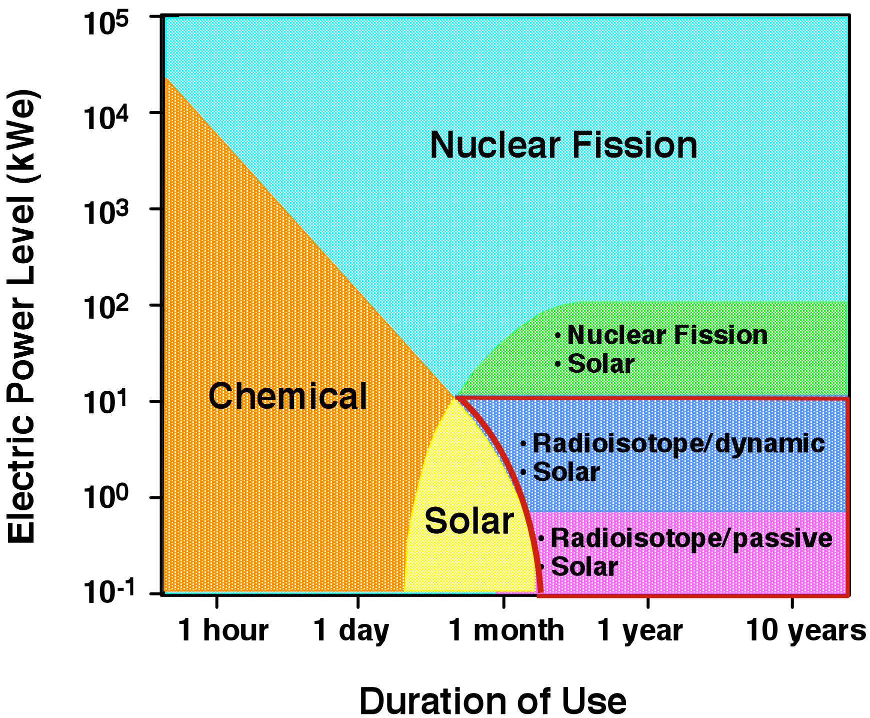


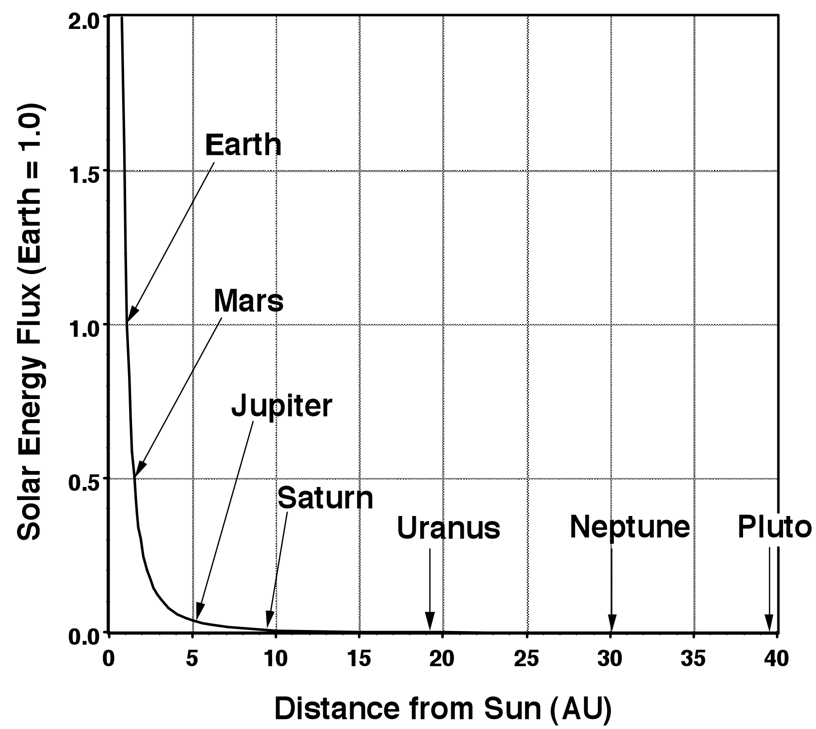
- Heat produced from natural alpha (α) particle decay of plutonium (Pu-238)
  - *87.7-year half-life*
- Small portion of heat energy (6%-35%) converted to electricity via passive or dynamic processes
  - *Thermoelectric (existing & under development)*
  - *Stirling (under development)*
  - *Brayton, TPV, etc. (future candidates)*
- Waste heat rejected through radiators – portion can be used for thermal control of spacecraft subsystems



Suitability of RPS

- Radioisotope generators will continue to serve a **critical role** in the scientific exploration of the solar system and deep space.
- ASRG's high efficiency maximizes use of radioisotope inventory and future production





Advanced Stirling Radioisotope Generator (ASRG)

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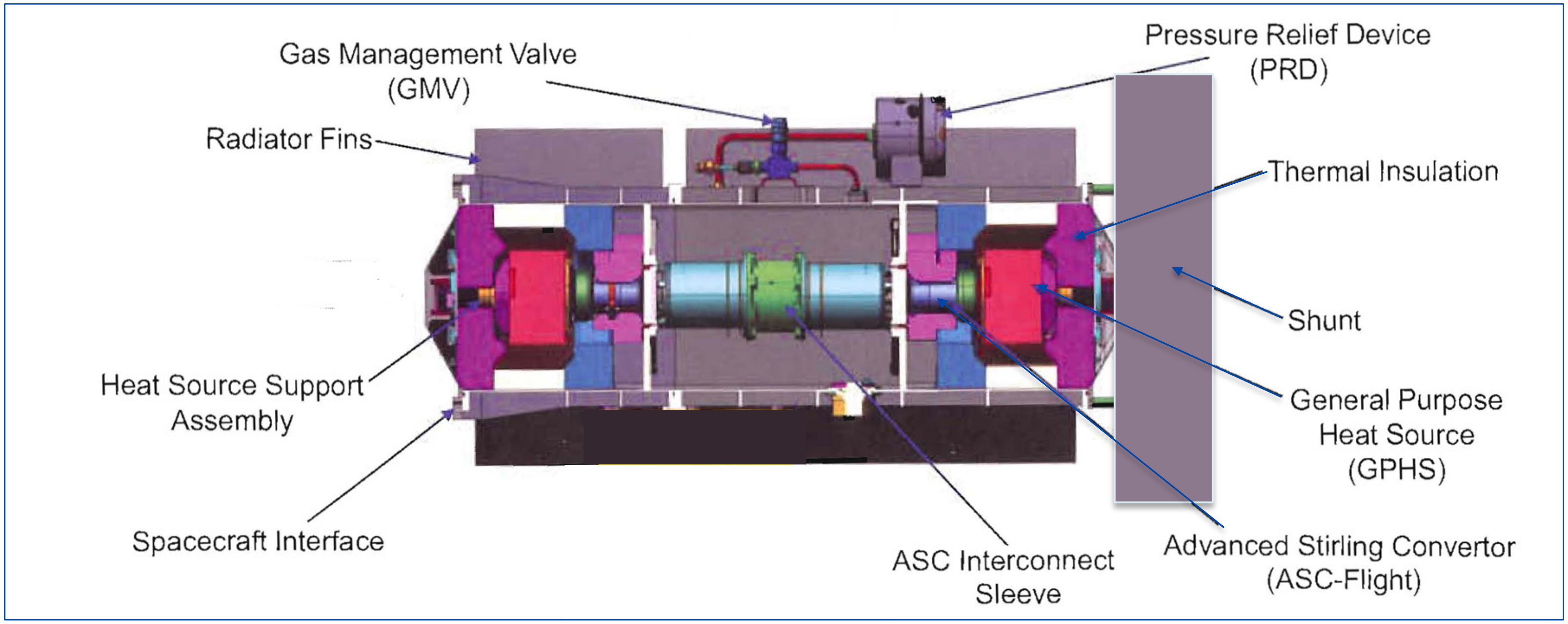
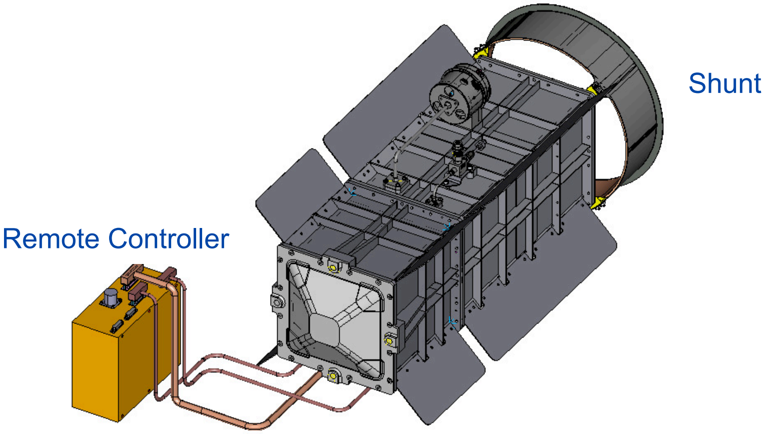
Cutaway





ASRG Requirement Status

- The RPSPO is acting as the “surrogate mission” for Discovery
  - *System requirements developed through Science Community and flight systems experience.*

- ASRG Flight Performance Specification derived that encompasses many mission envelopes
  - *Two Design Reference Missions (DRM) developed to also guide requirements and Concept of Operations (ConOps)*
  - *ConOps Team charted by NASA to develop ASRG operational parameters*
    - Covers both ground, launch pad and mission operations
      - Mechanical
      - Electrical
      - Planetary Protection
      - Space Radiation

ASRG Requirement Status (cont)

- Special spacecraft needs to accommodate the ASRG's operational parameters will be the responsibility of the mission.
  - *Potential spacecraft accommodations*
    - *Sun shade for Venus Flyby could be required to maintain ASRG maximum effective sink temperature limits*
    - *Vibration dampening for ultra sensitive instruments*
    - *Additional cooling tubes for spacecraft heating*

ASRG Summary (July 2010)

Parameter	ASRG
Power per Unit (BOM), (4° K, space vacuum)	128 We (includes 5% program reserve on 135 We)
Power per Unit (BOM), (Mars avg. temp, CO_2)	106.4 We (includes 5% program reserve on 112 We)
Voltage	22-34 VDC (Nominal Range)
Power Degradation Rate, [%/yr]	~ 0.8 (power decays roughly with fuel decay)
Mass per Unit, [kg]	~ 32 (includes 5% program reserve on 30.6 kg) (1)
Dimensions [cm]	Length: 76.2 cm; Width: 39.4 cm; Height: 45.7 cm
Radiation Tolerance	126 krad (2)
Additional Shielding, [kg]	Mission Specific, required only for controller in a high-radiation environment (3)
Number of GPHS Modules per Unit	2
Thermal Power (BOM), [Wt]	488-512 (min/max fuel load) (fuel processed in 2011)
Mechanical Disturbance (axial)	~ 22 N peak-peak (EU measured), (35 spec)
Frequency (Hz)	102
Controller	Single-fault tolerant, with N+1 redundant controller cards and the capability for the engines to operate independently of one another in the event of single engine failure.
External Radiator Temperature (4)	~ 45° C (space Vacuum, no Sun)
Operating Environment	Vacuum and Atmosphere
Lifetime Requirement, [years]	14 + 3 (storage)

(1) Mass does not include: optional spacecraft adapter ring for missions using launch vehicles (> ~ 0.1 g/Hz); adds 1.23 kg; ASRG housing to controller cable mass; adds ~1.8 kg/m.

(2) Radiation Tolerance: from 50kRad space and 13 kRad GPHS source Requirement, with RDF 2 applied

(3) For ASRG additional shielding is required to protect the controller electronics. (As an example, controller shielding mass for a Europa type mission was previously estimated at ~ 11 kg (TBR)).

(4) Case temperature for other environmental sink temperatures will vary

GPHS – General Purpose Heat Source BOM – Beginning of Mission

ASRG Power Output (Space)

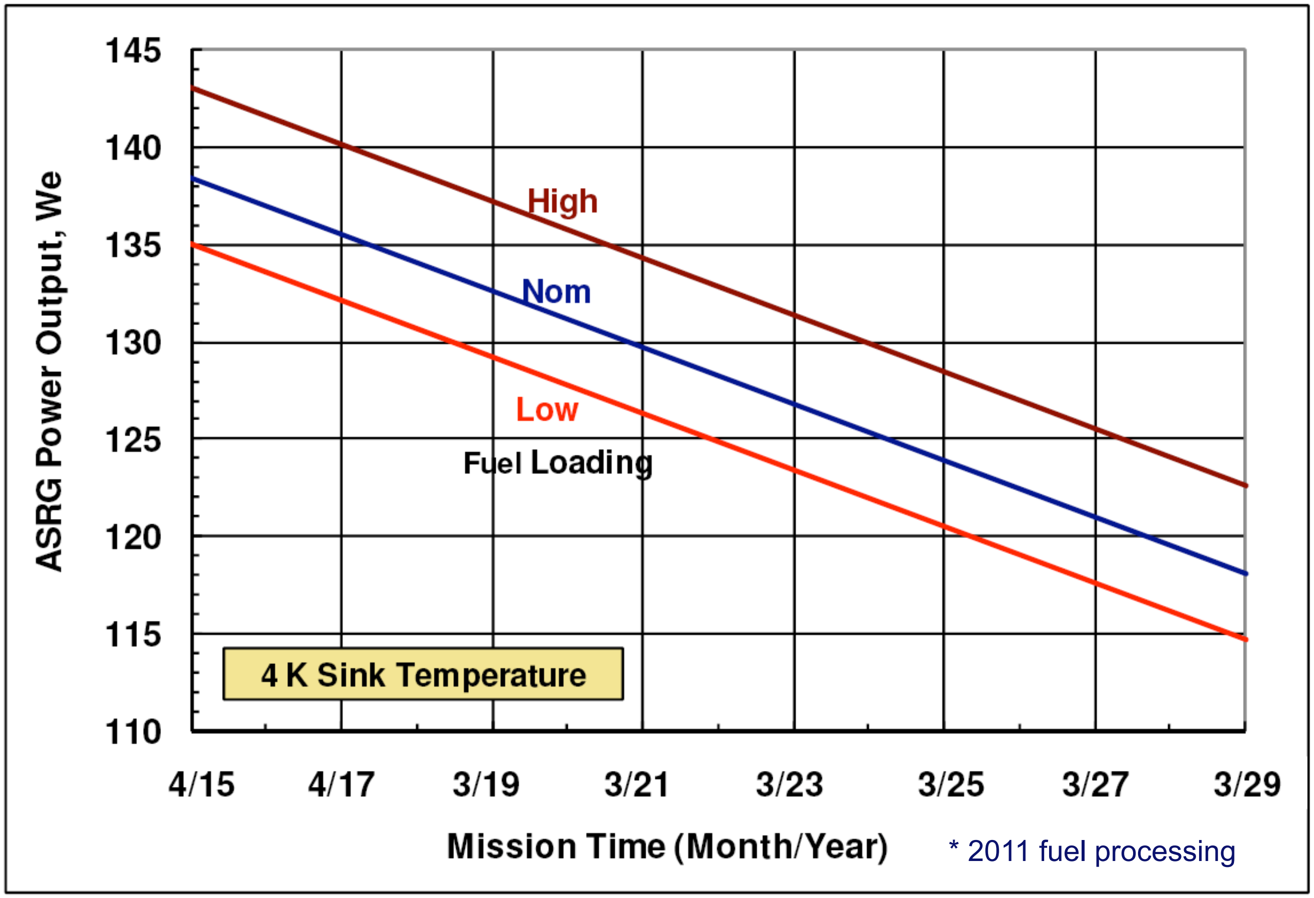


Figure 4.2-1. ASRG Power Output versus Mission Year.

ASRG Power Output (Mars)

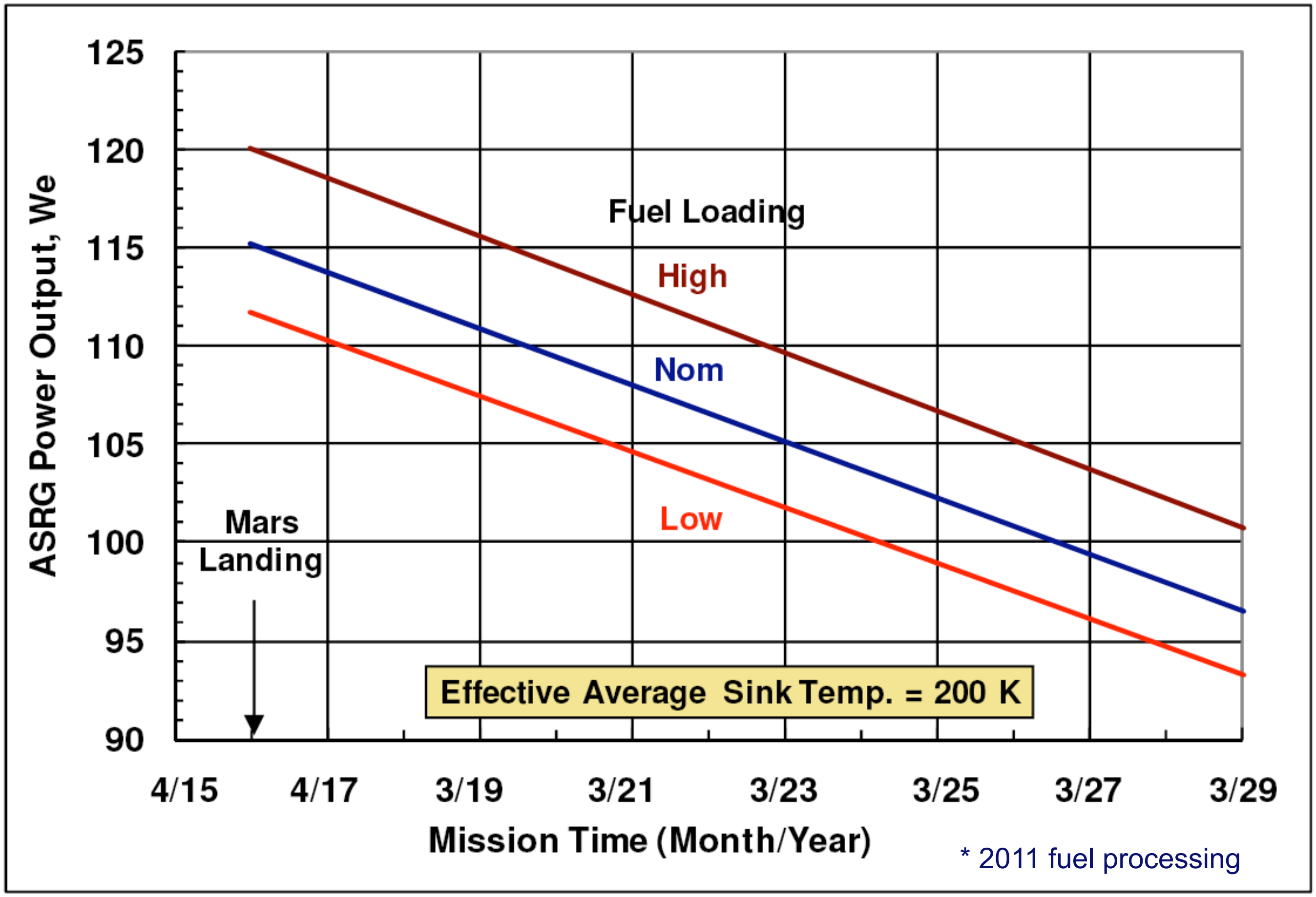
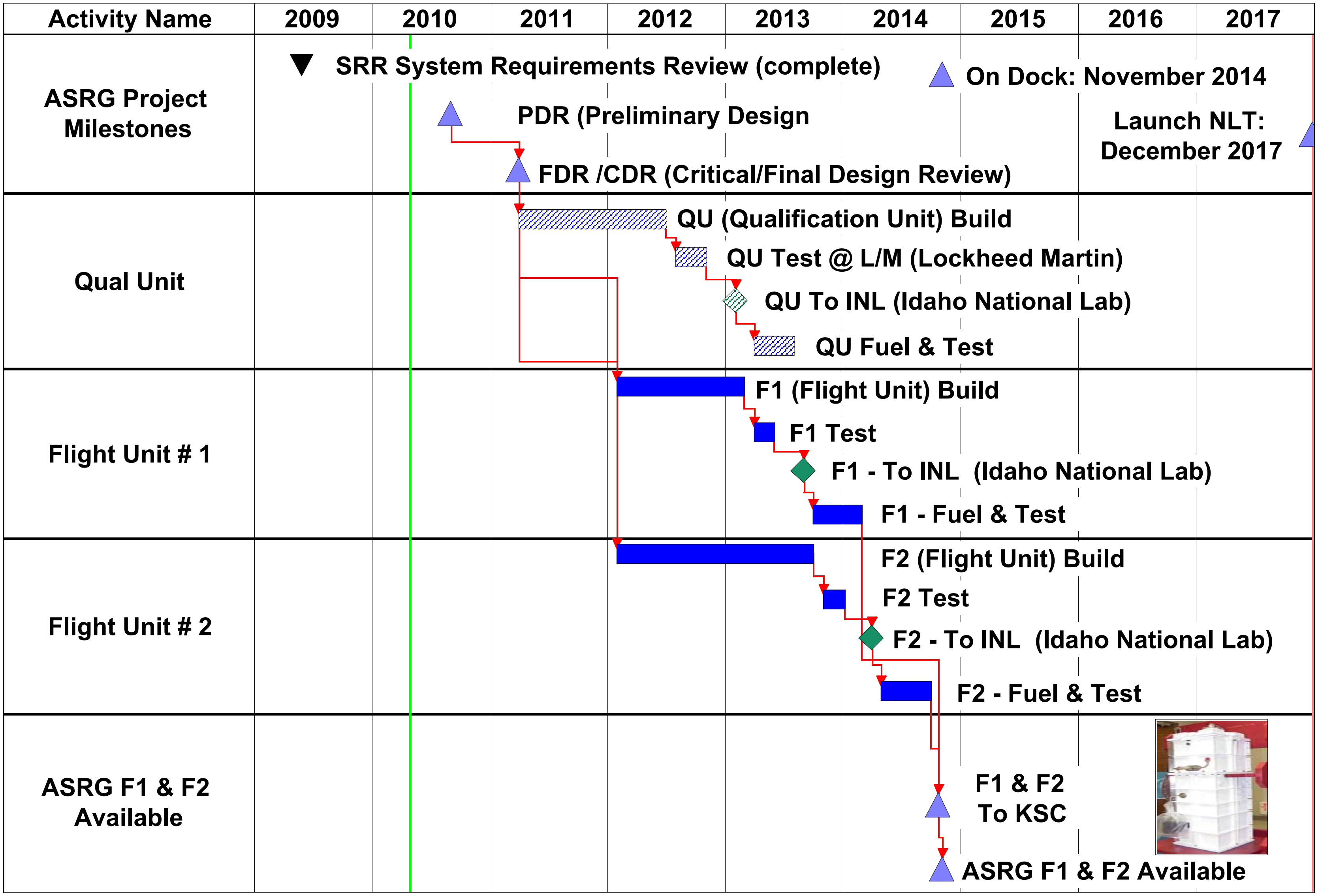


Figure 4.2-3. ASRG Power Output for Mars Surface Missions.

ASRG Development Schedule



ASRG and RHU AO Cost Considerations

Advanced Stirling Radioisotope Generator Costs	Mission-specific Costs
Cost for ASRG hardware	**Costs for launch approval processes (ASRG inc. RHU's)**
ASRG System Design and Safety Data	NEPA Compliance/Environmental Impact Statement (EIS)
Qualification Model (kept at INL by DOE)	Nuclear Safety Launch Approval (NSLA)
Thermal and Mechanical models	Emergency Preparedness and Planning
Two Flight Units	Risk Communication
Mission Cost: None (GFE)	**Mission Cost: $20M** (see AO Table 1)

(DDT&E value: ~$120M)
(F1 & F2 value: ~ $54M)

Nonstandard launch services
Mission Cost: $0M (see AO Table 3)

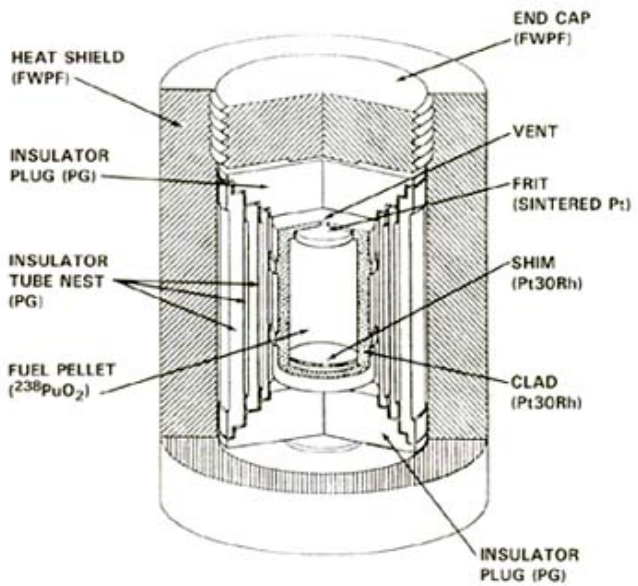
Radioisotope Heater Unit	**Cost/unit: $ 3K**
**Extra safety analyses are needed for missions employing RHUs only. These analyses are included in the Government-furnished ASRGs.*	**Launch approval process cost: $20M* (RHU only mission)**
	Nonstandard launch services cost: $20M (RHU only mission)

Radioisotope Heater Unit (RHU)

RHU Characteristics

Characteristics of RHUs include:

- *Highly reliable, continuous, and predictable heat output*
- *Simple, No moving parts*
- *Compact structure*
- *Resistant to radiation and meteorite damage*
- *Heat produced is independent of distance from the sun*
- *Heat is transferred through direct contact with components*
- *Extremely rugged and safe*
- *2 gms Pu-238*
- *20 RHUs available for Discovery (~ 0.85 Wth)*



Nuclear Launch Safety Approval Processes for Discovery Program: Proposer/Project Inputs and Support to Launch Approval Engineering Processes

Prepared by
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RPS Program Multi-Mission Launch Approval Engineering

U.S. Nuclear Launch Safety Processes Overview

- Process has four components
  - National Environmental Policy Act (NEPA) became law in 1969
    - NASA regulations explicitly require an environmental impact statement (EIS) for flight of space nuclear power sources (i.e., radioisotope heater units, radioisotope power systems)
  - Presidential Directive/National Security Council Memorandum #25 (PD/NSC-25), "Scientific or Technological Experiments with Possible Large-Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space"
    - Memorialized in 1977, a process formally in place since 1965
  - National Response Plan, Nuclear/Radiological Incident Annex originates with Federal Radiological Emergency Response Plan (1980) [Radiological Contingency Planning (RCP)]
  - Risk Communication (Risk Comm)
    - RPS-specific activities originated in activities undertaken to explain risk of Galileo mission in wake of 1986 Challenger and Chernobyl accidents
- The activities required to support these processes are collectively called "Launch Approval Engineering" (LAE)

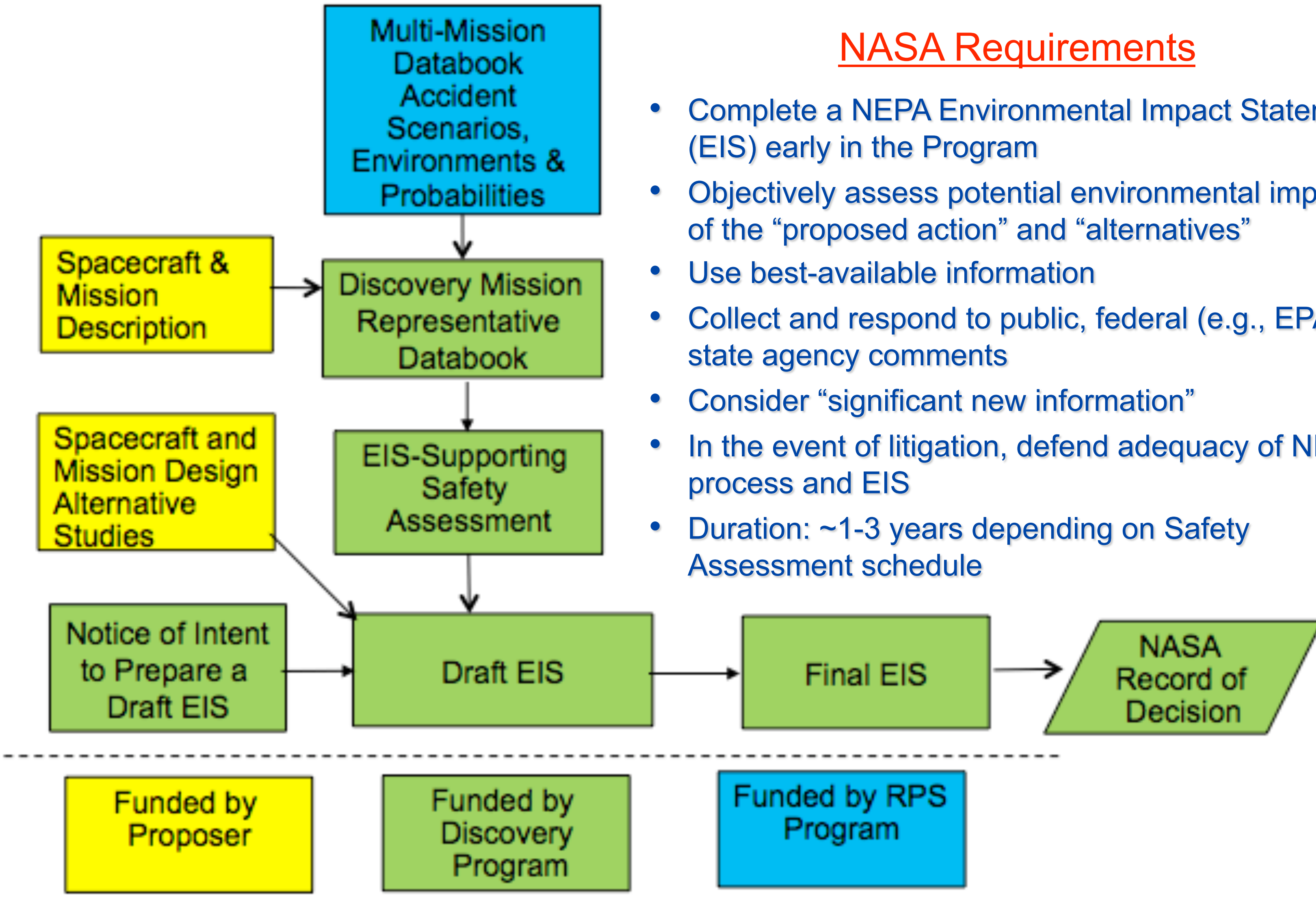
Overview of ASRG LAE Plan

- NASA HQ responsible for satisfying LAE process requirements based on input data provided by proposers
- RPS Program has initiated development of long-lead LAE-supporting information in parallel with proposal activities
  - Discovery LAE plan for NEPA and PD/NSC-25 compliance
  - Multi-Mission Representative Databook – a compendium of launch accident scenarios, environments and probabilities
- Prior to Step 1 decision, only limited information required for LAE processes
- Proposers selected at Step 1 will work directly with the Discovery LAE team to provide inputs required for timely compliance with NEPA, PD/NSC-25, RCP and Risk Comm processes

Project Inputs and Support to Nuclear Launch Safety Approval Engineering Processes

- NEPA
  - Spacecraft/mission descriptions
  - Alternative power system/trajectory design information
  - Participation in reviews, public meetings and response to government/public comments
- PD/NSC-25
  - Detailed spacecraft/mission design information
  - Trade studies and implementations supporting NPR 8715.3 paragraph 6.2.2
    - "b. Basic designs of vehicles, spacecraft, and systems utilizing radioactive materials provide protection to the public, the environment, and users such that radiation risk resulting from exposures to radioactive sources are as low as reasonably achievable."
    - "c. Nuclear safety considerations are incorporated from the initial design stages throughout all project stages to ensure that overall mission radiological risk is acceptable."
  - Participation in reviews
- Radiological Contingency Planning
  - Out-of-orbit contingency plans
  - Accident response team support
  - Participation in reviews
- Risk Communication
  - Public spokespersons
  - Inputs for and review of fact sheets, response-to-queries, web pages, etc.

National Environmental Policy Act (NEPA) Process



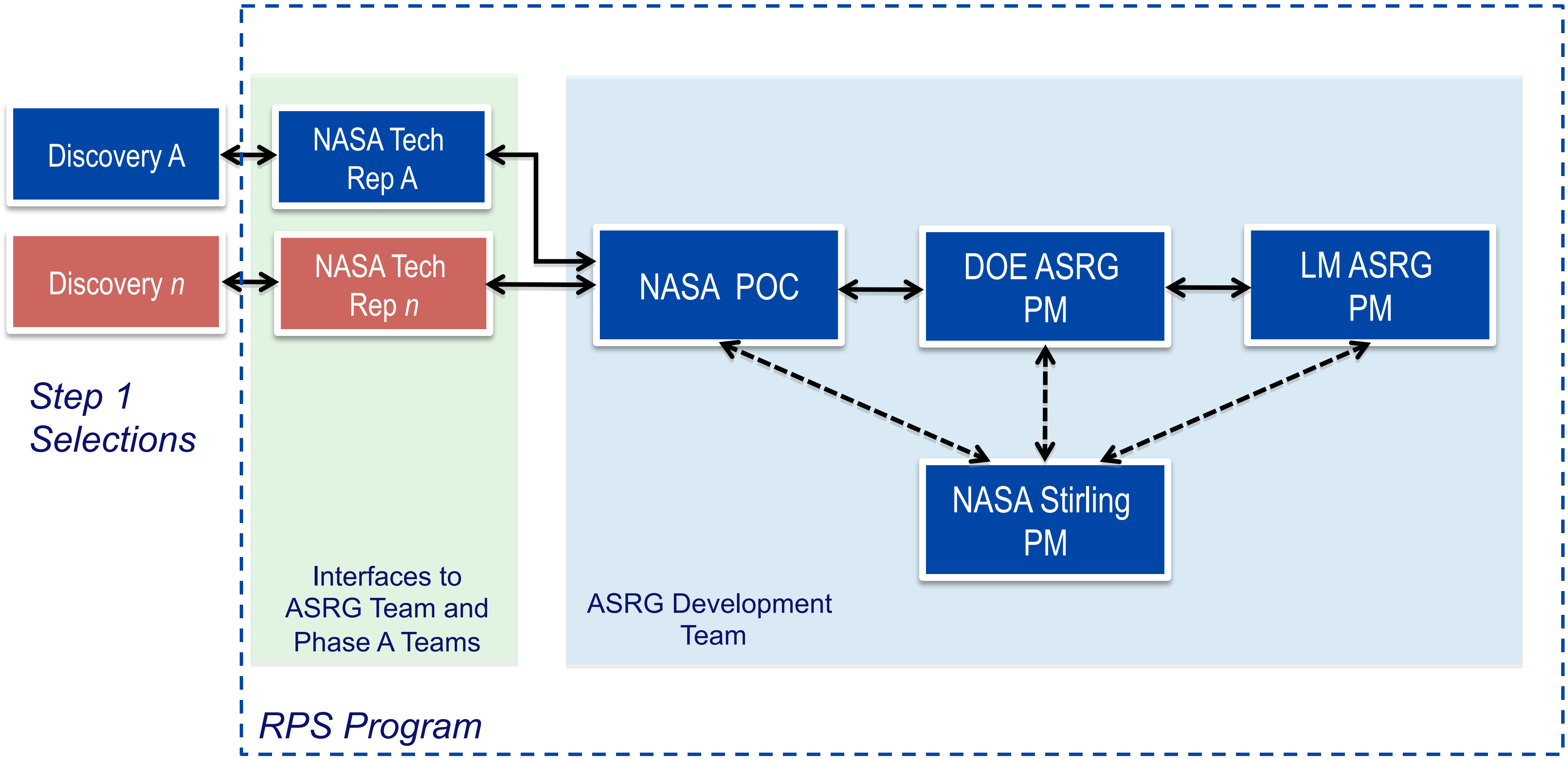
NASA Requirements

- Complete a NEPA Environmental Impact Statement (EIS) early in the Program
- Objectively assess potential environmental impacts of the “proposed action” and “alternatives”
- Use best-available information
- Collect and respond to public, federal (e.g., EPA) and state agency comments
- Consider “significant new information”
- In the event of litigation, defend adequacy of NEPA process and EIS
- Duration: ~1-3 years depending on Safety Assessment schedule

ASRG/RHU Documents in the AO Library

- *Advanced Stirling Radioisotope Generator Information Summary (#17)*
- *ASRG User ICD (#19)*
- *Electromagnetic Interference Data from ASRG Engineering Unit (#20)*
- *Low Frequency Magnetic Fields Near the ASRG Engineering Unit (#21)*
- *Radioisotope Heater Unit Information Summary (#6)*
- *ASRG Thermal Model available by request (Export Controlled)*

ASRG Discovery Proposed Technical Organization



ASRG Flight Systems Development

Stirling Radioisotope Generator / Stirling Engine Development

– Sunpower has developed several versions of their ASC on the path to flight. A total of 12 ASC's have been delivered and are under test with total accumulated hours of 75,000 hrs. Two ASC pairs have seen over 15,000 hours of testing.

– Significant development is underway to prove and certify the reliability of the ASC's for flight. Detailed analysis, metallics and organic material testing, component level testing and ASC performance and operation program is being performed.

Advanced Stirling Radioisotope Generator Development

– Lockheed Martin built the ASRG Engineering Unit and delivered the EU to NASA/GRC in 2008.

- The EU has been under near continuous (24/7) operations since delivery and has accumulated 10,000+ hours.

– LM will manufacture one qualification unit and two flight units.

– Two flight units delivery to KSC October 2014. (assumes NET March 2015 launch)

ASRG for Discovery 2010

Please see the AO Library for updates to the ASRG development schedule and also updates (quarterly) to power and mass as these numbers get further refined as the design matures.

Please refer to the ASRG User ICD for the most current characteristics and parameter value updates.