Radioisotope Power Systems (RPS) for Discovery 2010 Missions

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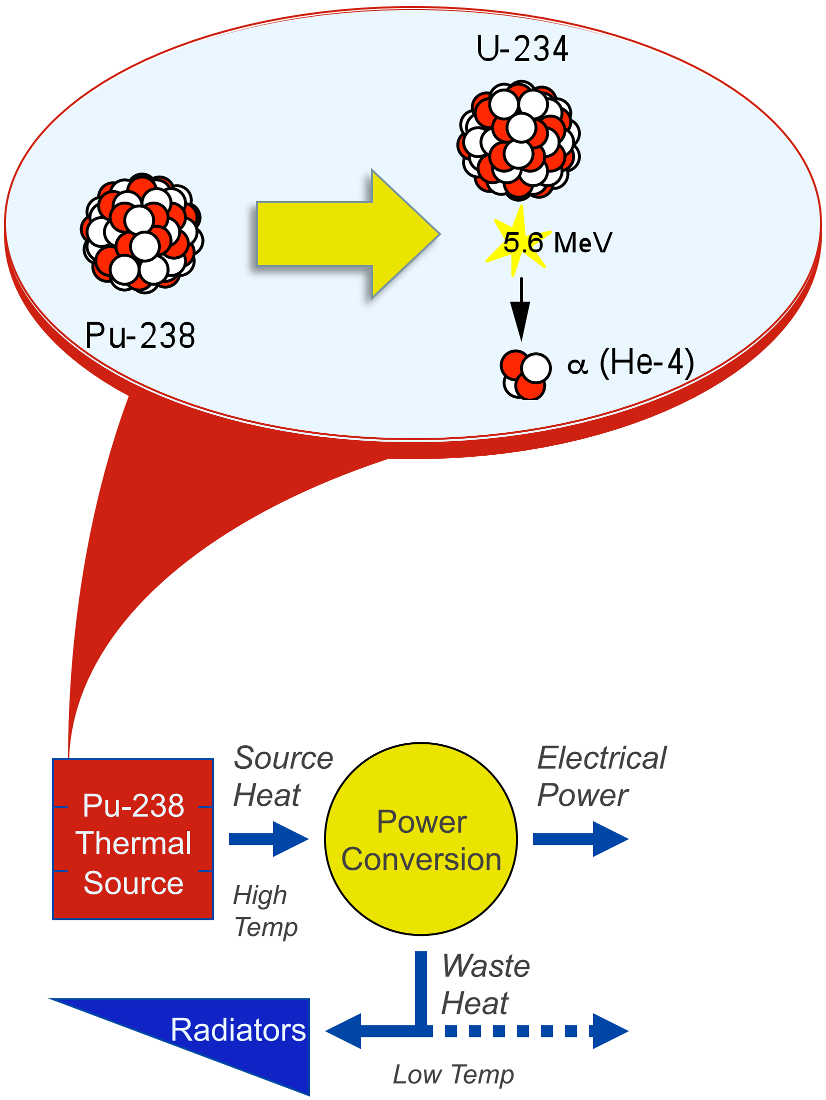
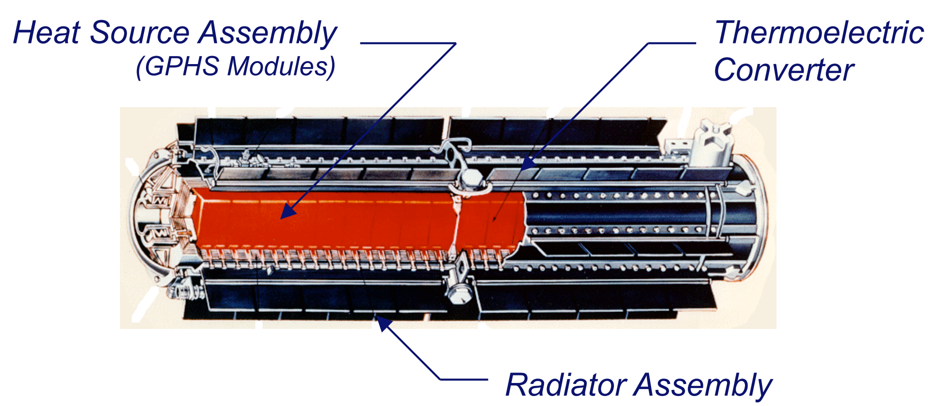
Radioisotope Power Systems (RPS)

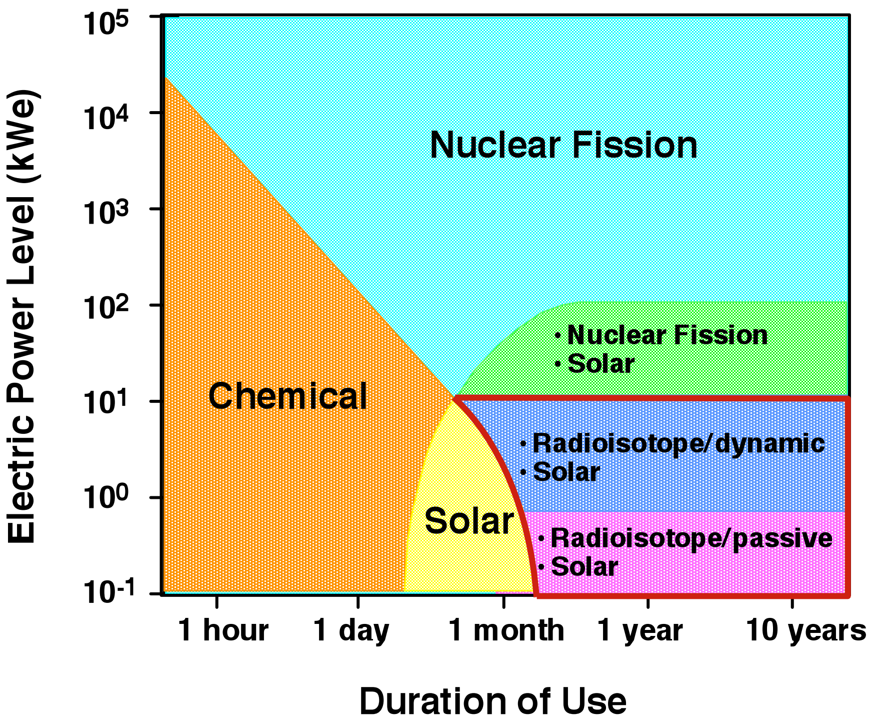


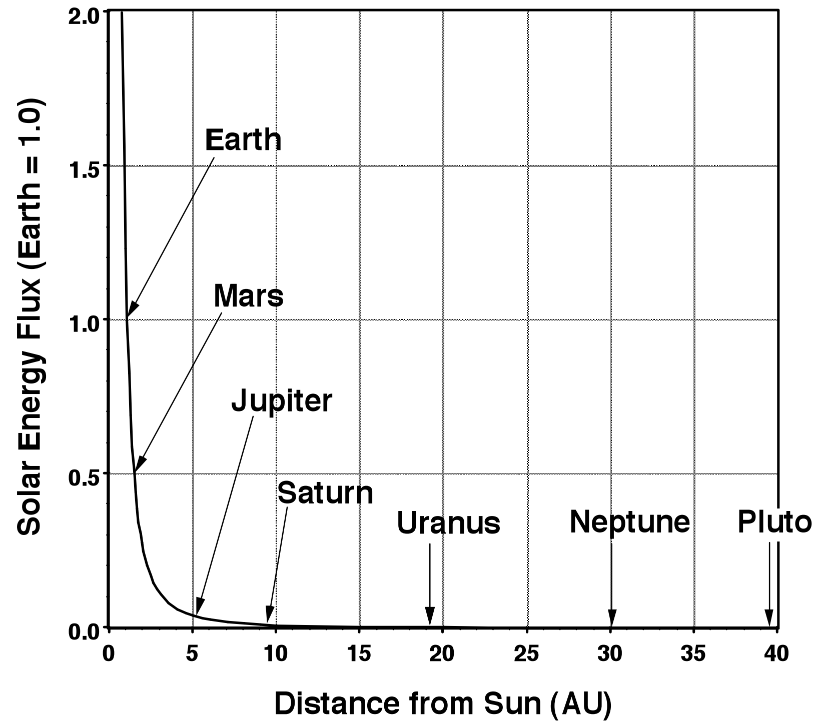
- Heat produced from natural alpha (α) particle decay of plutonium (Pu-238)
  - *87.7-year half-life*
- Small portion of heat energy (6%-35%) converted to electricity via passive or dynamic processes
  - *Thermoelectric (existing & under development)*
  - *Stirling (under development)*
  - *Brayton, 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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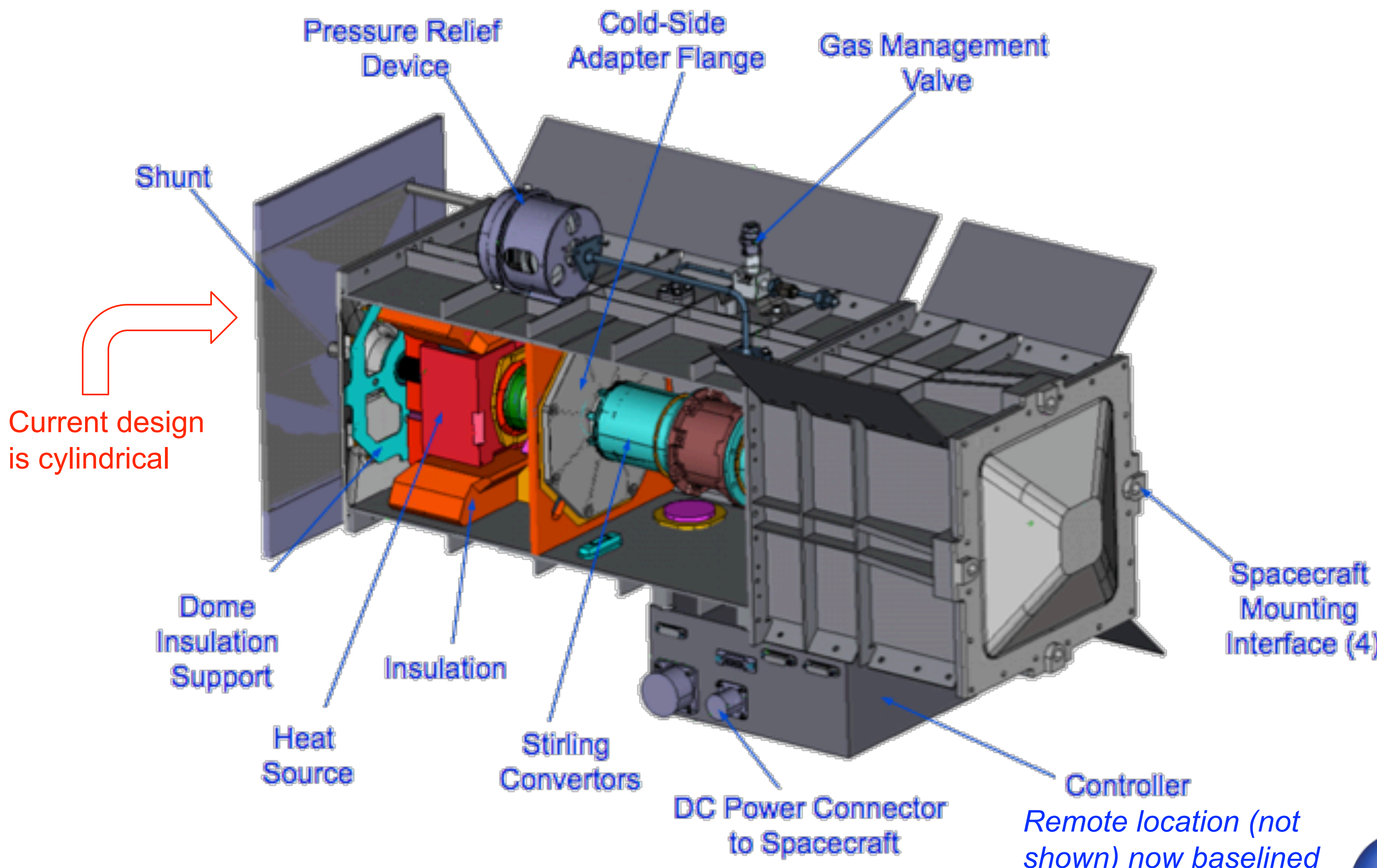
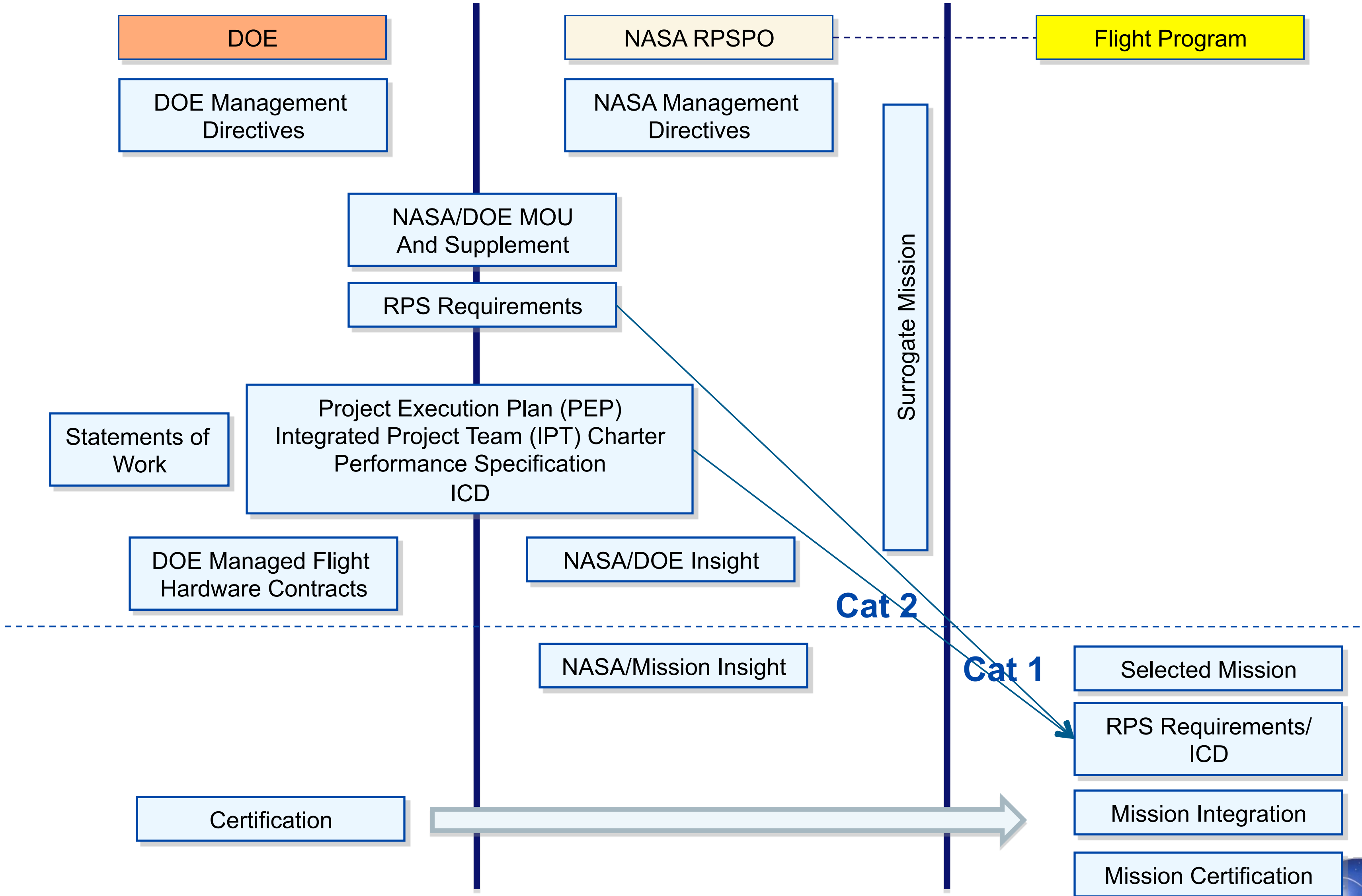
Flight Baseline Design



RPSPO Responsibility Transition to a Selected Mission



ASRG Requirement Status

- The RPSPO has acted as a “surrogate mission” to Discovery
  - *Requirements developed through Science Community and flight systems experience*
- ASRG Flight Performance Specification derived that encompasses many mission envelopes
- Adaptations for missions outside of this envelope require application of mission resources
  - *Spacecraft accommodations to adapt for use*

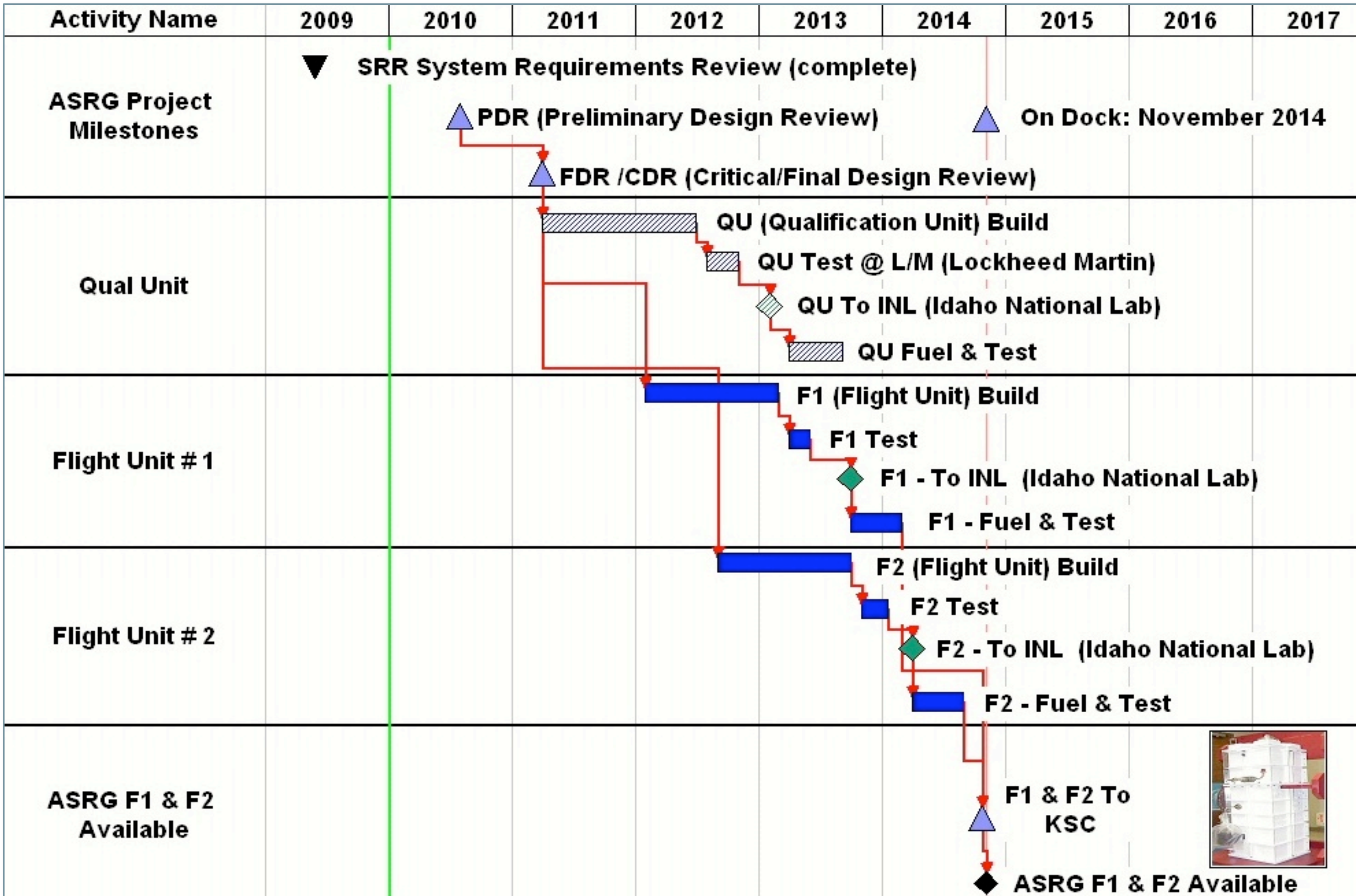
ASRG Characteristics

Parameter	ASRG
Power per Unit (BOM), (4° K, space vacuum)	133 W_e (includes 5% program reserve)
Power per Unit (BOM), (Mars avg. temp, CO_2)	121 W_e (includes 5% program reserve)
Voltage	28 +/- 6 VDC
Power Degradation Rate, [%/yr]	~ 0.8 (power decays roughly with fuel decay)
Mass per Unit, [kg]	~ 25 (includes 5% program reserve) (1)
Dimensions [mm]	Length: 800 mm; Width: 340 mm; Height: 340 mm
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)
Vibration (axial)	~ 22 N peak-peak
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.
(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 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)**
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: $17M** (see AO Table 1)
(DDT&E value: ~$120M) (F1, F2 value: ~ $27M)	
	Nonstandard launch services
	Mission Cost: $20M (see AO Table 4)

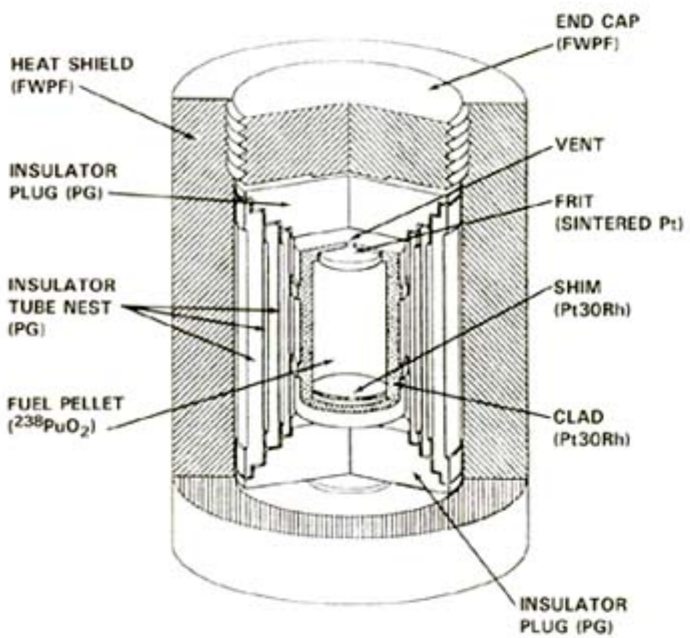
Radioisotope Heater Unit	
	Replacement cost/unit: ~~$0.150M~~ $5K
**Extra safety analyses are needed for missions employing RHUs only. These analyses are included in the Government-furnished ASRGs.*	**Launch approval process cost: $19M* (RHU only mission)**
	Nonstandard launch services cost: $17M (RHU 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*



- 1.3 inches long and 1 inch in diameter
  (the fuel pellet is about the size and shape of a pencil eraser)
- Approximately 2.7 grams of plutonium dioxide
  (2 grams of Pu-238)
- Total weight of the RHU is approximately 40 grams
  (1.4 ounces)
- RHUs can be used singly or in groups
- Installed via a bolt-on fixture

RHU Characteristics

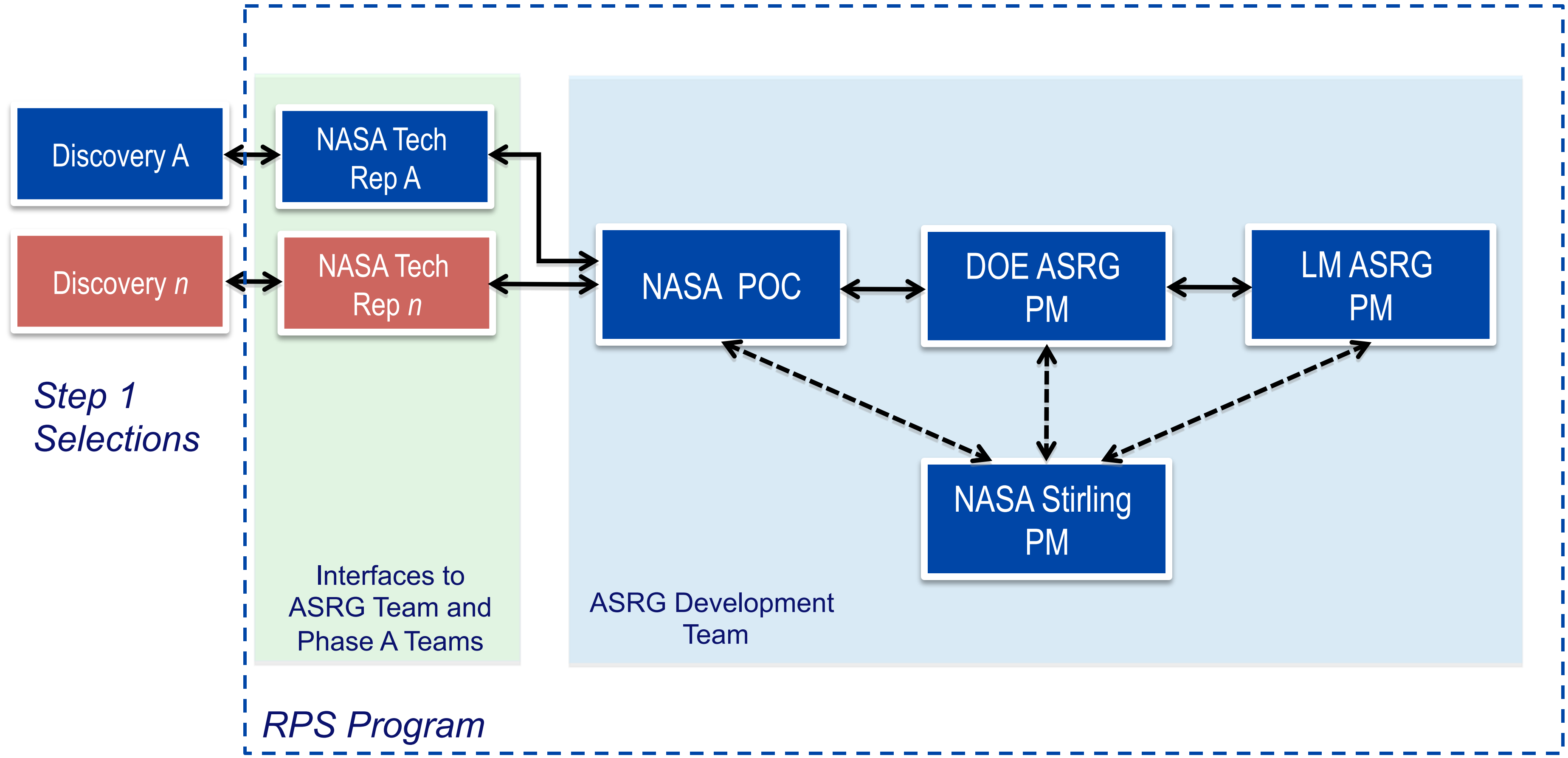
- RHUs are small devices that provide heat through radioactive decay of a small pellet of plutonium dioxide (comprised mostly of plutonium-238).
- Provides highly localized heating of sensitive equipment (such as electronics) in deep space where insulation is an insufficient source of heat.
- Transfers heat to spacecraft structures, systems and instruments directly without moving parts or intervening electronic components
- Cost ~~$0.150M~~ $5K

Benefits:
- Eliminates electric heaters
- More electric power for spacecraft, science
- Reduced complexity
- Less potential EMI
- Reliable, consistent thermal power for decades

ASRG/RHU Documents in the AO Library

- *Advanced Stirling Radioisotope Generator Information Summary*
- *ASRG Functional Description*
- *Electromagnetic Interference Data from ASRG Engineering Unit*
- *Low Frequency Magnetic Fields Near the ASRG Engineering Unit*
- *Radioisotope Heater Unit Information Summary*

ASRG Discovery Proposed Technical Organization



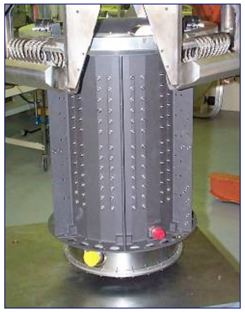
Other reference material for use

Radioisotope Power Systems Technology Maturation

NOTE: Graphics not to Scale

TRL 9

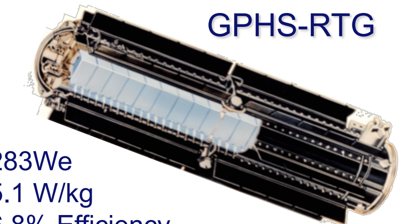
MHW-RTG



- 158 W_e
- 4.2 W/kg
- 6.6% Efficiency
- 14 Year life
- LES 8/9, Voyager 1 & 2

TRL 9

GPHS-RTG



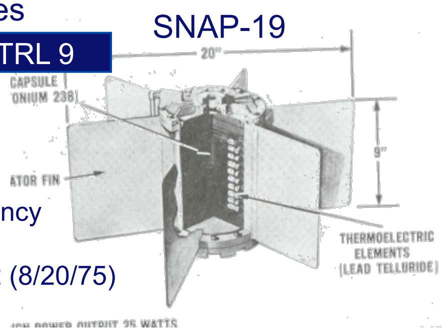
- 283We
- 5.1 W/kg
- 6.8% Efficiency
- > 14 Year life
- Ulysses, Gallileo, Cassini, New Horizons

- ~100 W_e
- Multi-mission
- Lifetime >14 yr
- Reliable
- Modular

SNAP Series

TRL 9

SNAP-19



- 40 We
- 3 W/kg
- 6.2% Efficiency
- 14 Year life
- Viking 1 & 2 (8/20/75)

- Efficiency
- Specific Power
- Reliability
- Scalability
- Multi-mission

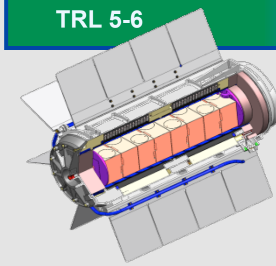
Radioisotope Power Systems Development

MMRTG

TRL 5-6 → TRL 7-8 → TRL 9

MSL

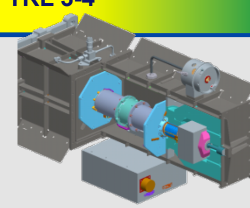
OPF



123 W_e
2.8 W/kg
6.3% Efficiency

ASRG

TRL 3-4 → TRL 5-6 → TRL 7-8 → TRL 9



Eng Unit
> 140 We
~ 7 W/kg
> 28% Efficiency

Validation Mission

Radioisotope Power Conversion Tech (RPCT)

TRL 1-2 → TRL 3-4 → TRL 5-6

ATEC, TPV, Advanced Stirling

1970 | 1980 | 1990 | 2000 | 2005 | 2010 | 2015

ASRG Differences from DSMCE Study Timeframe

Parameter	Sept 2007 Configuration (DSMCE)	Jan 2010 Configuration
Max Heater Head Temp	650 C	850 C
Power per Unit (BOL), [W_e]	143	133 (140W_e @488W_t less 5% program reserve)
Power Degradation Rate, [%/yr]	~ 0.8 (power decays roughly with fuel decay)	~ 0.8 (power decays roughly with fuel decay)
Mass per Unit, [kg]	~ 20.2	~ 24
Dimensions [mm]	Length: 762 mm; Width: 294 mm; Height: 457 mm	Length: 800 mm; Width: 340 mm; Height: 340 mm
Thermal Power (BOL), [W_t]	500	500 nom. (488 min; 512 max)
Conversion Efficiency	~ 28%	~ 29%
Controller Location	Mounted to Housing	Remotely Mounted on S/C

- GPHS provides nominal 500 W_t (488 min; 512 max)
- Lifetime requirement remains the same at 3 yrs storage + 14 years mission = 17 years

ASRG Flight Systems Development

Stirling Radioisotope Generator / Stirling Engine Development

- Infinia SRG-110 Stirling Engine originally targeted for MSL, began development in 2001. The MMRTG was eventually baselined.
- SRG-110 transitioned back to technology development in 2004. It was upgraded to Advanced Stirling Convertor (ASC) with the switch to Stirling technology developed by Sunpower, Inc.
  - Sunpower has developed several version 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

- DOE re-scoped Lockheed Martin (LM) contract to provide the ASRG Engineering Unit. LM delivered the EU to NASA/GRC in 2008.
  - The EU has been under near continuous (24/7) operations since delivery and has accumulated 7,600+ hours.
- LM re-scoped for a qual unit and two flight units in Fall of 2009 for delivery to KSC of two flight units in 2014.