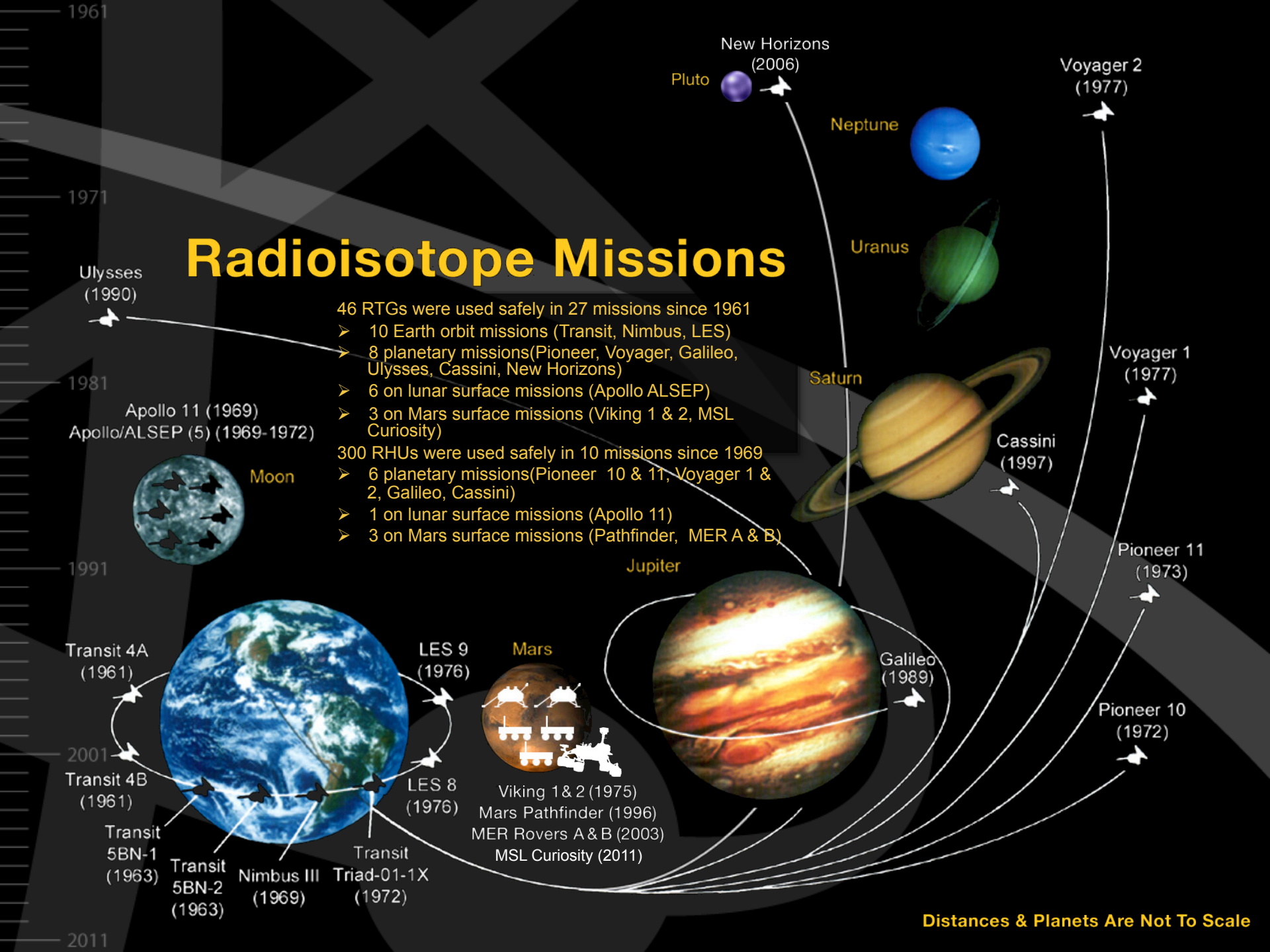
Leonard Dudzinski

RPS Program Executive

RPS Status for VEXAG

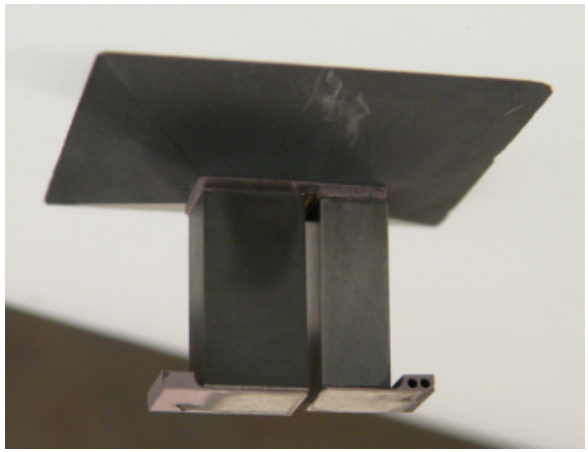
November 2012

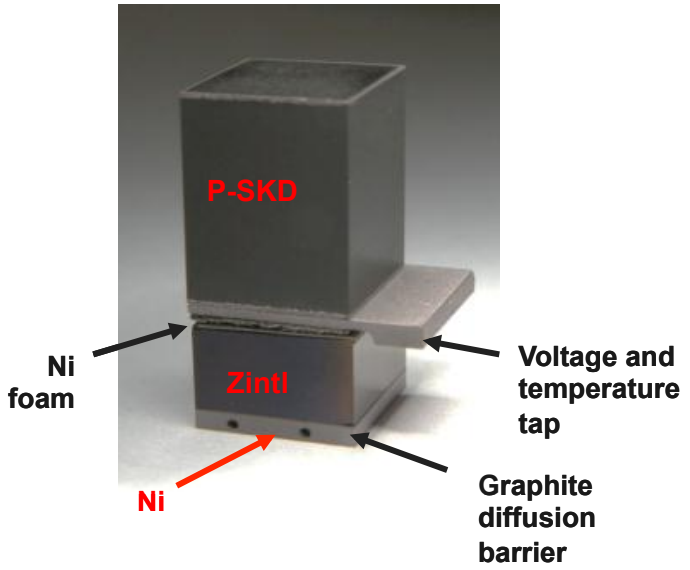

1961
1971
1981
1991
2001
2011
Radioisotope Missions
46 RTGs were used safely in 27 missions since 1961
10 Earth orbit missions (Transit, Nimbus, LES)
8 planetary missions(Pioneer, Voyager, Galileo, Ulysses, Cassini, New Horizons)
6 on lunar surface missions (Apollo ALSEP)
3 on Mars surface missions (Viking 1 & 2, MSL Curiosity)
300 RHUs were used safely in 10 missions since 1969
6 planetary missions(Pioneer 10 & 11, Voyager 1 & 2, Galileo, Cassini)
1 on lunar surface missions (Apollo 11)
3 on Mars surface missions (Pathfinder, MER A & B)
New Horizons (2006)
Pluto
Voyager 2 (1977)
Neptune
Uranus
Ulysses (1990)
Voyager 1 (1977)
Saturn
Cassini (1997)
Apollo 11 (1969)
Apollo/ALSEP (5) (1969-1972)
Moon
Pioneer 11 (1973)
Jupiter
Transit 4A (1961)
LES 9 (1976)
Mars
Galileo (1989)
Pioneer 10 (1972)
Transit 4B (1961)
LES 8 (1976)
Viking 1 & 2 (1975)
Mars Pathfinder (1996)
MER Rovers A & B (2003)
MSL Curiosity (2011)
Transit 5BN-1 (1963)
Transit 5BN-2 (1963)
Nimbus III (1969)
Transit Triad-01-1X (1972)
Distances & Planets Are Not To Scale

MMRTG F1

MMRTG Forward

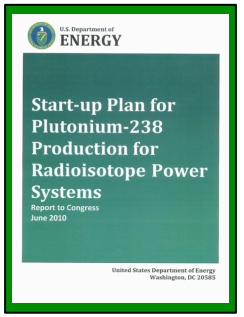
- F2 demonstrated good performance (in storage)
- F3 to be completed 2013
- DOE Teledyne Contract Ends June 2013
- Investigating sustainment path forward
- Potential integration of advanced thermocouples into MMRTG body
  - Potential improved system efficiency > 9%





Pu-238 Domestic Production Status

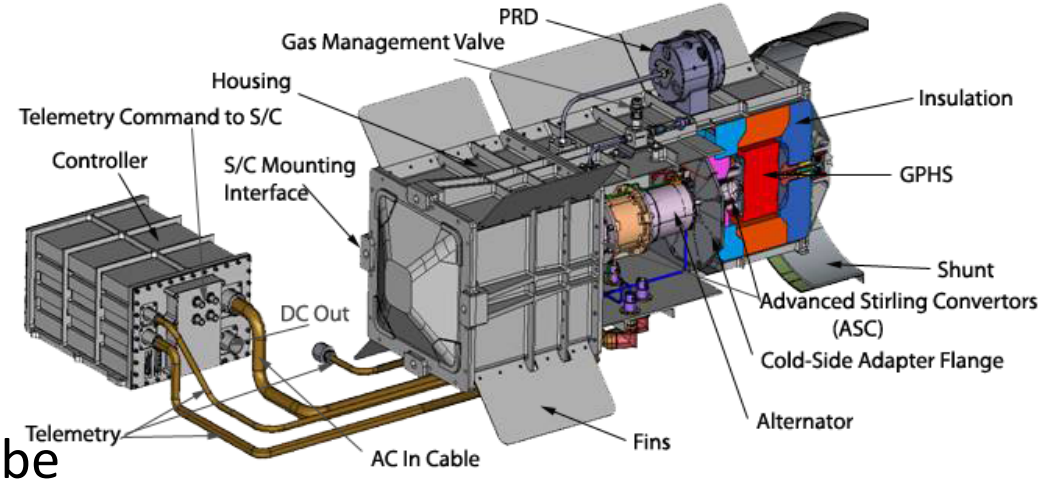
- NASA Authorization Act of 2010 authorized NASA to fund DOE efforts in Pu-238 Production under a reimbursable agreement.
- DOE has begun a multi-phase Plutonium-238 Supply Project consistent with the published Start-up Plan to achieve full-scale production late in the decade.



- Phase I efforts to be completed by December 2012.
  - Project planning, NEPA assessment, analysis of project alternatives, cost and schedule estimate
- Technology demonstration efforts will achieve by the end of 2013:
  - A qualified neptunium-237 target for irradiation in the High Flux Isotope Reactor *(target currently in reactor)*
  - A qualified process for post-irradiation target processing
  - A qualified Pu-238 product
  - A project plan for scale-up to full-scale production at 1.5-2.0 kg/year
- PPBE FY15 will take into account NASA fully funding Pu-238 production

Advanced Stirling Radioisotope Generator (ASRG)

- ASRG provides increased efficiency (4X current)
- Offered as GFE in Discovery 12
- Highly enabling for science missions
- Conducted Final Design Review in July 2012
- Engineering units in test
- Controller design modified to be more robust to radiation environment
- Qualification unit (QU) build in progress



ASRG Summary Specification

Parameter	ASRG
Power per Unit (BOM), (4° K, space vacuum)	128 We (1.5% reserve on 130We)
Power per Unit (BOM), (Mars avg. temp, CO_2)	106.4 We (1.5% reserve on 108 We)
Voltage	22-34 VDC (Nominal Range)
Power Degradation Rate, [%/yr]	~ 0.8 (power decays roughly with fuel decay)
Mass per Unit, [kg]	35.6 (includes 11% reserve on 32 kg) (1), (Includes ASRG to S/C power cables)
Dimensions for Generator Housing/Controller [cm]	L: 78 cm, W: 37.4 cm, H: 38.6 cm (GHA), L: 26.5 cm, W: 22.2 cm, H: 13.5 cm (ACU)
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 2012)
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 (CO_2)
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; ~ 1 kg of telemetry cables not included.

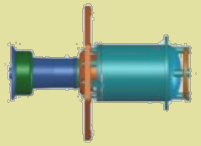
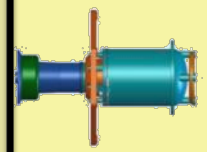
(2) Radiation Tolerance: from 50kRad space and 13 kRad GPHS source Requirement, with RDF 2 applied

(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

ASC Technology Development to Flight Evolution

	A. Tech. Development			B. Flight Transition			C. Flight
	ASC-1	ASC-0	ASC-1HS	ASC-E	ASC-E2	ASC-E3	ASRG
							
Material	MarM-247		MarM-247		MarM-247	MarM-247	MarM-247
		IN718		IN718			
Hermetic		X	X	X	X	X	X
Progress	• Demo high efficiency and Low Mass • High temp components and joints demo. (HH, and Disp.)	• Develop Hermetic Processes • Identify and resolve developmental issues • Initiated QA/process documents • Extended Operation, in a	• Demo Hermetic Processes on High temp units • Improve processing (brazes, gas bearings, etc.) • Extended Operation, in thermal-vac	• ASRG integration Interfaces • Major Improvement in quality & docs. • Improve processing (i.e. Closure weld, flow bench, etc.) • Configuration control (ERB)	• Develop and Implement Quality Project Plan – Based on DOE Nuclear standard • Enhance interfaces • Refine high temp. processes & joints • Enhance reliability and manufacturability • Infrastructure – Dedicated Facility – Design Software – Laser Welder – Inspection (CMM) – Epoxy Mixer	• Manufacture refinement as needed • Refinement to Include any new mission or generator derived requirements • LM, DOE, NASA, and SP joint product team	• NASA completes Sunpower ASC technology development and hands off to DOE for Flight implementation

Complete

In Production

GRC/SP Contract

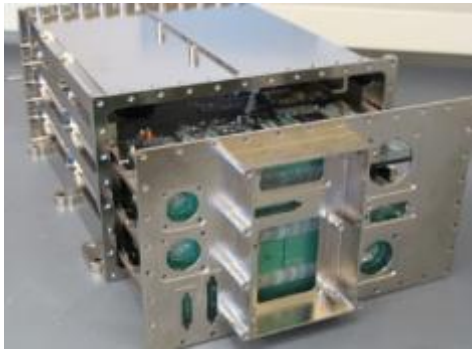
DOE/LM/SP Contract

Progressive Refinement Towards Flight Implementation

Nati

ASRG QU, Demonstration, and GSE

QU Inboard / Outboard Housings, Finish Machined



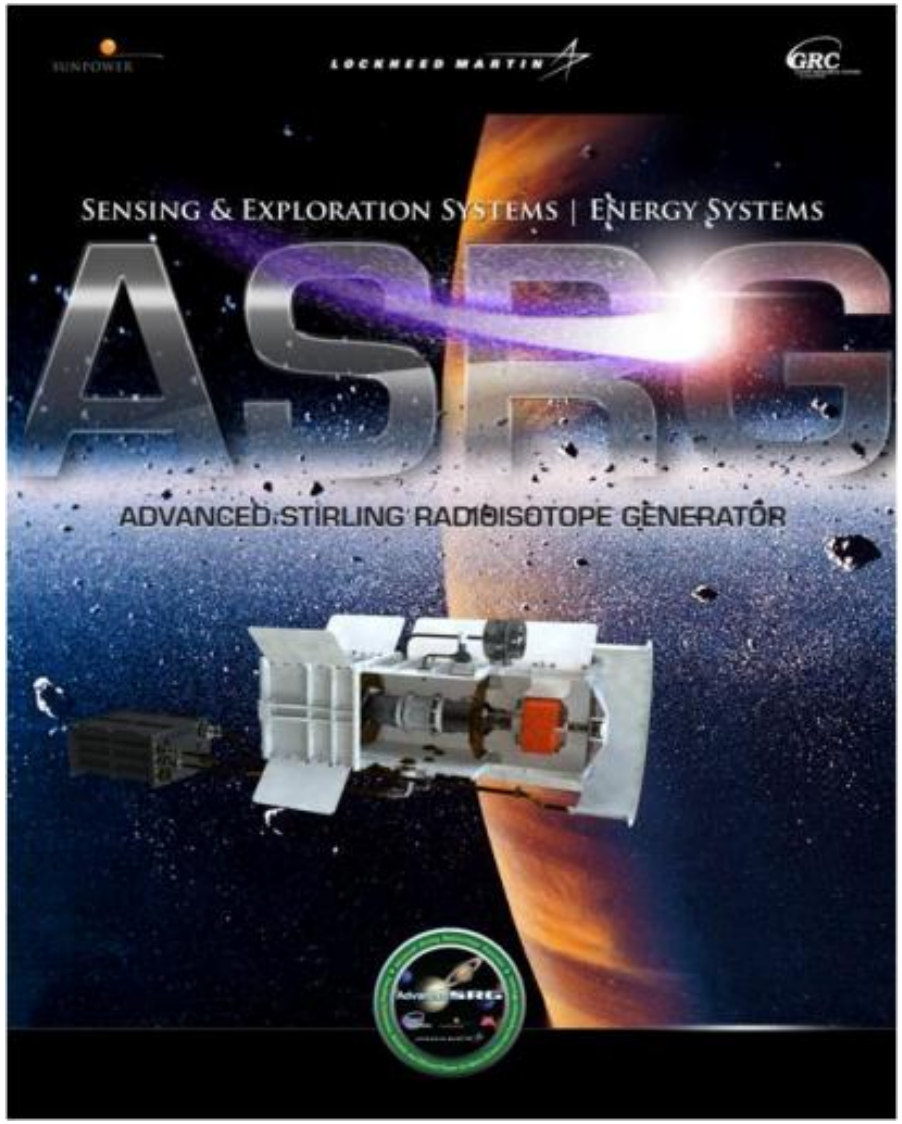
EDU 3 Controller (ACU)

Fit Up Model GHA

Electrical Ground Support Equipment in Production

ASRG Forward

- Flight Systems
  - Fueled Qual Unit
  - F1 and F2 Unfueled Units by NLT 10/2016
    - Ready for D-13
    - Ready for NF-4
    - Ready for Mars 2018
    - Other
- “M1” Project
    - Integrate with S/C bus
    - Independent V&V

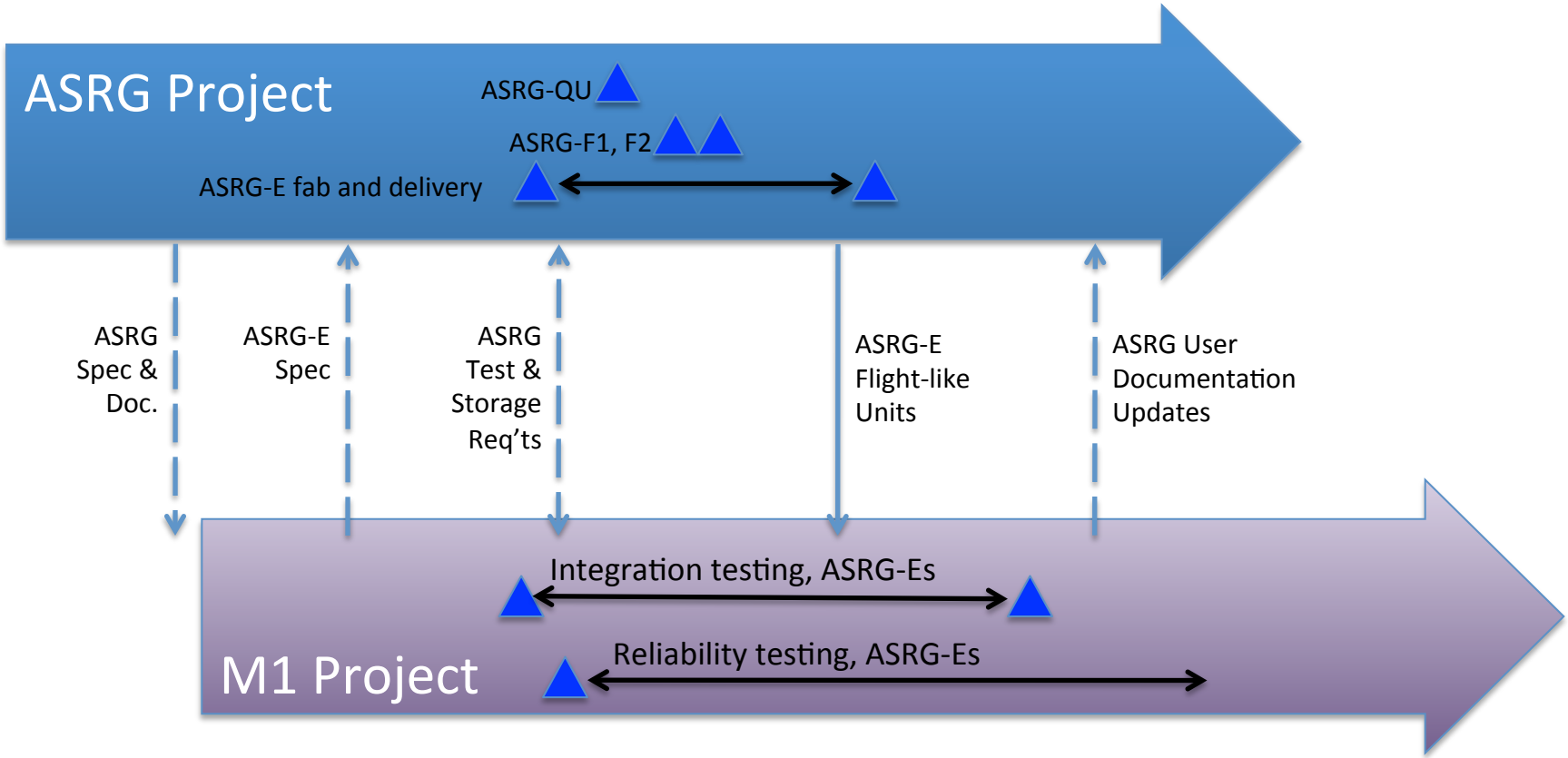


M1 Project Goals

- To be a platform to independently verify system-to-spacecraft interface requirements and to validate integrated system performance
- To be a pathfinder for future missions regarding the integration, operation and use of an ASRG
- To assess and characterize the ASRGs for mission use
- To develop documentation to enable easier integration of the ASRG into future missions and future AO proposal cycles.

The program intends for the M1 project to fill the knowledge gaps lost with the Discovery12 flight opportunity. The RPS Program requires the ability to thoroughly benchmark, checkout, and integrate the ASRG in the same capacity if a planetary mission was receiving, integrating and utilizing two ASRG on a spacecraft.

ASRG/M1 Project Interactions



***NOTIONAL Activity sequencing and duration

M1 Products & Outcomes

- Mission inputs to extended testing of ASRG qualification unit at INL
- Mission inputs to bonded storage of 2 ASRG flight units at INL
- Electrically-heated ASRG units (received from ASRG Project)
- Spacecraft integration test campaign
- ASRG durability and reliability risk reduction test campaign
- Improved system documentation for next Announcement of Opportunity or other mission opportunity
- System Integration Laboratory with spacecraft testbed

Key Messages

- The ASRG development status did not effect the Discovery 12 selection
- The ASRG flight specification for F1 and F2 has been frozen since 2010, and will remain so
- The RPS Program will continue to act as a surrogate mission for ASRG development through the implementation of the “M1” project
- The ASRG development will be completed on an appropriate schedule, with two flight units ready for fueling by October 2016
- Planetary Science Division is considering mission options for ASRG F1 and F2
  - Discovery 13 as GFE
  - Mars 2018 or 2020


NASA