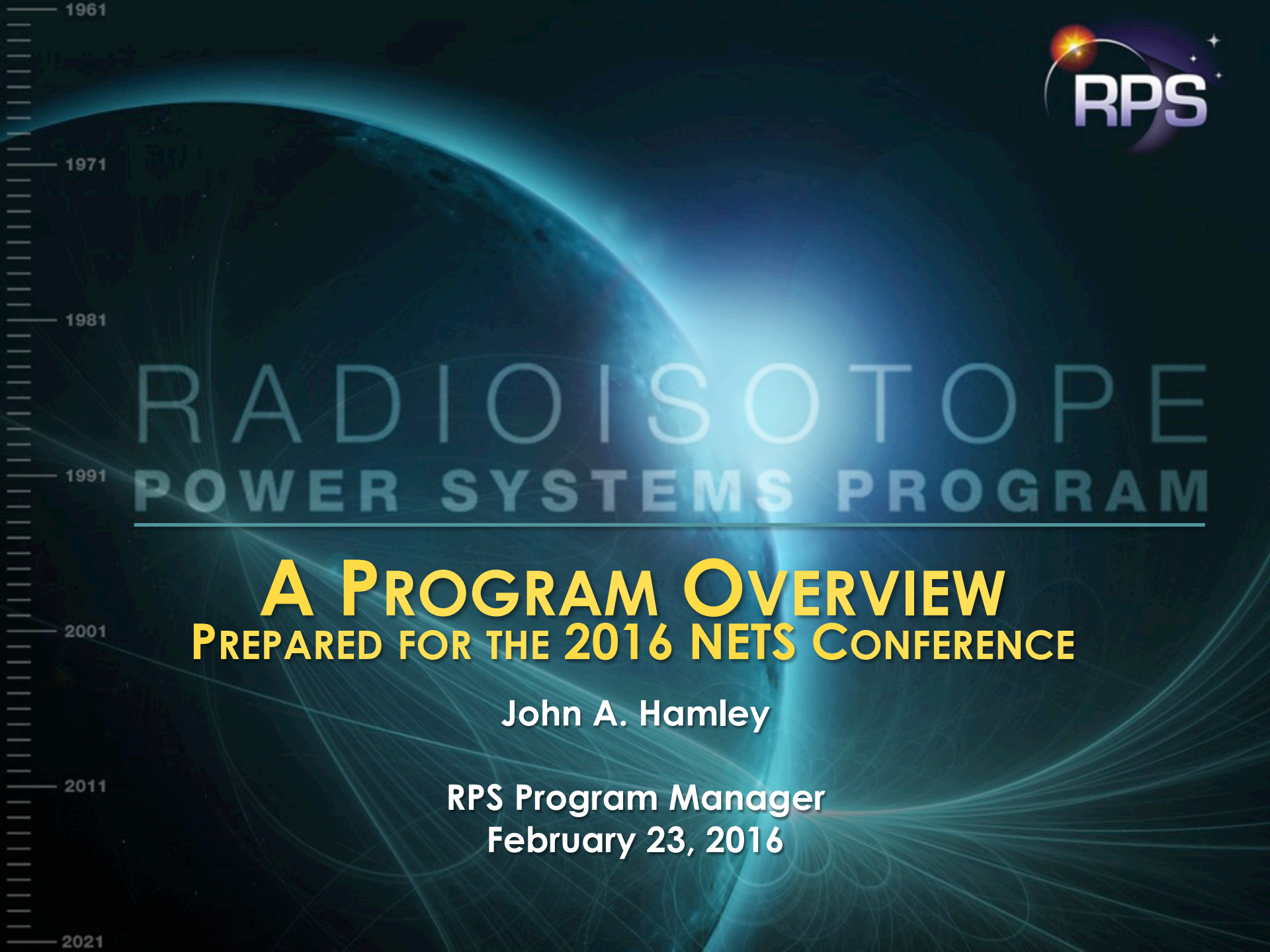


A Program Overview

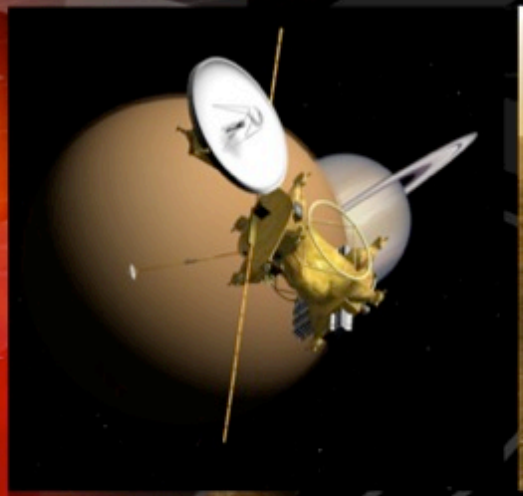
Prepared for the 2016 NETS Conference

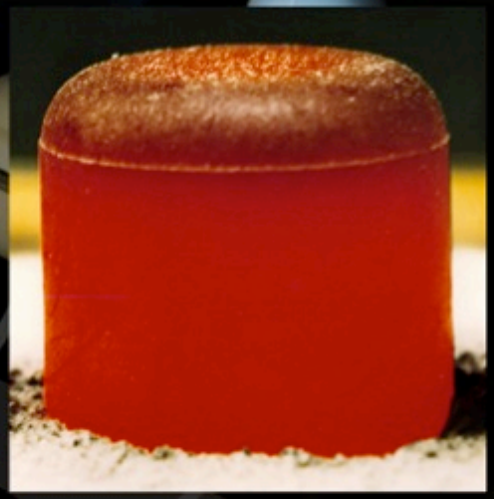
John A. Hamley

RPS Program Manager

February 23, 2016

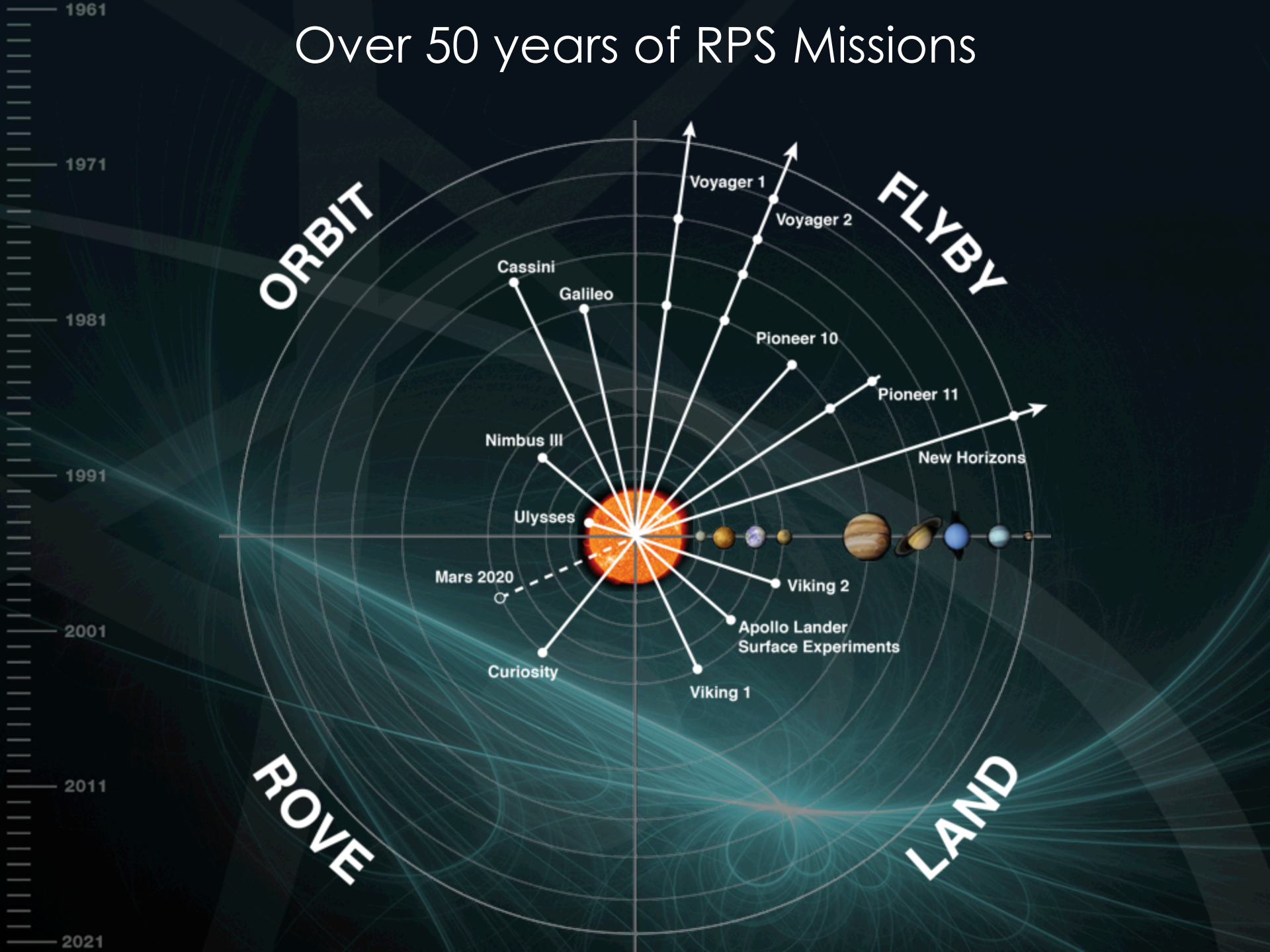
Radioisotope Power Systems





- Enable and enhance missions by providing electrical power to explore remote and challenging environments where solar power is unavailable
  - Spacecraft operation
  - Instrumentation
- Converts heat from a Radioisotope into electricity
  - Heat is the product of the natural decay process of the isotope

Over 50 years of RPS Missions

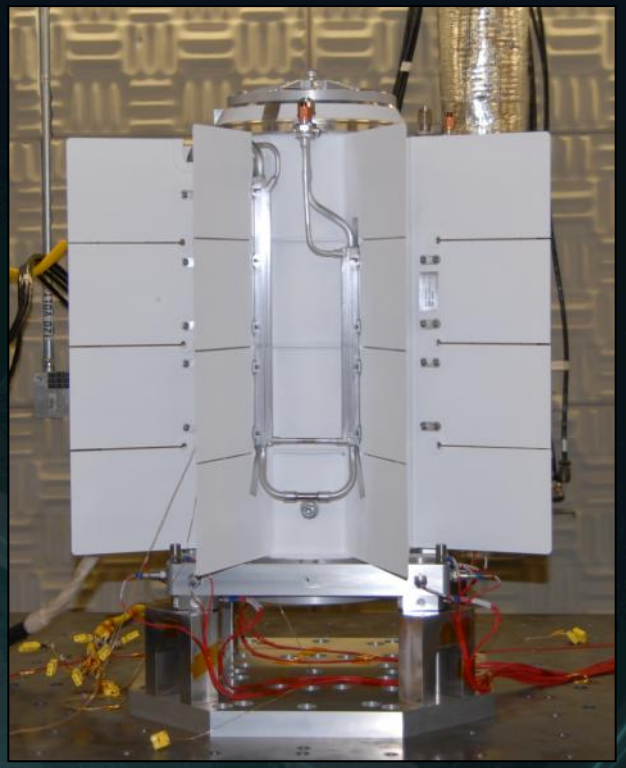


Flight Systems for Current Missions

1961
1971
1981
1991
2001
2011
2021

General Purpose Heat Source - Radioisotope Thermoelectric Generator (GPHS-RTG)

Multi-Hundred Watt - Radioisotope Thermoelectric Generator (MHW-RTG)



Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)

Operational Missions

1961

1971

1981

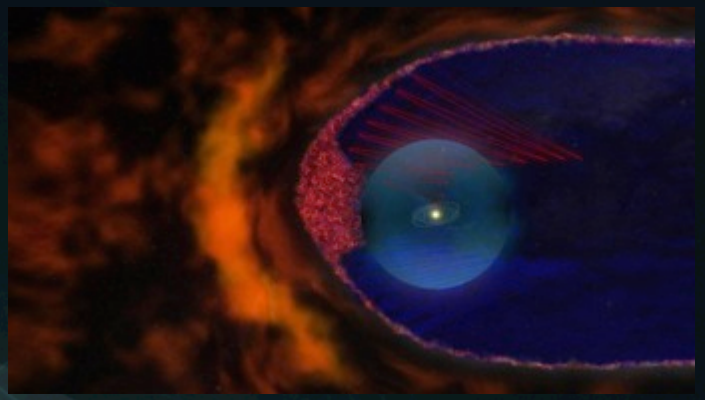
1991

2001

2011

2021

- Voyager 1 & 2– *Extended Operations*
  - Launched: August 20, 1977 & September 5, 1977
  - Arrival at Jupiter, Saturn, Uranus, Neptune: 1979, 1980/1981, 1986, 1989
  - Science Mission duration: 35+ yr science
  - Power Source:
    - Three MHW-RTG
    - 474 W_e BOM



- Cassini – *Extended Operations*
  - Launched: October 15, 1997
  - Arrival at destination: July 2004
  - Science Mission duration: 7 yr cruise, ~ 8+ yr science
  - Power Source:
    - Three GPHS-RTG
    - ~885 W_e BOM

Operational Missions (cont'd)

- Pluto/New-Horizons – *Operational*
  - Launched: January 19, 2006
  - Closest Approach / Flyby: July 14, 2015
  - Science Mission duration: 9.5 yr cruise, 5 yr science
  - Power Source:
    - One GPHS-RTG
    - 243 W_e BOM; ~200 W_e at arrival

- Mars Science Laboratory – *Extended Operations*
  - Launched: November 26, 2011
  - Gale Crater: August 6, 2012
  - Science Mission duration: ~ 2 yr
  - Power Source:
    - One MMRTG
    - ~110 W_e BOM; ~105 W_e at arrival

1961
1971
1981
1991
2001
2011
2021

1961

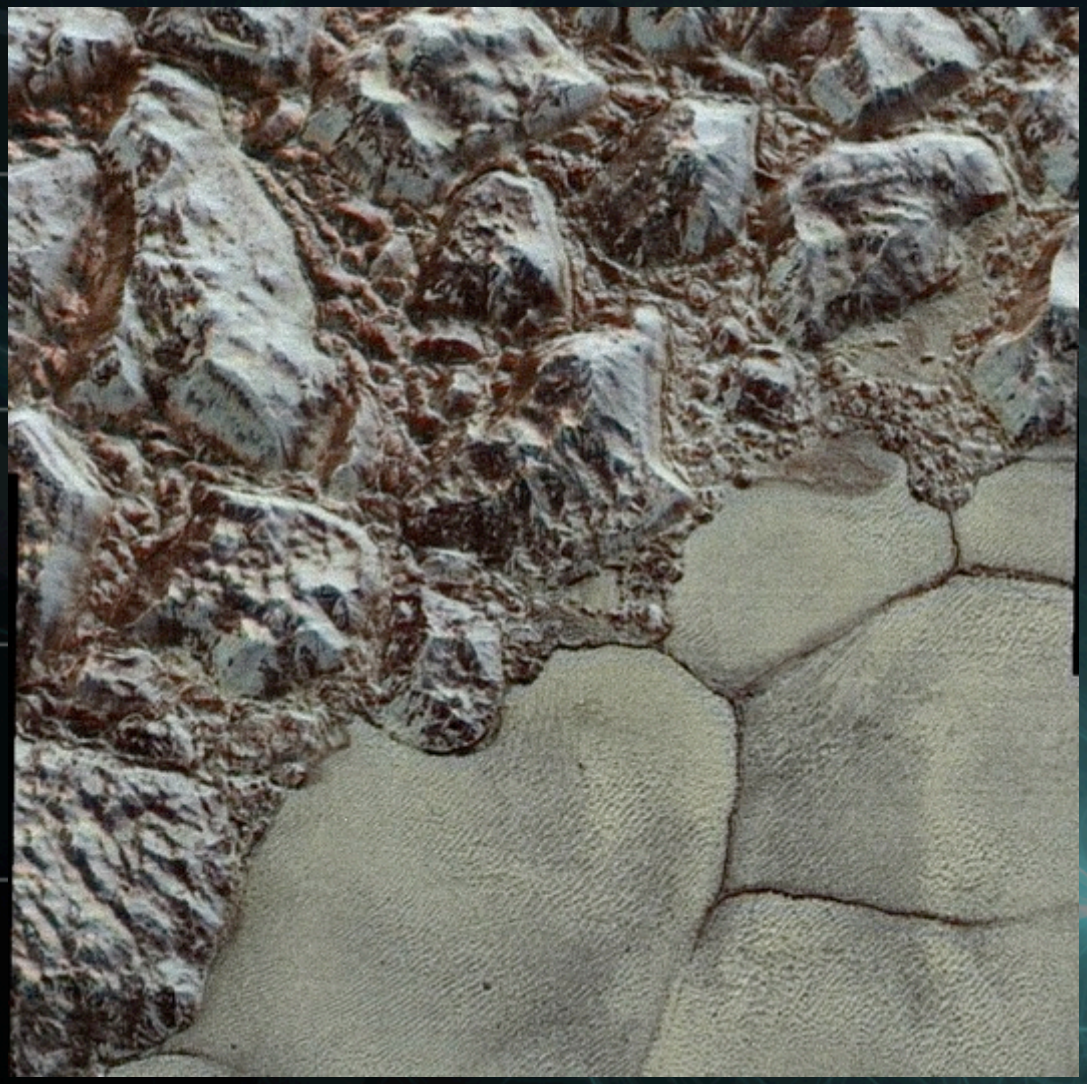
Curiosity – Extended Mission

2021

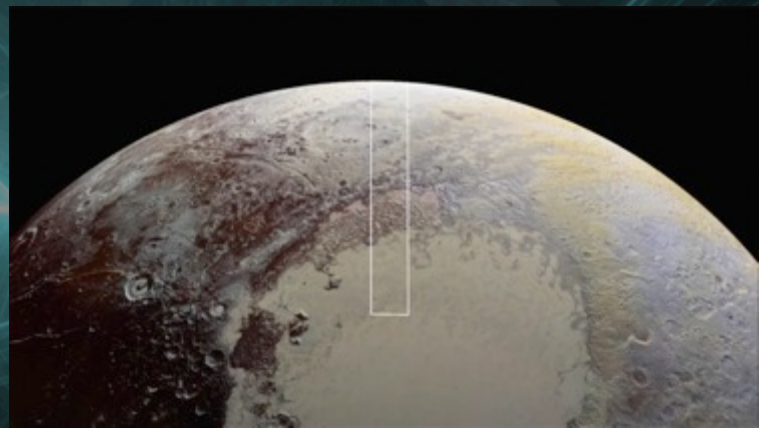
1961

1971

Pluto: Higher Resolution…



A cosmic shoreline is pictured here, where the vast icy plain informally named Sputnik Planum borders rugged mountains made of water ice blocks standing up to 1.5 miles tall.



2021

A Partnership with the Department of Energy

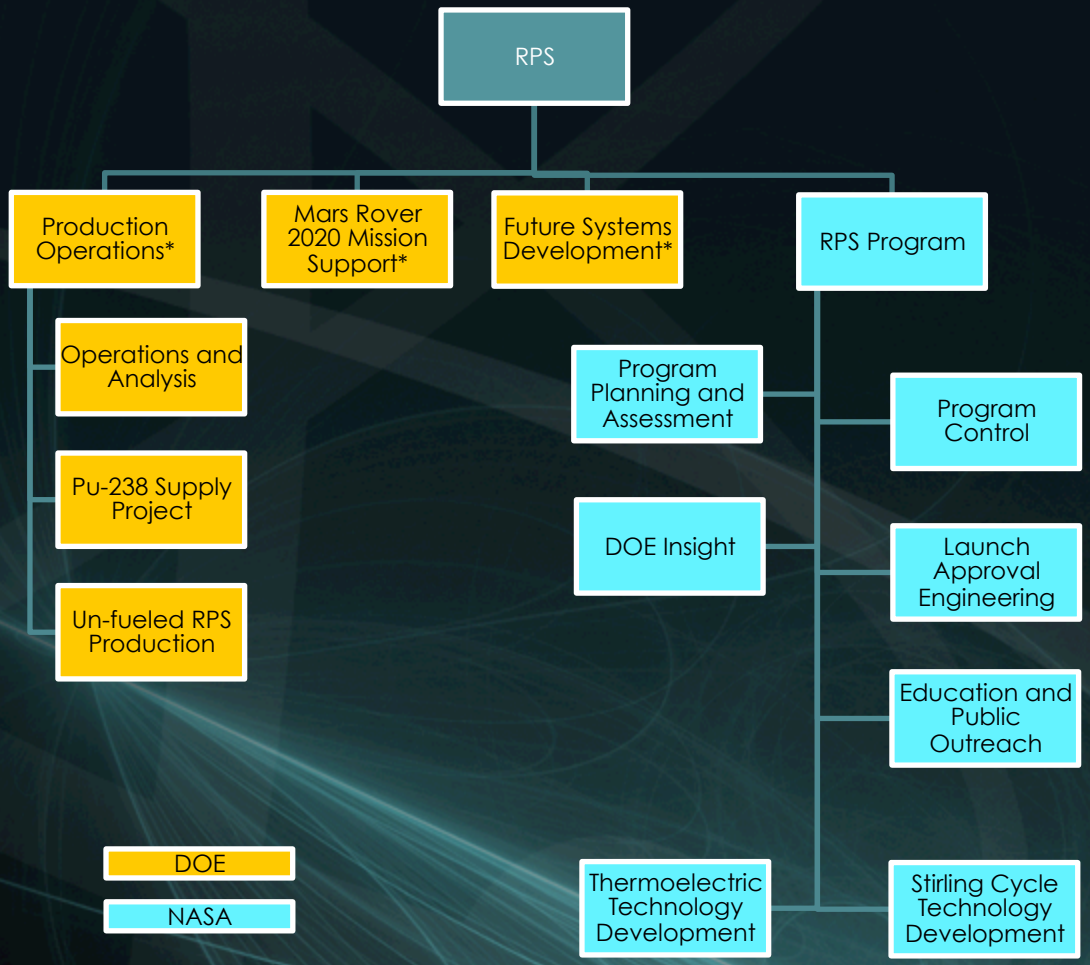
NASA

- Program Management
- Program Control (cost/ schedule/risks)
- Program Planning and Assessment
- Launch Approval Engineering
- Education and Public Outreach
- Technology Projects
- DOE Insight

DOE

- Systems Acquisition
- Flight system deployment to missions (e.g. Mars 2020)
- Maintain/Augment capabilities
  - Operations and Analysis
  - Plutonium-238 Supply Project

Program With DOE Content

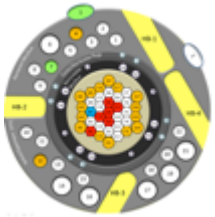


* NASA-funded DOE activities with unique Inter Agency Agreement

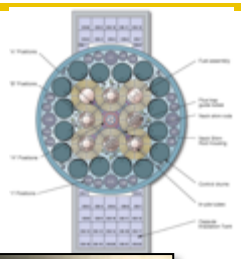
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Plutonium-238 Supply Project– Oak Ridge National Laboratory

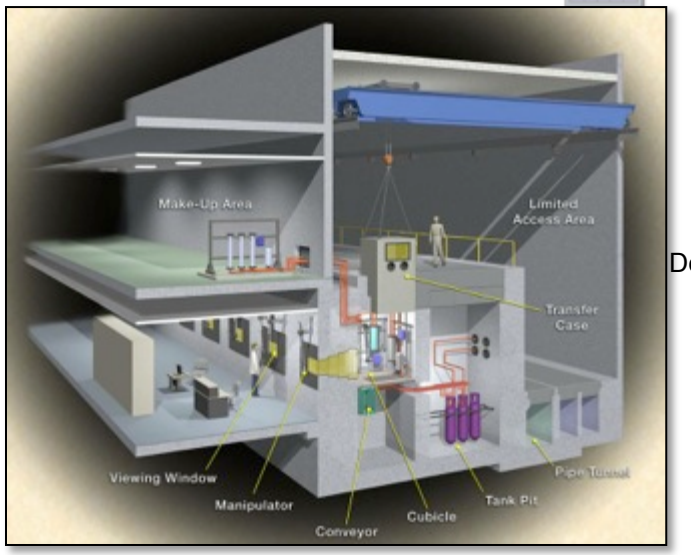
- **Oak Ridge National Laboratory is the lead to re-establish domestic production of ^{238}Pu**
- **Specific tasks:**
  - Develop qualified irradiation targets for both the INL Advanced Test Reactor and the ORNL High Flux Isotope Reactor
  - Establish target fabrication capability
  - Establish chemical processing to recover and purify both neptunium and plutonium
  - Establish capabilities for all shipment of nuclear materials
- ***50g of new material produced***



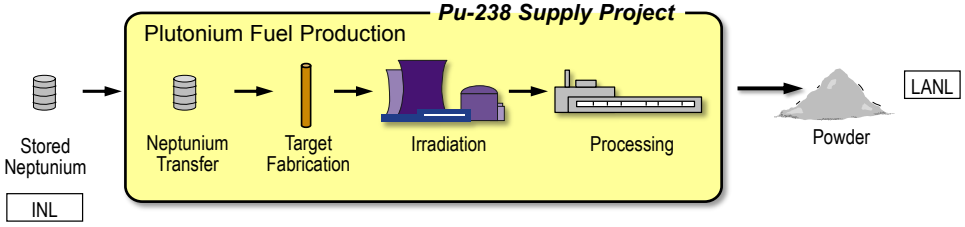
High Flux Isotope Reactor



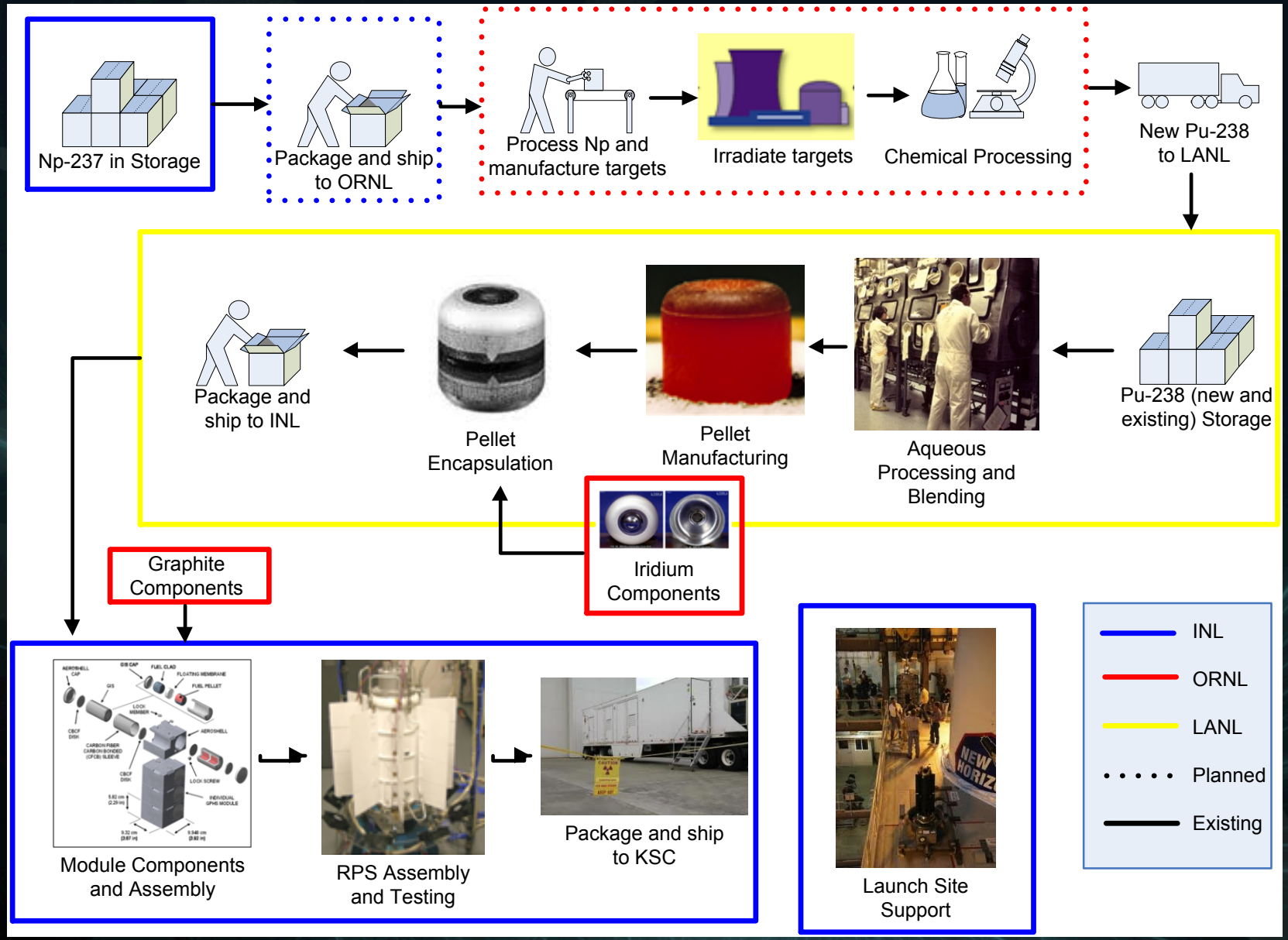
Advanced Test Reactor



Radiochemical Engineering Development Center



DOE – Operations and Analysis

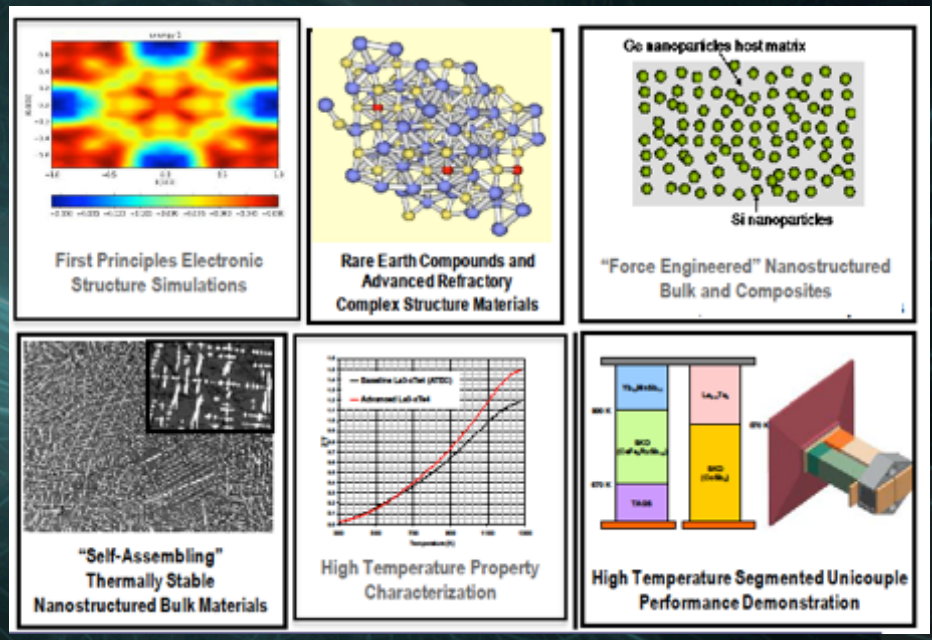


Program Planning and Assessment

- Develops requirements and sustainment strategy
  - eMMRTG
    - Improves EODL power by > 50% compared to MMRTG
  - SRG
    - Higher power, robust, reliable
- Assesses State of Art for RPS technologies
  - RFI for Stirling
- Mission Studies to inform system needs to support planetary science
  - CubeSat and SmallSat
- Customer / User engagement
  - Missions – Mars 2020, NF
  - Assessment Groups (OPAG, SBAG, etc.)
  - Developing User's Guide for MMRTG – See LPSC peripheral session & RPS website
- Performs as the Surrogate Mission
  - Cross Flight Center with DOE Mission Team
- Developing life performance prediction models
  - MMRTG LPPM
  - SRG Risk Informed Life Models and Prediction Models

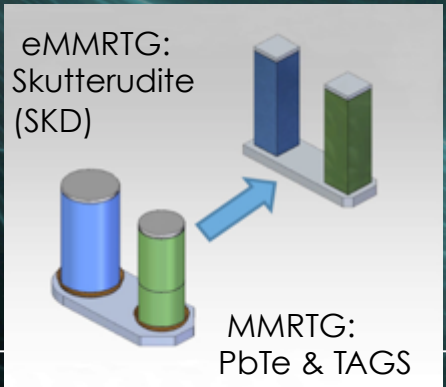
Thermoelectric Technology Development Project

- Sustain industry capability to manufacture and test thermoelectric converters
  - Manufacture Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs) and components at Teledyne Energy Systems (TESI)
- Sustain NASA (JPL) workforce of thermoelectric technologists
  - Continue testing at JPL thermoelectrics labs
  - Leverage investments in technology/component development for transition to flight
  - Actively transition advanced technologies to industry



Future Work- Thermoelectrics (FY16)

- Enhanced Multi-Mission Radioisotope Thermoelectric Generator (eMMRTG) Concept
  - Retrofit the MMRTG with new thermoelectric (TE) couples
    - Substitution of current MMRTG PbTe/TAGS couples with skutterudite (SKD) couples
    - Technology developed with NASA support at the Jet Propulsion Laboratory over the last 20 years
    - Key industry partners include Teledyne Energy Systems and Aerojet/Rocketdyne
  - Addition of a surface oxidation layer to the heat source liner inner surface to allow for increased hot junction temperatures



	MMRTG	eMMRTG
No. of GPHS Modules	8	
TE Type	PbTe/TAGS	SKD
No. of Couples	768	
Beginning of Life (BOL) Power (W)**	121	140.8
BOL System Efficiency**	6.0%	7.0%
BOL Specific Power (W/kg)**	2.7	3.1
Mass (kg)	45	
Mission Usage	Multi-mission	
Development Time	In Use	~5 years
Potential Future Missions	MSL, Mars 2020	Future Discovery and New Frontiers missions, Mars missions

*** BOL is defined as fueling complete; for consistency between the power estimates the following conditions were applied: thermal inventory = 250Wth per GPHS; V_Load = 32V; thermal sink = 4K*

Stirling Cycle Technology Development Project

- Reassess Stirling Technology industry capability
- Manufactured Advanced Stirling Converters at Sunpower through end of CY15
- Sustain NASA workforce of Stirling technologists
  - Continue testing at GRC Stirling Labs
  - Leverage investments in technology/component development for transition to flight
  - Assess state of readiness of technology for flight
  - Develop requirements for flight system

Completed ASC-E3
Prior to Delivery

ASRG EU2 on extended testing at GRC

Future Work- Stirling (FY16)

- Focus on fault tolerance and robust architectures
- Develop requirements for flight system based on mission pull and technology availability
  - Power level
  - Efficiency
  - Lifetime
- Eventual transition to flight system to support missions
- With DOE, develop qualification unit prior to inclusion in a flight opportunity announcement

Launch Approval Engineering

- Activities which support the nuclear safety process compliant with Presidential Directive/NSC-25 (PD/NSC-25) and the Interagency Nuclear Safety Review Panel (INSRP) process that are not mission specific
  - Launch vehicle data books
  - Systems simulations
  - Systems and vehicle component destructive tests
  - Accident investigations and analysis
  - Site environmental sensors
  - Risk communications

RPS Mission Planning

1961

1971

Strategic / New Frontiers / Discovery / Mars / Lunar / Other	Projected Launch Year	Power Reqmnt (W_e)	RPS Type (Flight + Spare)	Pu-238 Availability
Mars Science Lab **Operational**	2011	100	1 MMRTG	Yes
Mars 2020 **In Development**	2020	120	1 MMRTG	Yes
New Frontiers 4 **In Planning**	2025*	~300	Up to 3 MMRTG/eMMRTG	Yes
New Frontiers 5 **Notional**	2030	~300	TBD	Yes

1991

- Potential 5-6 year-cadence for New Frontier mission opportunities
  - RPS not required for all mission concepts

2001

- Radioisotope heater units may be used on missions not requiring RPS
- Strategic missions often require RPS; 2 highest priority strategic missions in current decadal (Mars 2020 and Europa) are already in work

2011

  - Mars 2020 will use an MMRTG
  - Europa mission will be solar powered

*Nuclear launches are in 2025

2021

Courtesy J. Green (HQ)

Summary

- RPS Program provides NASA a robust, end-to-end program capability
  - Customer engagement
    - Missions, 'AGs, other Stakeholders
  - DOE systems acquisition (MMRTGs)
  - DOE partnership/sustained capabilities
- Ongoing capability enhancements
  - Systems (eMMRTG)
  - Missions (Mars 2020, potential NF-4)
  - Infrastructure (Plutonium Supply Project)

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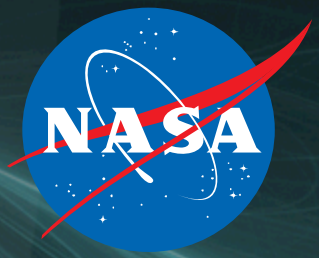
2001

2011

2021



Glenn Research Center
Jet Propulsion Laboratory
Applied Physics Laboratory

Idaho National Laboratory
Los Alamos National Laboratory
Oakridge National Laboratory
Sandia National Laboratory

http://rps.nasa.gov