National Aeronautics and Space Administration

1961
1971
1981
1991
2001
2011
2021

RADIOISOTOPE POWER SYSTEMS PROGRAM

Radioisotope Power Systems Program Status and Expectations

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Presented by:

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Agenda

- Program Background & Changes
- RPS Related NEPA/Launch Approval Processes
- Next Generation RTG Study
- Dynamic RPS Status
- Constant Rate Production
- Q&A

Radioisotope Power Systems

- Radioisotope Power Systems (RPS) are ideally suited for missions that need autonomous, long-duration power
  - Proven record of operation in the most extreme cold, dusty, dark, and high-radiation environments, both in space and on planetary surfaces.
- RPS provide long-lived power solutions for future Planetary Decadal Science missions
  - Mars 2020 (sample return precursor)
  - Uranus Orbiter/Probe
  - New Frontiers (Ocean-Worlds, Saturn, Lunar)
- RPS technologies offer potential to serve a wide range of missions from Small-sat/Cube-sat to Flagship-class Science (1-1000 We)
  - Thermoelectric (Pb-Te/TAGS; Skutterudite)
  - Dynamic (Stirling)
  - Radioisotope Heater Units
- RPS Program has an established relationship with DOE and has processes in place to work effectively

RPS have successfully powered NASA Missions for over 40 years and continues to serve the needs of NASA in its exploration of the Solar System

Programmatic Change

- Several changes have occurred in the Program over the last three years
  - DOE MOU for RPS has been renegotiated
    - Plays to strength of agencies
    - Allows for the formulation of Integrated Project Teams (IPTs) for flight system development
  - RPS Program now includes DOE activities for Pu238 production and processing into flight fuel forms
  - Nuclear Launch Safety and NEPA activities managed by the Program Office for Program Executives
  - The Technology Advancement Project has been divided into two projects
    - Thermoelectric Technology Development (JPL)
    - Stirling Cycle Technology Development (GRC)
  - Support Mars 2020 program

NASA/DOE Memorandum of Understanding

- DOE MOU for RPS has been renegotiated
  – Plays to strength of agencies
  – Allows for the formulation of Integrated Project Teams (IPTs) for flight system development

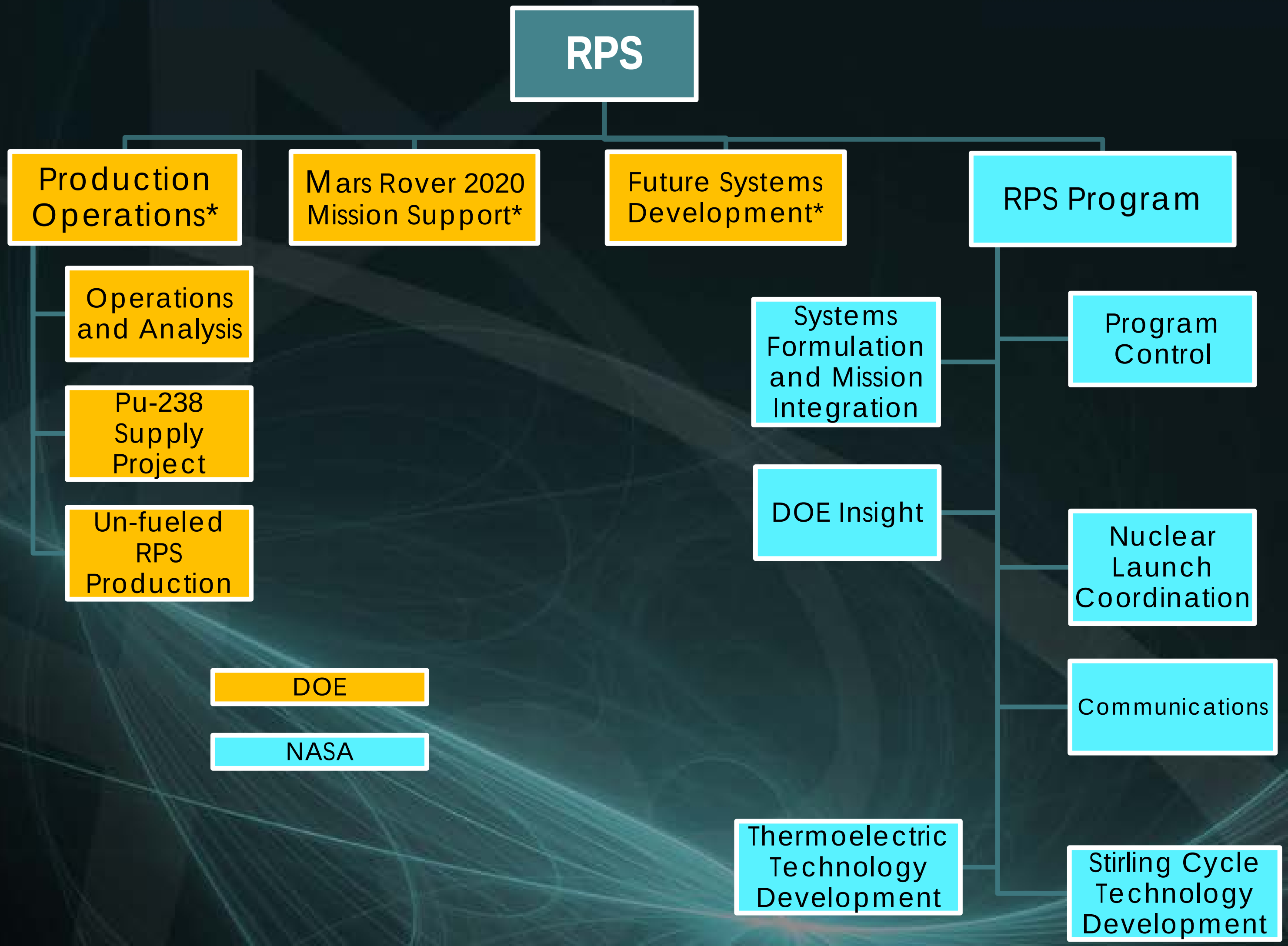
RPS Objective and Level I Requirements

- Program Objective
  - Ensure the availability of RPS for the exploration of the solar system in environments where conventional solar or chemical power generation is impractical or impossible.

- Program Level I Requirements
  - PCA-1: The RPS Program shall procure RPS for SMD missions.
  - PCA-2: The RPS Program shall sustain the capability to conduct RPS missions.
  - PCA-3: The RPS Program shall develop RPS technologies for insertion into flight systems.
  - PCA-4: ***The RPS Program shall manage the nuclear launch safety approval process for RPS.***

1961
1971
1981
1991
2001
2011
2021

Program With DOE Content



* NASA-funded DOE activities with unique Inter Agency Agreement

Nuclear Launch Coordination

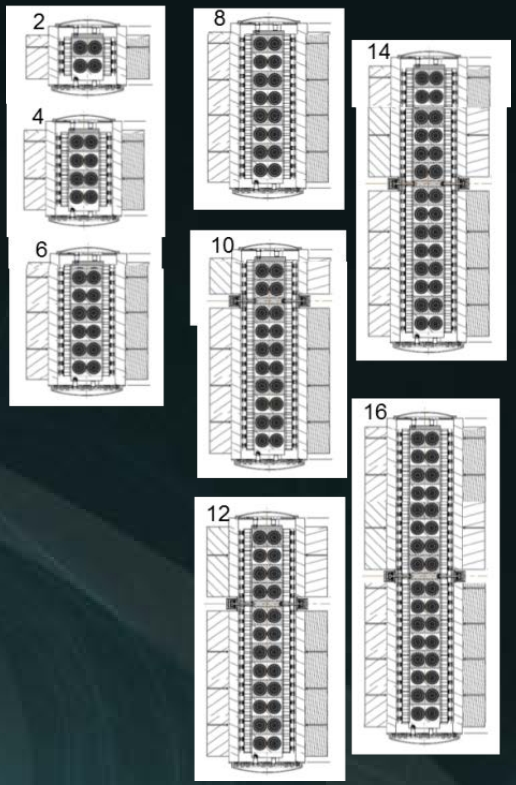
- Management of activities which support NASA NEPA and NPR 8713.5 compliance and the nuclear safety process compliant with Presidential Directive/NSC-25 (PD/NSC-25)
- The RPS Program now coordinates this process on behalf of the Mission Program Executive
  - NEPA compliance
  - EIS/EA completion
  - Mission databooks
  - Launch vehicle data books
  - Systems simulations
  - Systems and vehicle component destructive tests as required
  - Accident investigations and analysis as required
  - Site environmental sensors
  - Risk communications
  - Analysis of alternate isotopes

RPS Program – Coordination Role

- Coordination with
  - Mission Program Executive and Manager
  - NASA Headquarters NEPA lead
  - NASA Office of Safety and Mission Assurance
  - DOE
  - INSRP and processes
- Management of all NASA-executed activities in support of the launch of RPS, RHUs or nuclear materials on a mission
- Support of all Announcements of Opportunity or directed mission activities when RPS, RHUs or nuclear material will be present.
- Multi-Mission support activities, including but not limited to the production of launch vehicle databooks.

Next Gen RTG- Key Considerations

- End of mission power
  - Degradation rate
- Integration & Operations
  - Number of generators per mission 4 or less
- Risks to get to a generator
  - TE TRL maturity
  - Generator design heritage
- PSD mission focus in next 10 years (as best aware)
  - Flyby and orbit OP
  - Land and rove OW
- Balance of RPS Program
  - MMRTG
  - Dynamic
  - Other



Next Gen RTG Future Characteristics

- System designed to operate in vacuum
- System designed to be modular
  - Requires process for modular qualification
- System (16 GPHS) provides at least 400 We at BOL with a goal of 500 We
- System (16 GPHS) mass is 60 kg or less
- System degradation rate, including fuel degradation, is 1.9%
  - To be rewritten in terms of EODL power
- System to be designed to be upgraded with new TCs as technology matures

Stirling Cycle Technology Development Project

- Reassess Stirling/Dynamic Power Generation Technology industrial capability
  - ROSES NRA process
  - End goal is 200-500W flight system
  - First flight opportunity 2028
  - Phased approach
    - SOA assessment
    - Requirements definition
    - Prototype system
    - Flight contract with DOE
- Maintain GRC In-House capability
  - Stirling Lab (B. 301) RSIL (B.333)
  - Fundamental component/systems research
  - Spacecraft Integration

Why a DRPS?

Dynamic Power Systems provide benefits that enable spacecraft to meet NASA objectives and PSD science objectives

- Destination flexibility
- Fuel efficiency/ Less Fuel
- Less Waste Heat
- Higher Potential Power at EODL
- Path to higher power systems (Benefits to SMD and HEO)

Dynamic Power Technology Objective

In the context of developing a 200-500 W_e RPS determine the development readiness and risk associated with dynamic power conversion technologies

- Key technology evaluation characteristics
  - Reliability
  - Robustness
  - Manufacturability
  - Life-cycle and sustainability costs
  - Performance

RPS Dynamic Power Conversion

- Dynamic Power Converters for RPS Contracts
  - One signed with ITC Start July 3, 2017
  - One contracts ready to be finalized and signed
  - Two contracts in negotiation; anticipating July contract award
- Dynamic Power Conversion for RPS Contracts
  - Kickoff meetings with contractors, Jul. 2017
  - Phase 1 convertor designs, Jan. 2018
  - Phase 2 demo convertors, Sep. 2019
  - NASA prototype convertor test reports, Sep. 2020
  - NASA recommendation report, Dec. 2020

DOE RPS Supply Chain

Pu-238 Isotope Production
- Oak Ridge National Laboratory
- Idaho National Laboratory

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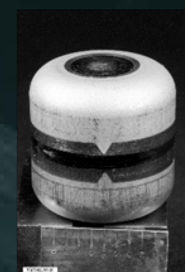
Fueled Clad Manufacturing
- Oak Ridge National Laboratory
- Los Alamos National Laboratory



Fueling/Testing/Delivery
- Idaho National Laboratory

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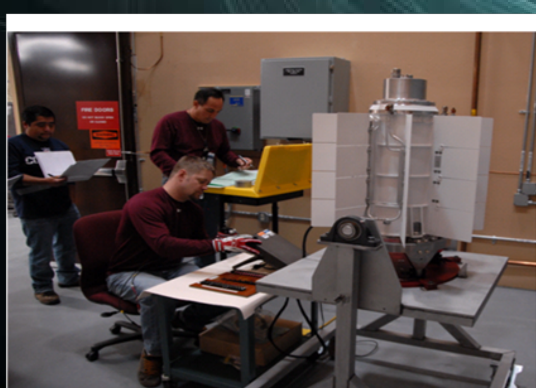
Launch Support
- Kennedy Space Center



16

RPS Program Operations – Transition to Constant Rate Production

- DOE and NASA have agreed to transition to a Constant Rate Production model across the supply chain to better meet NASA mission needs
  - Established annual average production rates for Pu-238 and fuel clads, across the DOE RPS supply chain
  - Transitioning Pu-238 Supply from a project-based approach to a campaign model
  - Accelerating research to optimize the supply chain
  - Improving integration of RPS activities across the DOE complex to inform future investment decisions

17

Constant Rate Production Benefits

- Leverages DOE standard campaign model providing flexibility for NASA missions
  - New irradiation target designs
  - Equipment investments for fuel clad manufacturing
  - Utilization studies for the Advanced Test Reactor
  - Evaluation of new technology
- Maintains qualified work force
- Reduces mission costs
  - New Frontiers initial estimates reduced approximately 25%
- Provides more predictable operation pace that level-loads resources

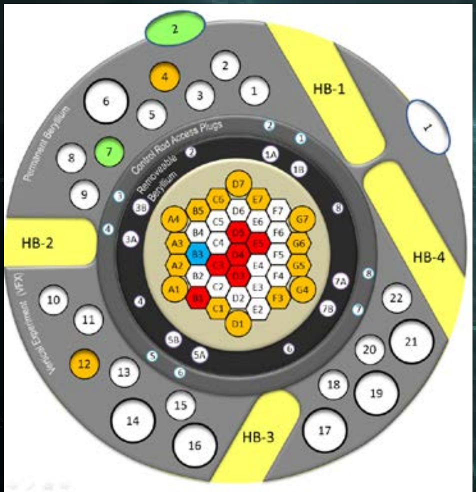
Pu238 Production

- Objective: Restart domestic production of Heat Source Pu238 (HS-PuO_2)with a planned rate of 1.5 kg/yr at the end of FY23
- **First new US Pu-238 production since the late 1980s**
  - ~ 100 gm total HS-PuO_2 has been produced
  - Small samples have been shipped to LANL to compare analytical results
  - Plan to include some new material in Mars 2020 fuel load
- Target production already well underway for second demonstration
  - Demonstrate larger batch sizes
  - Implement process improvements
- Target Irradiation in the High Flux Isotope Reactor (HFIR) at ORNL continues
- Currently investigating options for additional target irradiation at the Advanced Test Reactor (ATR) at INL

End State Vision - Isotope Production

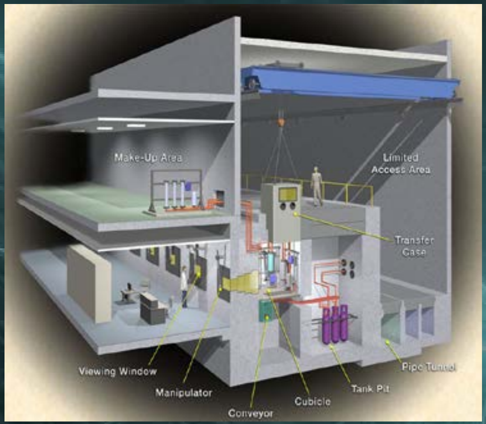
- By fiscal year 2021, add additional irradiation capability at the Advanced Test Reactor (ATR) for redundancy
- By fiscal year 2025, maintain average production rate of 1.5 kg/y with surge capacity to ~2.5 kg/y (if funded)

High Flux Isotope Reactor (HFIR)

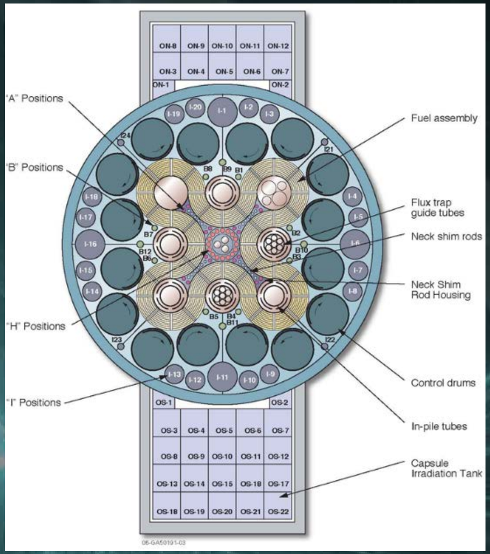


Reflector positions can be used to irradiate NpO_2 in the HFIR

ORNL Processing Capability



Advanced Test Reactor (ATR)



Reflector positions and flux traps can be used to irradiate NpO_2 at ATR

End State Vision – Fueled Clad Manufacturing

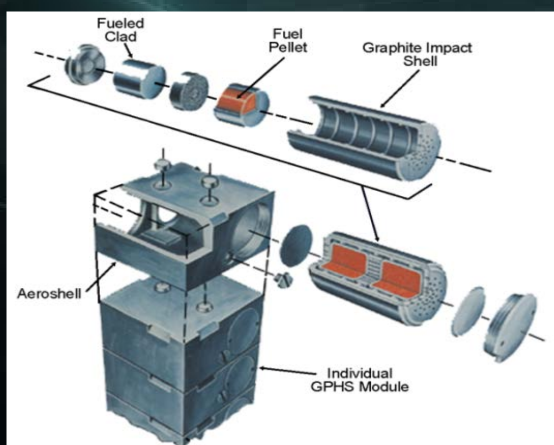
- By fiscal year 2021, maintain 10-15/year constant-rate of fueled clads at Los Alamos and shipped to Idaho
- By fiscal year 2025, completed modernization campaign at Los Alamos to improve reliability of critical infrastructure and enhance worker safety

Aqueous Line

21

End State Vision – Fueling/Testing/Delivery

- By fiscal year 2021, modify storage at INL to reduce risk and add scheduling flexibility for fueling RPS
- By fiscal year 2025, implement process to match fuel for NASA missions based on heat output, providing more flexibility to make adjustments



General Purpose Heat Source Module

22

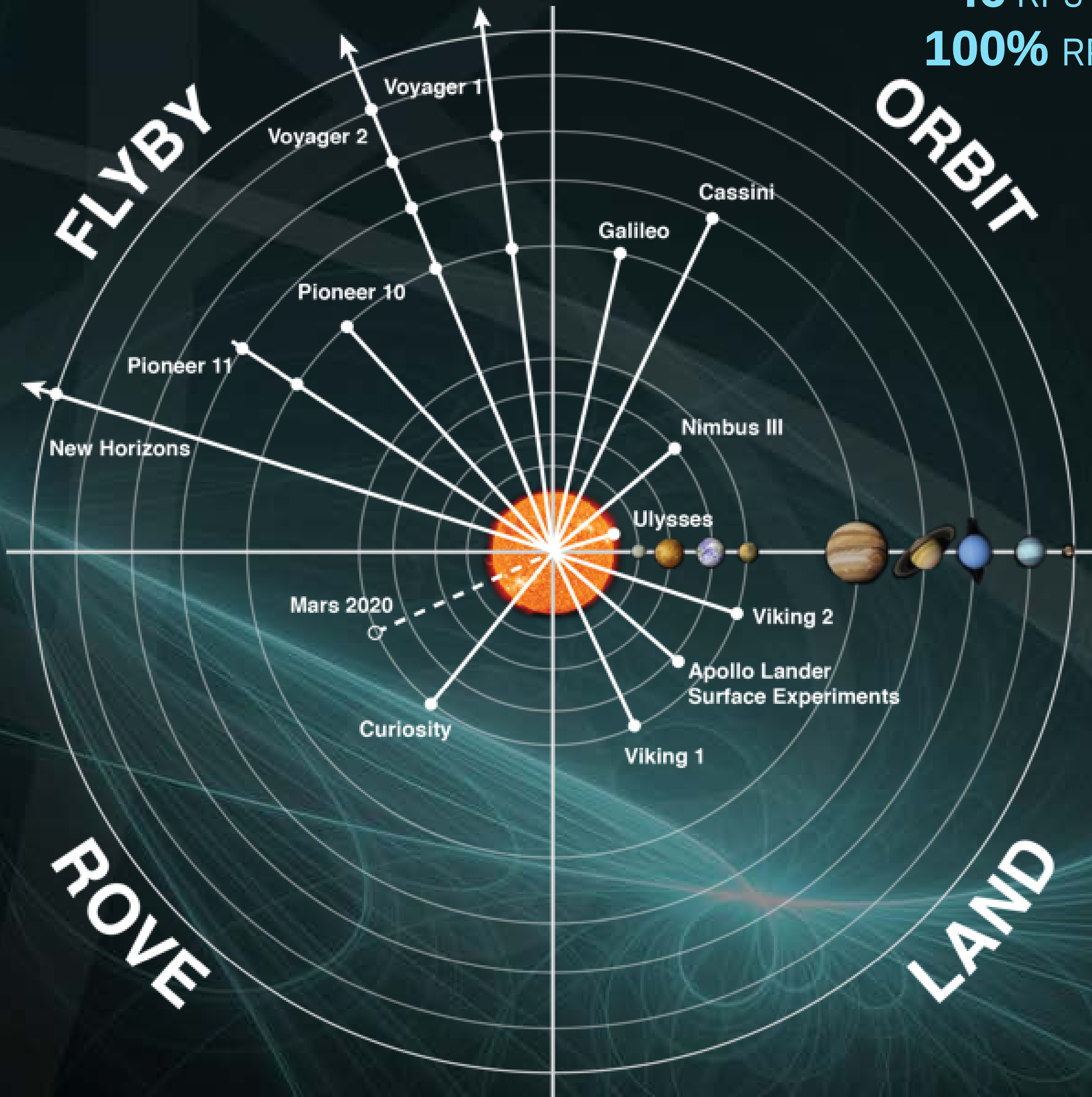
Summary

- RPS Program provides NASA a robust, end-to-end program capability
  - DOE partnership/sustained capabilities
  - DOE systems acquisition (MMRTGs)
  - Mission target driven technology development
  - Customer engagement
- Ongoing capability enhancements
  - Infrastructure & Plutonium Supply Project
  - Nuclear Launch Coordination
  - Systems (eMMRTG)
  - Technologies (thermoelectrics and Stirling)
- Service to Missions
  - Operational (Voyager, Cassini, New Horizons, Curiosity)
  - Future (Mars 2020, potential NF-4)

Over 50 years of RPS Missions

27 MISSIONS
46 RPS
100% RPS SUCCESS

1961
1971
1981
1991
2001
2011
2021



1961
1971
1981
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2001
2011
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Applied Physics Laboratory

Idaho National Laboratory
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Oak Ridge National Laboratory
Sandia National Laboratories

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