Assessment of Plutonium-238 Production Alternatives

Briefing for
Nuclear Energy Advisory Committee

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Statement of Work

Independently evaluate the Pu-238 heat source requirements for NASA's mission projections and assess Pu-238 production assumptions, strategy and alternatives for meeting those requirements

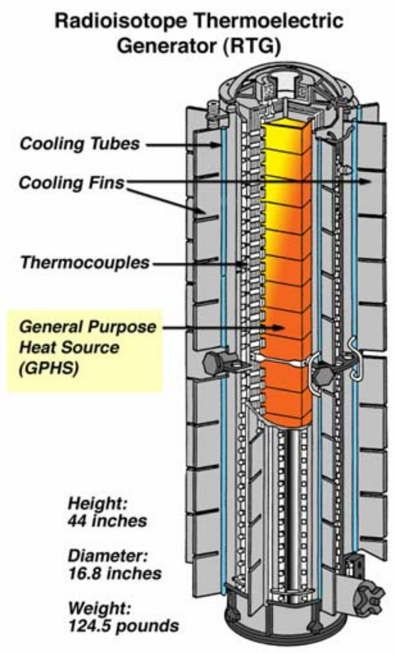
- Desired end state:
  - Reliable, sustainable, affordable supply of Pu-238 suitable for NASA applications
- Assumptions:
  - NASA obtains funding for planned missions
  - Russia is out of material to sell to US
  - DOE maintains balance of radioisotope power source infrastructure during period of depleted supply

Why Pu-238 as a Heat Source?

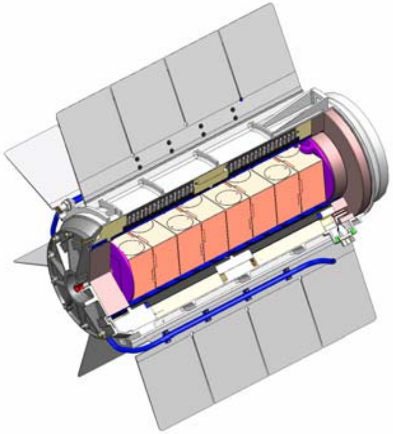
- Long half-life- 87.7 years
- High power density/specific power ~ 0.57 watts/gram
- Low radiation levels – primarily an alpha emitter
  - limit radiation exposures of operating personnel during production, fabrication, testing and delivery
  - low-mass configurations for space applications offer very little self shielding
  - compatibility with sensitive instrumentation for space exploration
- High thermal stability – oxide form with high melting point
- Low solubility rate in the human body and environment
- Producibility in sufficient quantities and schedule to meet mission needs
- Other isotopes considered and dismissed over the years
  - investigated several times in response to concerns over supply

RPS Designs - Current and Under Development

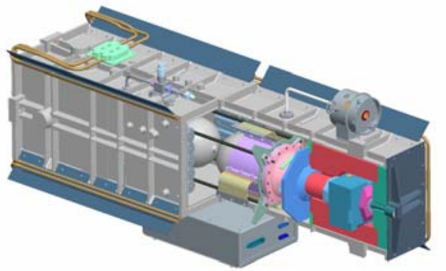
- GPHS Radioisotope Thermoelectric Generator (RTG)
  - 18 GPHS modules, ~7.9 $kg_{Pu\text{-}238}$
  - electric power ~210 watts beginning of mission (BOM)
  - Galileo, Ulysses, Cassini and New Horizons missions (no longer available for future missions)



- Multi-mission RTG (MMRTG)
  - 8 GPHS modules, ~3.5 $kg_{Pu\text{-}238}$
  - ~120 W_e BOM
  - Mars Science Laboratory (to be launched Sep 2009)

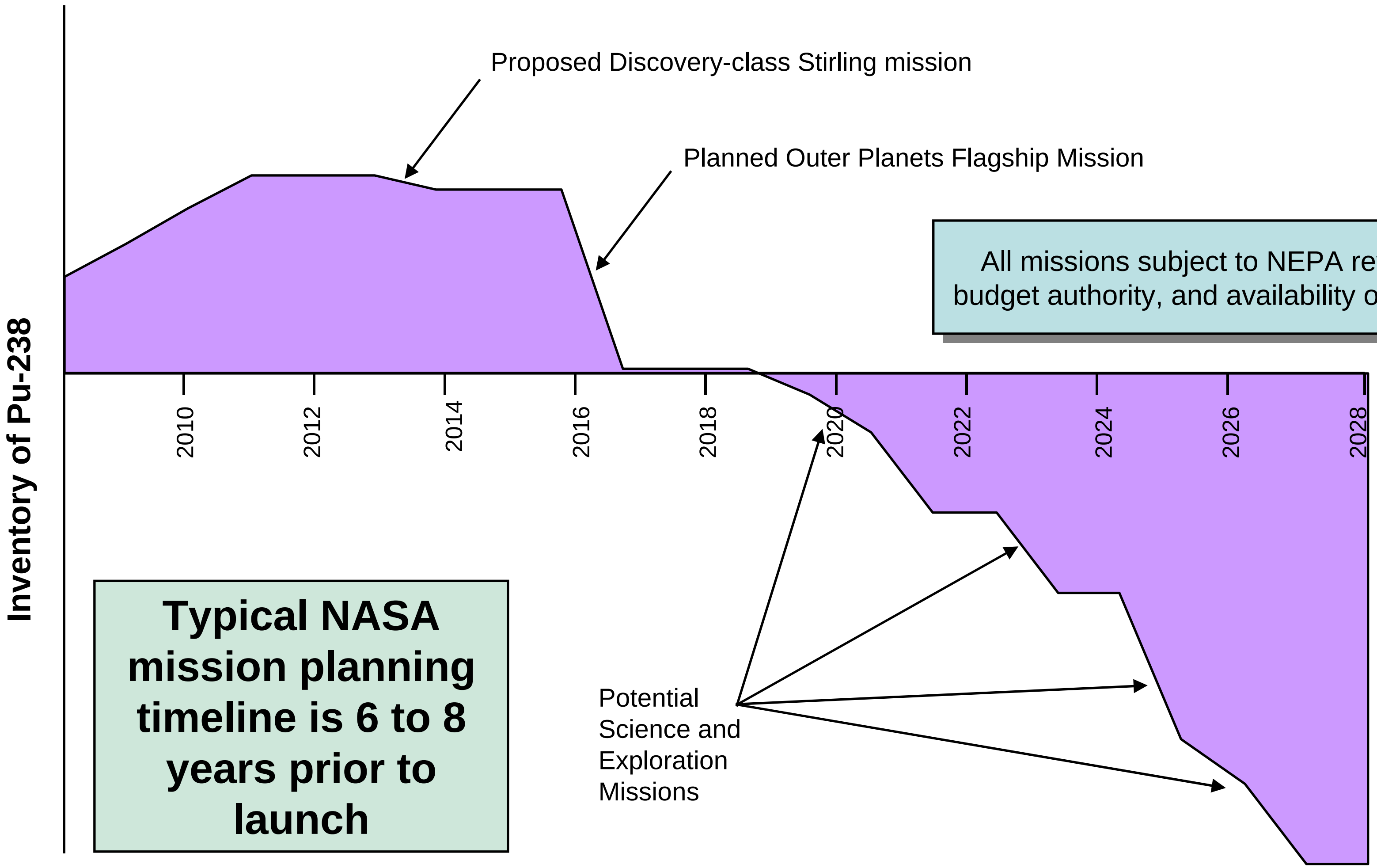


- Advanced Stirling Radioisotope Generator (ASRG) – dynamic system, under development
  - 2 GPHS modules, ~0.88 $kg_{Pu\text{-}238}$
  - ~140 W_e BOM



The Problem

Next two budgeted NASA RPS missions will exhaust remaining inventory (including planned Russian purchases)



All missions subject to NEPA review, budget authority, and availability of Pu238

Typical NASA mission planning timeline is 6 to 8 years prior to launch

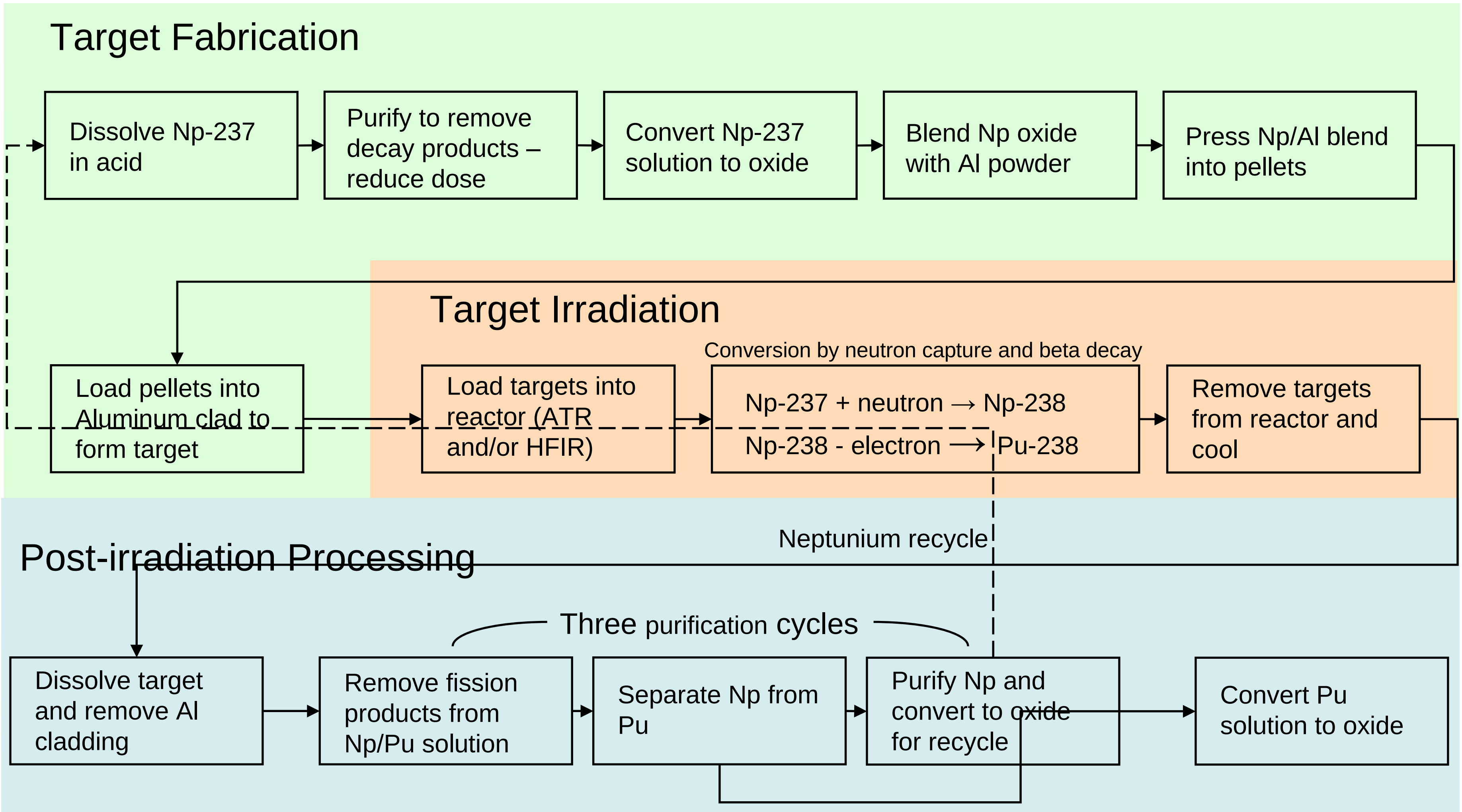
The Plan for Production

- FY 2008 – CD-0 Approve Mission Need
- FY 2009 – CD-1 Approve Alternative Selection
  - Issue university grants to develop alternatives
  - Promising concepts would be considered in CD-1 alternatives analysis
- Timing for CD-2, CD-3 and CD-4 will depend on alternative

Considerations for Candidate Alternatives

- Product must be suitable as feed to current fuel fabrication process
- Thermal power density of product must be consistent with current radioisotope power system designs
- Process must have the potential to offer significant advantages in cost, schedule or technical risk relative to historic production process, taking into account:
  - safety, licensing
  - security
  - technology development and demonstration
- Process must be scalable to produce 5 kg Pu-238 per year

Historic Process Flow for Pu-238 Production and Recovery



Product is plutonium dioxide powder with an isotopic content of Pu-238 greater than 80%. Each production cycle converts 10-15% Np-237 to Pu-238 with remainder of Np recycled.

Examples of Candidate Alternatives

- Alternate target fabrication approaches
- Alternate irradiation approaches
- Alternate post-irradiation processing approaches

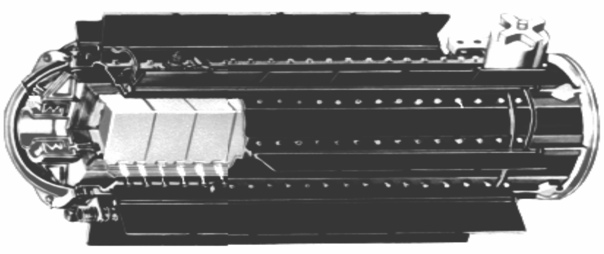
Back-up Charts

Motivation for Study

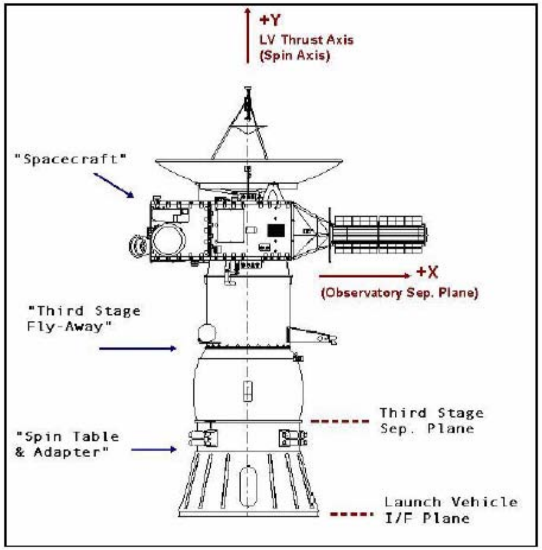
- The United States has not produced Pu-238 since shut down of K Reactor at SRS in late 1980's
- Procurement of Pu-238 from Russia commenced in early 1990's and will conclude in 2010
  - Approximate quantity purchased from Russia by that time will be 30-40 kg
  - Russia also lost its capability to produce new Pu238
  - By agreement, Pu-238 from Russia can not be used for national security applications
- Preliminary cost estimates indicate that re-establishment cost for infrastructure to support domestic production of Pu-238 will be several hundreds of millions of dollars

Radioisotope Power for Space Missions

- Radioisotope Power Sources (RPS)
  - Converts heat from radioactive decay of plutonium-238 to usable electrical power
  - 2 major components: General Purpose Heat Source and electric converter
  - Technology is culmination of over 40 years of design evolution
- Long history of RPS use in space
  - First launched in 1961
  - Used safely and reliably in missions for 40 years
    - » 5 on the Moon (1960s - 1970s)
    - » 8 in Earth orbit (1960s - 1970s)
    - » 2 on Mars (1970s & 2 heater units 1996, 2003)
    - » 8 to outer planets and the Sun (1970s - 2006)



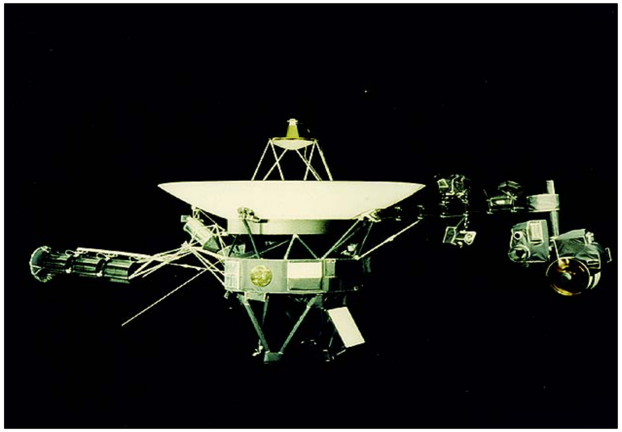
Radioisotope Thermoelectric Generator



New Horizons

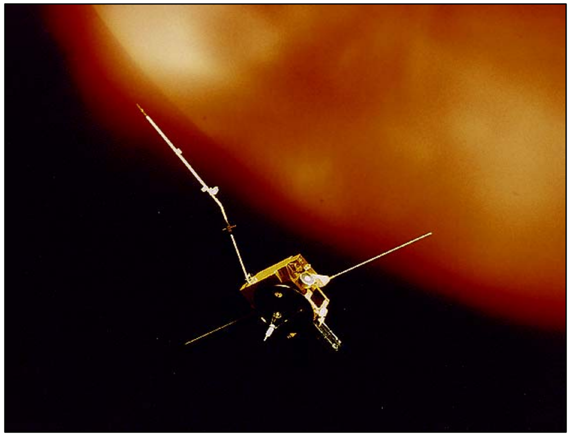
Examples of Space RPS Missions

Apollo (1969 - 1972)

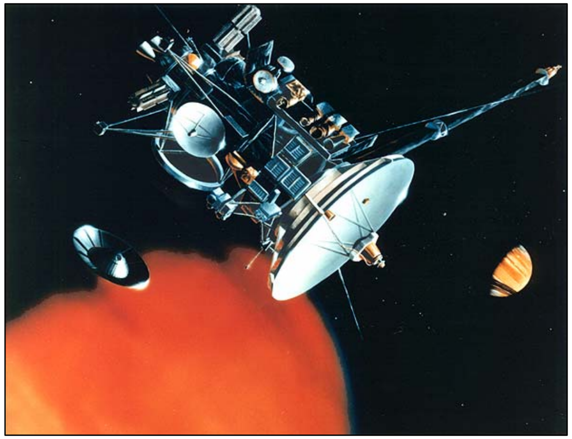


Voyager (1977)

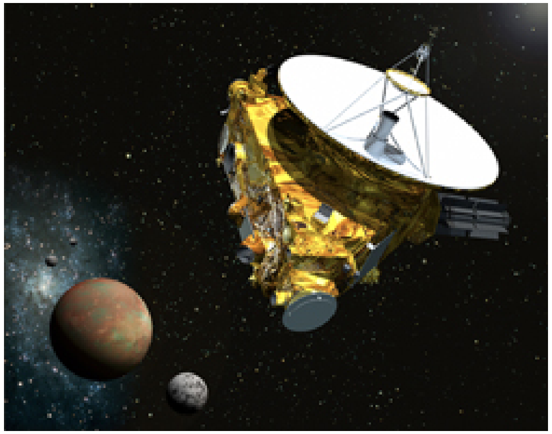
Galileo (1989)



Ulysses (1990)



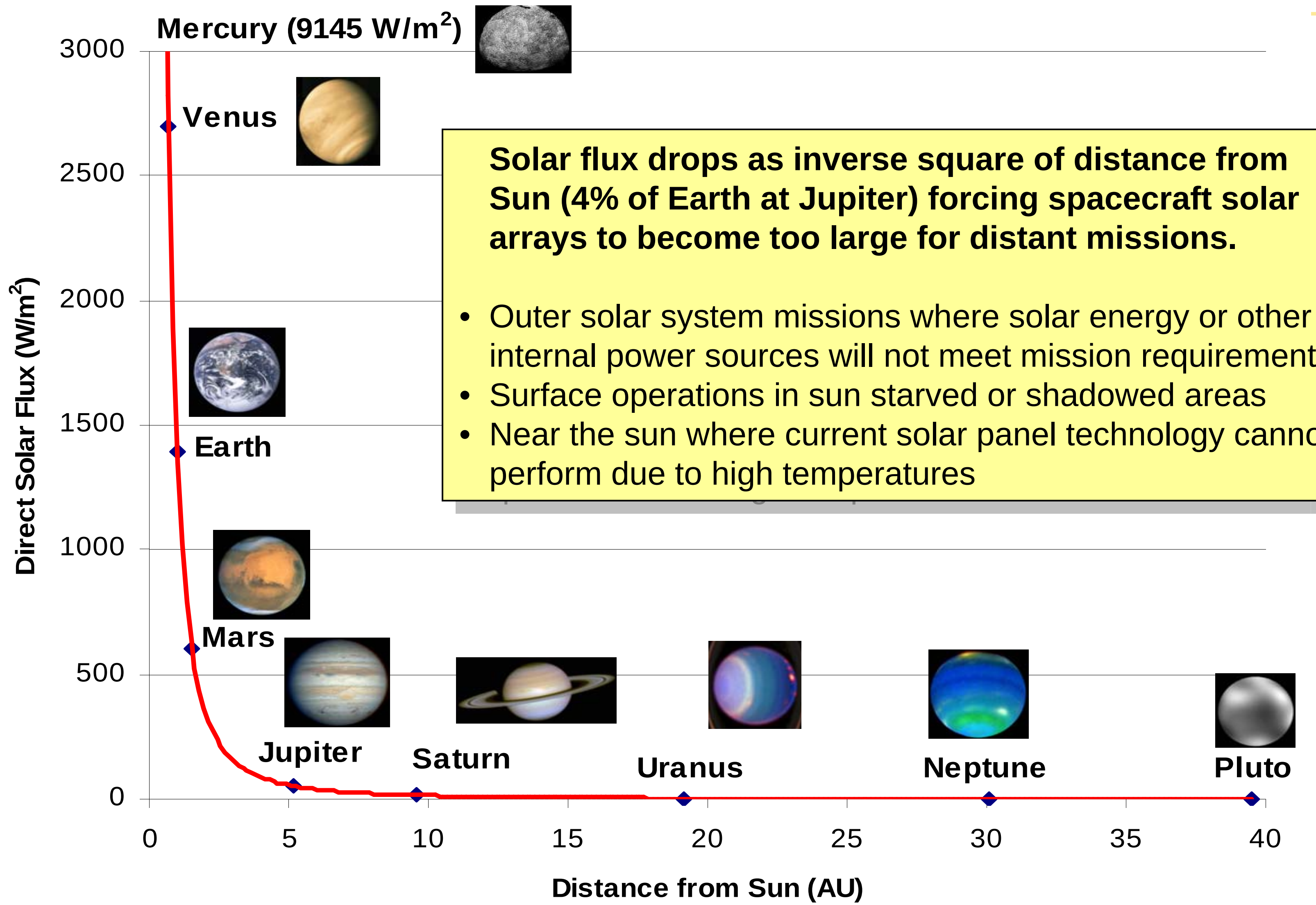
Cassini (1997)



New Horizons (2006)

For all prior missions, RPS have continued to operate far beyond their design life

Radioisotope Power Enables Missions

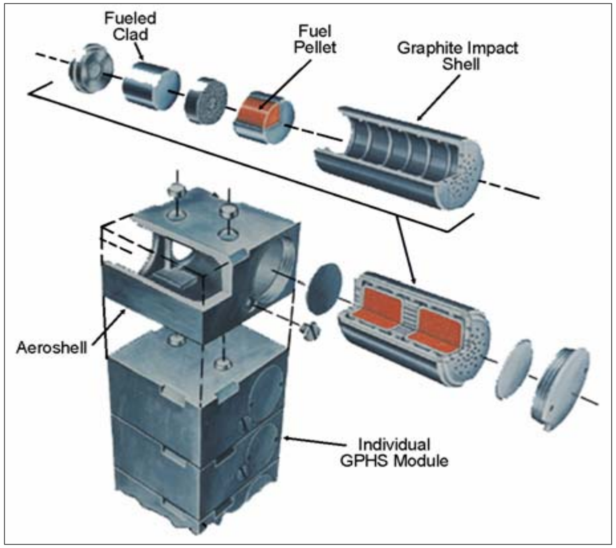


Solar flux drops as inverse square of distance from Sun (4% of Earth at Jupiter) forcing spacecraft solar arrays to become too large for distant missions.

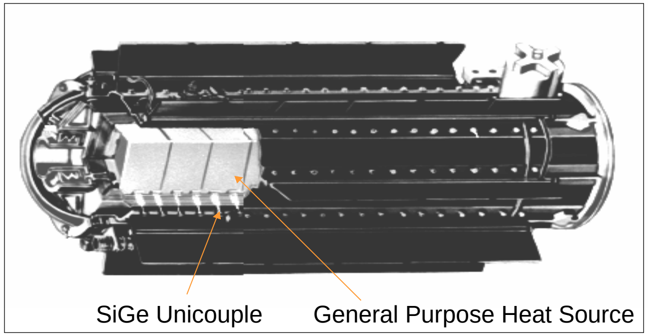
- Outer solar system missions where solar energy or other internal power sources will not meet mission requirements
- Surface operations in sun starved or shadowed areas
- Near the sun where current solar panel technology cannot perform due to high temperatures

Key Safety Features of Space Radioisotope Power Sources

- Ceramic Pu-238 fuel (generates decay heat)
  - Robust to high temperatures (low vaporization rate)
  - Fractures into largely non-respirable chunks upon impact
  - Highly insoluble
- Cladding (encases the fuel)
  - Provides protection against impact and high temperatures
- Graphite components (protects fuel & cladding)
  - Impact shell provides impact protection
  - Aeroshell protects against heat of re-entry
- Generator housing design
  - Designed to release individual aeroshell modules in cases of inadvertent re-entry (minimizes terminal velocity)



General Purpose Heat Source Module



Radioisotope Thermoelectric Generator

Safety Analysis Process

- Accident Scenarios and Probabilities
- Accident Environments
- Nuclear Hardware Response Modeling
  - Mechanical Impact Environments
  - Liquid and Solid Propellant Fire Environments
  - Reentry Environments
- Source Terms
- Radiological Consequence Analysis (Dose, Health Effects, Risk and Land Contamination)
  - Atmospheric Transport and Dispersion Modeling
  - Low Altitude Releases
  - High Altitude Releases (Particulate)
  - High Altitude Releases (Small Particles)
- Exposure Pathway Modeling
  - Inhalation, ingestion and external
- Radiological Consequences
  - contamination, doses and health effects

Accuracy of source term estimates depends on thorough understanding of hardware response to accident environments

DOE Safety Tests

- Testing Purposes
  - Validate Design
  - Calibrate Deformation Models
  - Develop Source Term Models
- Explosion Overpressure
- Propellant Fires
- Fragment Impacts
- Reentry Ablation
- Surface Impact
  - RPS Converter
  - GPHS Module
  - Fueled Clad

Safety tests address complex environments of potential launch and reentry accidents