Nuclear Power For Outer Planet Missions

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Outer Planets Assessment Group Meeting

Thursday, 24 July 2014
Ballrooms CD
Doubletree Bethesda Hotel and Executive Meeting Center
Bethesda, Maryland

10:45 AM - 11:15 AM

APL
The Johns Hopkins University
APPLIED PHYSICS LABORATORY

Topics

- **Nuclear Infrastructure Support**
- **Nuclear Power Assessment Study (most of the presentation)**
- **Pu-238 Supply Project (from Dr. Robert M. Wham - Science Advisor for the Pu-238 Supply Project in the ORNL Fuel Cycle and Isotopes Division)**

Nuclear Infrastructure Support

- **The President's FY 2014 budget shifted fiscal responsibility and target budget for maintenance of NASA-required DOE infrastructure from DOE to NASA as a work for others (WFO) program**
  - Committee in Senate Report 113-78 included $150,900,000 for Technology" under Planetary Science, which matches the President's budget request ($3M more)
  - Included within this item is "To sustain the necessary capacity to meet future missions' power needs, the FY 2014 NASA budget request includes an additional $50 million to support radioisotope power system production infrastructure at the Department of Energy (DOE)."
  - The Technology item also includes the Pu-238 Supply Project funds
  - $146.0 M was enacted for Technology
- **The President's FY2015 budget includes $137.2 for Technology within Planetary Science**
  - Infrastructure support and the Pu-238 Supply project remain funded
  - No further detail is provided

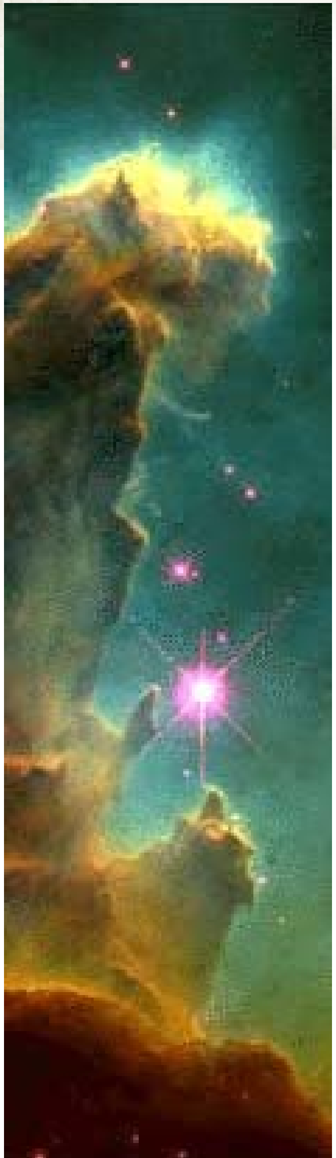
Study Objective

NASA Radioisotope Power Systems Program
Nuclear Power Systems Assessment
Terms of Reference
March 15, 2014

Identify opportunities and challenges of a sustainable provisioning strategy for safe, reliable, and affordable nuclear power systems that enable NASA Science Mission Directorate (SMD) missions and are extensible to Human Exploration and Operations Mission Directorate (HEOMD) needs in the next 20 years.

What Is At Stake

- This study is to motivate and guide development on new technology for NASA
- Development of new technology – at least the technology that makes a real difference – is typically underestimated in difficulty, complexity, cost requirements and development time
- Everyone knows this …
- But if the situation gets too out of hand from the initial approach and plan – and/or if there are too many failures, the initiative will become a terminal dead end, no matter how promising

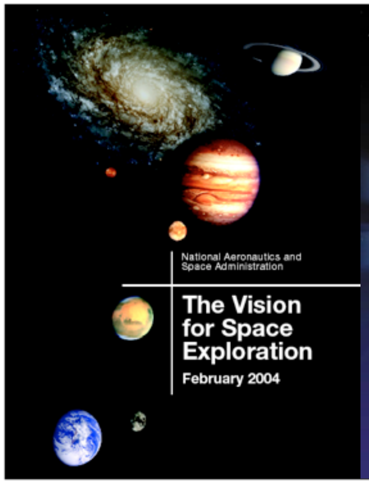


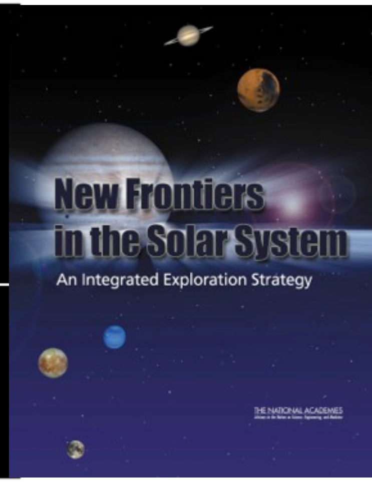
For Any Mission There Are Four Key Elements:

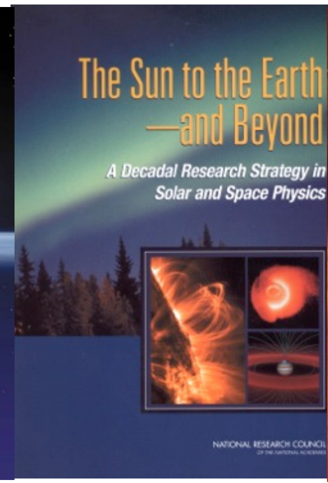
▪ National Policy/Science	the case to go
▪ Technology	the means to go
▪ Strategy	the agreement to go
▪ Programmatics	the funds to go

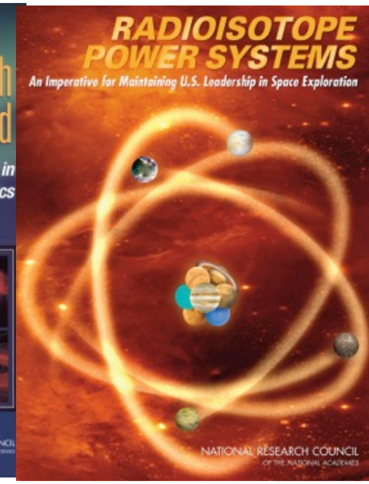
A well-thought-out approach with all key elements is required to promote and accomplish a successful exploration plan

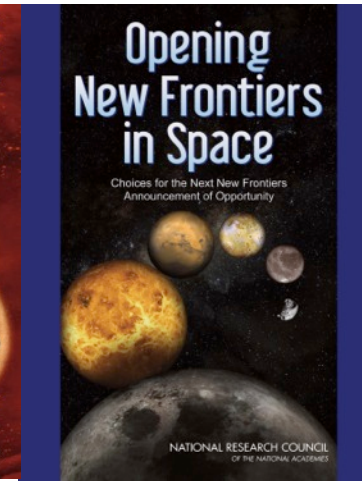
The Case for Going: Science/Politics

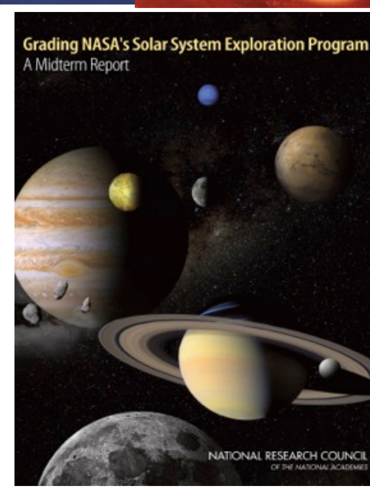


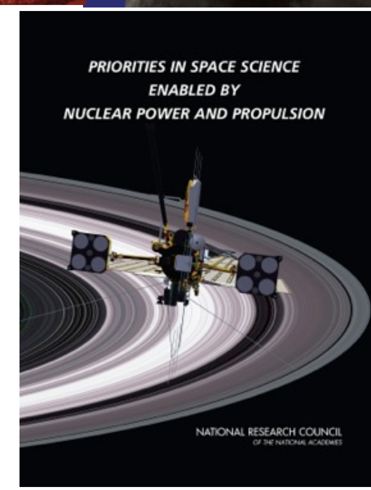












Study Methodology

- **Nominal flowdown:**
- **Start with the anticipated mission needs and determine future nuclear power systems:**
  - Technologies and systems capabilities to meet mission needs
  - Technologies development costs and risk
  - Systems development and production costs and risks
  - Sustainment investments that can be used to support technologies and systems development and any resulting future sustainment investment that could be required with proposed plan
  - Missions that can be uniquely and commonly supported by the proposed systems
- **Iteration between nominal missions and systems capabilities and approaches are needed – and will occur both explicitly and implicitly**

Study Stakeholders

- **Organizational entities with a vested interest in the outcome**
  - Technology and Mission Investors - NASA/SMD, HEOMD, Space Technology Mission Directorate (STMD)
  - Mission Providers - Jet Propulsion Laboratory (JPL), Goddard Space Flight Center (GSFC), Johns Hopkins University Applied Physics Laboratory (APL)
  - Nuclear Power System Providers - DOE Office of Space and Defense Power Systems (NE-75), DOE National Nuclear Security Administration (NNSA)

Study Background

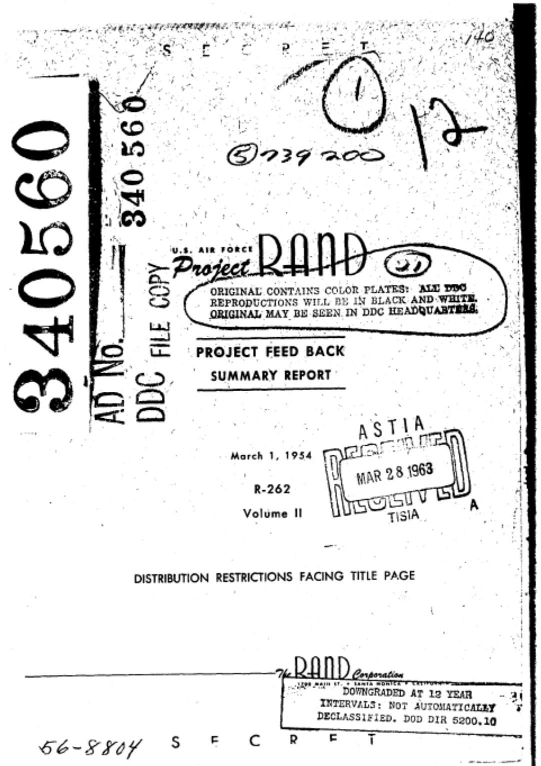
- **NASA's Planetary Science Division (PSD) within the Agency's Science Mission Directorate (SMD) uses Decadal Studies and Provisioning Studies to inform investments in technology and capability development**
- **Last study of this type was the 2001 Provisioning Study**
    - New RPS design for Mars surface operation
    - Driving considerations included mission scenarios, requirements, existing assets, fuel availability, process and process limitations, safety and launch approval, redundancy and convertor technologies.
  - Nuclear Power Assessment Study (NPAS) is this type of study and will be used to inform PSD decision makers on provisioning of Radioisotope Power Systems (RPS) and Fission Power Systems (FPS) for future mission needs

Study Deliverables

- **Final Report and Presentation by November 2014 - (Oral brief to Planetary Science Division scheduled 5 September)**
  - Discussion of a strategy/roadmap and rationale of RPS and FPS common component technology development for SMD with possible extension to HEOMD needs
    - Top-level requirements for dual components
    - Extensibility to HEOMD future missions
    - If and/or when to convert to or include fission systems
    - Impacts to NASA and DOE infrastructure
    - Limitations and/or impacts of radioisotope and fission heat sources
  - Discussion of flight system development costs, risks and other considerations
  - Discussion of safety impacts and required analyses of FPS
  - Identification of follow-on studies or trades requiring further investigation
- **A status briefing July 2014 (held Tuesday 22 July)**

Sidebar 1
Why Include "Fission" ? (1 of 2)

- **The U.S. began investigating both fission and radioisotope power supplies for auxiliary power supplies under "Project Feed Back" – a RAND Corporation study – since declassified – from the late 1940's/early 1950's**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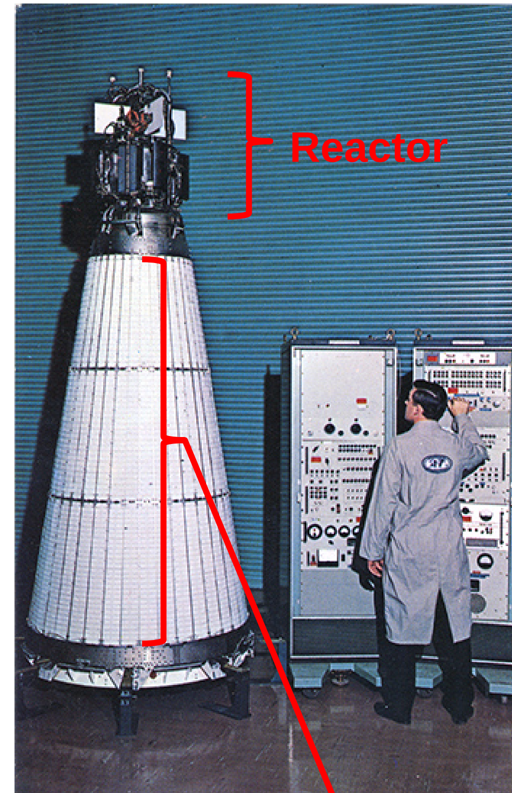


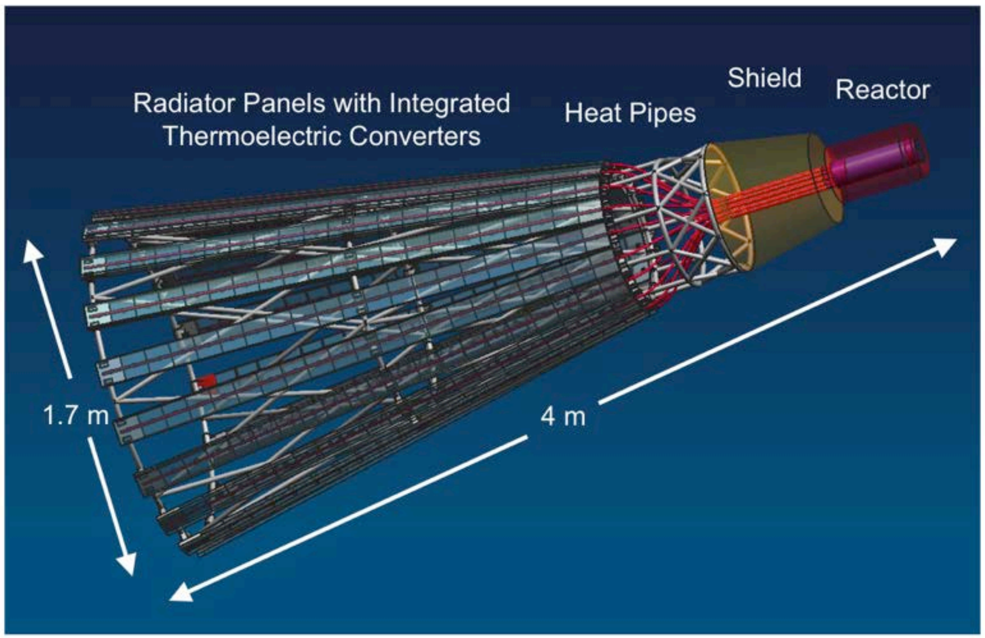
SNAP 10A in test

The U.S. effort culminated in flying SNAPSHOT with the SNAP 10A reactor on board from Vandenberg on 3 April 1965

Failed 43 days later due to electrical fault in the spacecraft – unrelated to the reactor

Sidebar 2
Why Include "Fission" ? (2 of 2)

- **White paper contribution to the most recent Decadal Survey effort re-examined the possible use of compact fission reactors**



Innovative approach uses high temperature heat pipes and metallic UMo HEU fuel (pioneered in liquid-metal fast breeder reactors in 1950s and 1960s)

Allows for higher power levels ~ 1,000 W_{elec}

SNAP 10A was ~ 500 W_{elec}

Fuel supply – highly enriched uranium (HEU) is available in the U.S. (need for reactor is ~25 to 30 kg per flight; U.S. stockpile is being downblended to eliminate HEU – inventory contained 590.5 metric tons of U-235 isotope on 30 September 2004

Players: NASA-GRC, LANL, NNSA (Y12)

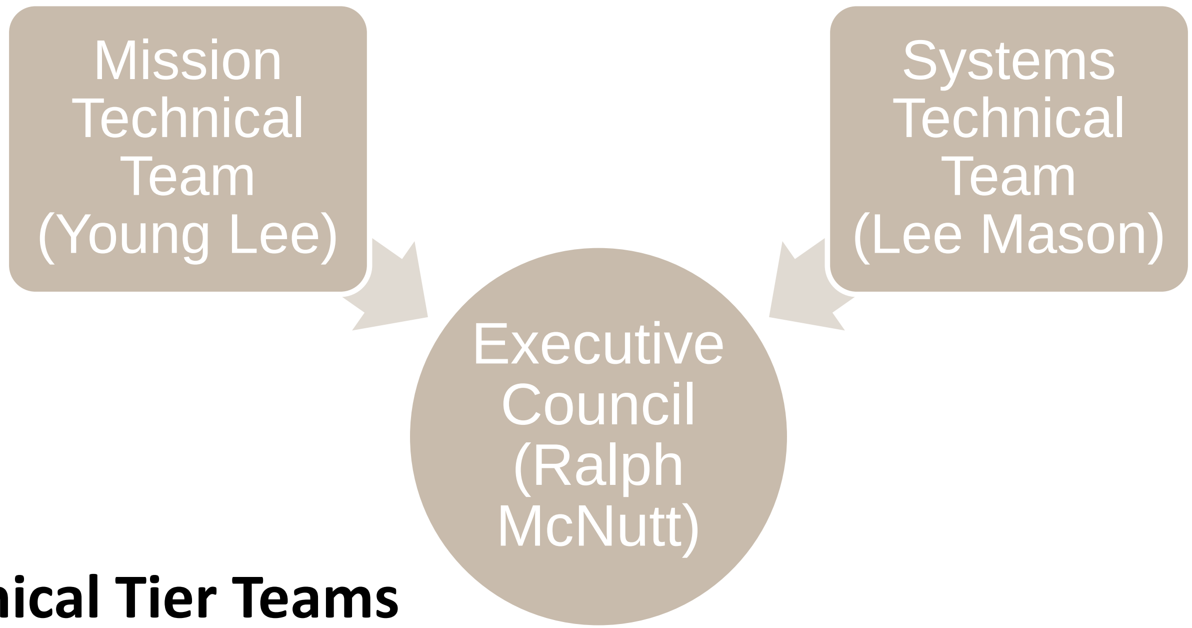
Study Drivers

- **Nuclear Power, whether RPS or FPS based, is necessary to support space science and exploration**
  - Where sunlight is very faint or where variations in environmental conditions like shadows, thick cloud or dust can impact spacecraft performance.
- **NASA needs efficient power generation systems to serve multiple mission architectures**
  - "Efficient" systems to focus on, at minimum, 1) end of mission power being more critical than beginning of mission, and 2) power produced per amount of fuel required as a function of inventory, cost, and system needs.
- **A long-range, cross-cutting-technology investment and systems-development plan is needed to use NASA's limited resources to achieve both science and exploration objectives**

Coordinated Results Are Essential

- **Technology development and system development approaches must ensure:**
  1. The plan results in hardware necessary to support SMD and potentially Human Exploration and Operations Mission Directorate (HEOMD) Mission’s needs
  2. The budget, timeframe and risks are affordable and reasonable
  3. The capabilities, accommodations, and challenges from each Mission Directorate’s and the Department of Energy’s view point are integrated and addressed

Study Organization



Technical Tier Teams

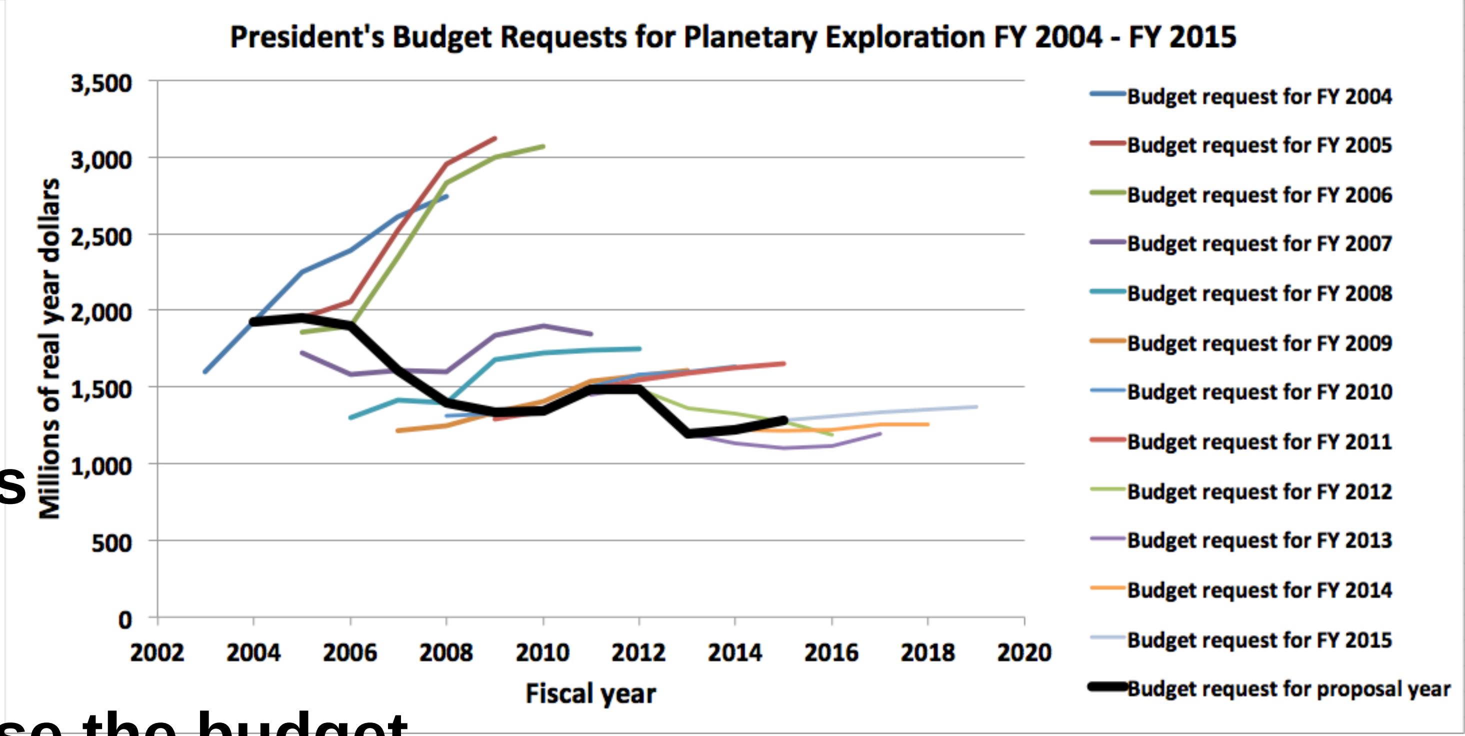
Will focus on addressing specific questions needed to be considered for overall plan development

Executive Team

Will assimilate technical tier teams' reports and develop recommendations

Funding Reality

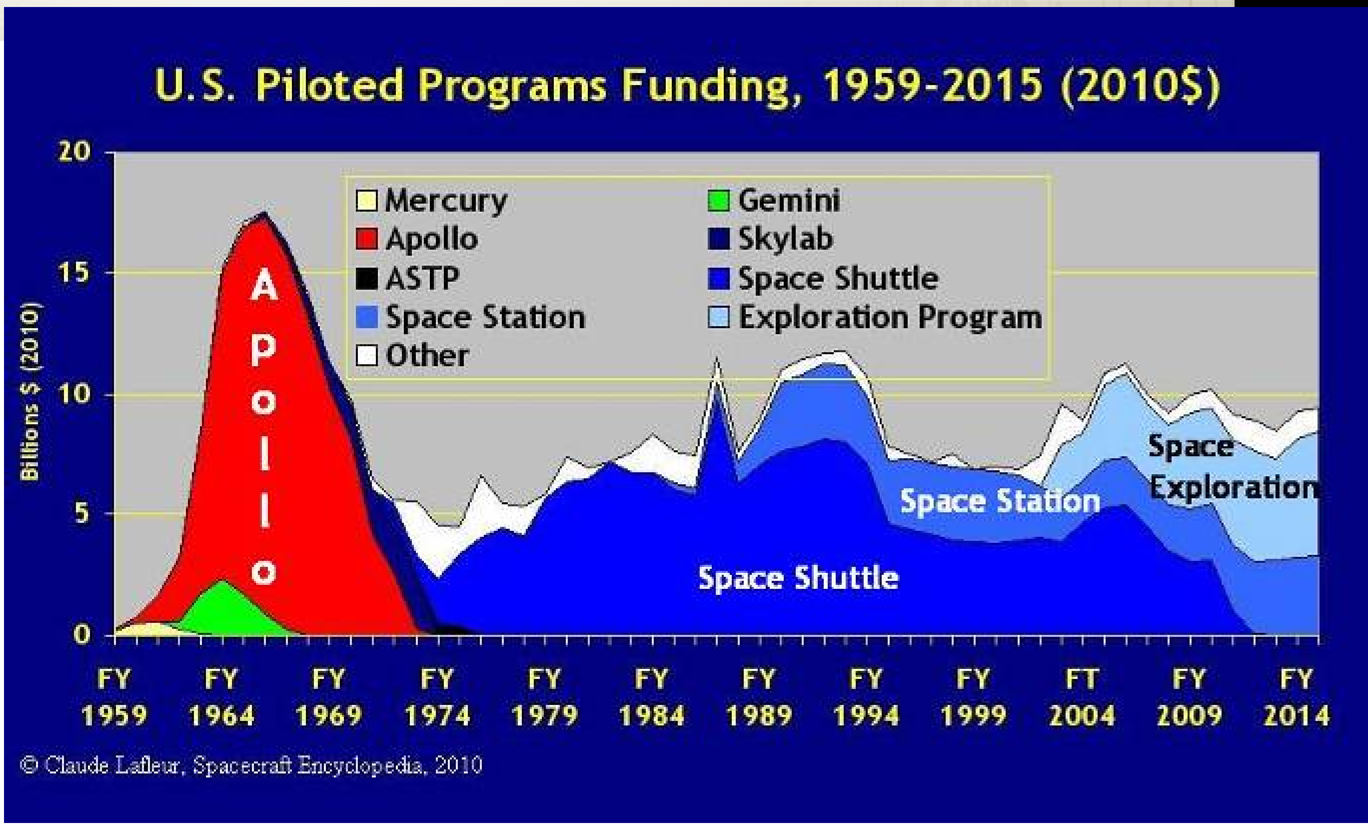
The Planetary Science Division budget has been cut substantially in recent years



Solutions:

1. **Increase the budget**
2. **Find a magical solution to do it cheaply**
3. **Proceed prudently until our austerity era ends**

Option 1: Increase Funding



The US has spent $486 billion over 57 years on human spaceflight, an average of $8.3 billion a year

- **The Planetary Program is a small fraction of the human spacecraft program in expenditures – but there is no relief in sight**

Option 2: “Magical Solution”

- **“So I call these things cargo cult science, because they follow all the apparent precepts and forms of scientific investigation, but they're missing something essential, because the planes don't land.”**
  - R. Feynman (1974)

Option 3: Continued Steady Progress

- **The reason for this study**

Study Considerations

- **Sustainable Technology Development Strategy**
  - NASA's goal for higher power, efficient systems
  - Technology and system applicability to meet the breadth of current and future mission needs
  - Conversion technology independence and dependence to nuclear source
  - Conversion technology and nuclear source independence and dependence to mission needs
  - Common component approaches
    - Conversion technologies state-of-the-art (SOA) and capabilities
    - Commonality and unique aspects of components, specifically related to the convertor, controller, and thermal systems.
    - Energy conversion architectures that aggregate smaller components to achieve larger power systems
  - Dual applicability of conversion technologies to radioisotope and fission powered systems

Study Considerations

- **Technology Capability Sustainment**
  - Continuity of safety certifications of workforce and facilities
  - Sustainment of industry and government knowledge, capabilities, skills and infrastructure
- **Programmatic Feasibility**
  - Fuel availability, quality, production, and process limitations to support future mission scenarios
  - Onramps to flight and funding sources
  - Costs, schedules and risks associated with provisioning
- **Nuclear Safety Considerations and Processing Considerations**
  - Safety analysis, safety databooks
  - Nuclear power system ground testing and shipping
  - Launch approval process

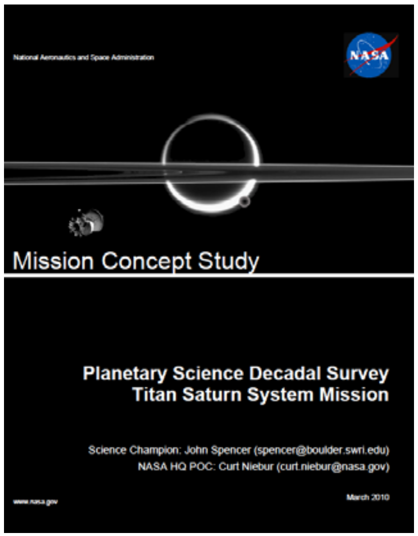
Study Considerations

- **Infrastructure Impacts**
  - Changes to current DOE infrastructure implied by nuclear power system technology and technology development strategy
  - Planning horizon required to modify DOE infrastructure to accommodate technologies and development strategy
- **Spacecraft Configuration Constraints and System Integration**
  - Power system design and redundancy considerations related to system and mission reliability
  - Spacecraft integration with nuclear power system and operation
  - Assembly, Test, and Launch Operations (ATLO) considerations including launch: launch vehicle (LV) integration, Kennedy Space Center (KSC) operations, and Radiological Contingency Planning (RCP)

Study Constraints

- **The Step 2 General Purpose Heat Source (GPHS) is the assumed, standard component for RPS systems.**
- **No changes to the NNSA, LANL, and Y-12 infrastructure to develop and fuel reactors or test fission systems**
- **NASA mission scenarios, requirements and timelines as described in the Vision and Voyages for Planetary Science in the Decade 2013-2022**
- **Consideration of potential HEOMD missions that would benefit from nuclear power technologies will be included**
  - Mars habitat
  - In-Situ Resource Utilization (ISRU)

Missions Selected for Detailed Study Drawn from Decadal

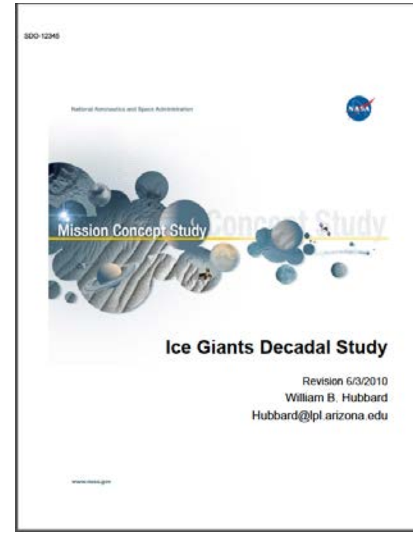


Rationale:

TSSM – high cost end; complexities could be reduced by new power supply

Ice Giants (aka UOP) - near the lower cost end and "3rd in line" for flagship

Could NEP help enable as well?



- **Technical Studies were available**
- **CATE – risk and cost estimates - were available**
- **NO CHANGE in Decadal science or traceabilty**
- **NO CHANGE in Decadal instrument complement**
- **Example results to be used to help inform issues for smaller missions as well (New Frontiers and Discovery)**
- **Selection made by Executive Council consensus**
- **Both RPS and FPS power supplies for these are under study**
- **Work is in progress**

Pu-238 Supply Project

- Solicited report from Dr. Robert M. Wham - Science Advisor for the Pu-238 Supply Project in the ORNL Fuel Cycle and Isotopes Division

The Pu-238 Supply Project to Reestablish U.S. Capability for Pu-238 Production is well Underway

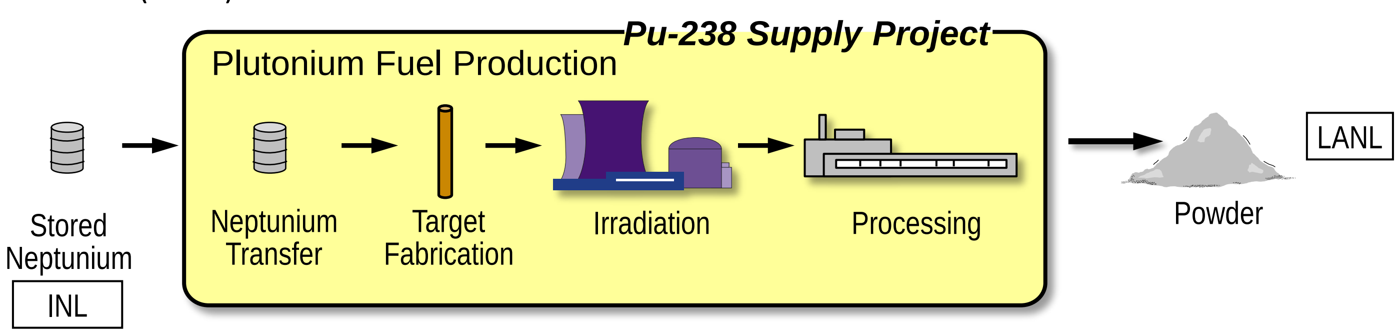
Participants	Cost	Time to complete	Outcome
• ORNL: Lead • Idaho National Lab (INL)	$86-125M (funding supplied by NASA)	7-9 years (from start in 2012)	Capacity to produce average 1.5 kg of Pu-oxide annually

Transfer of Np stored at INL to ORNL

Target fabrication and processing at ORNL Radiochemical Engineering Development Center (REDC)

Target irradiation in Advanced Test Reactor (ATR) at INL and High Flux Isotope Reactor (HFIR) at ORNL

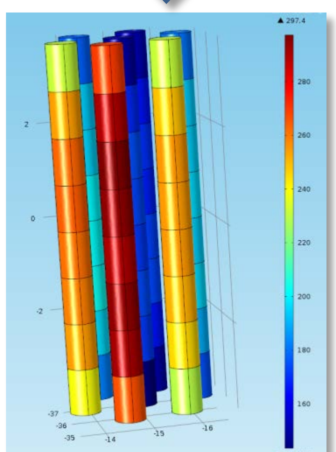
Shipment of Pu-238 to LANL for processing (TA-55)



During FY2013 Target Irradiation Has Been Scaled Up By >100X

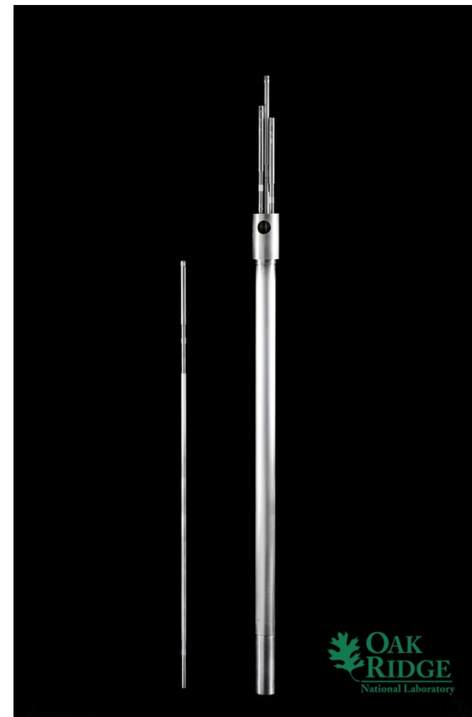
Starting with NpO_2

Single pellets were irradiated in FY2012 (~ 0.6 g NpO_2)



Multi pellet test targets were irradiated and analyzed

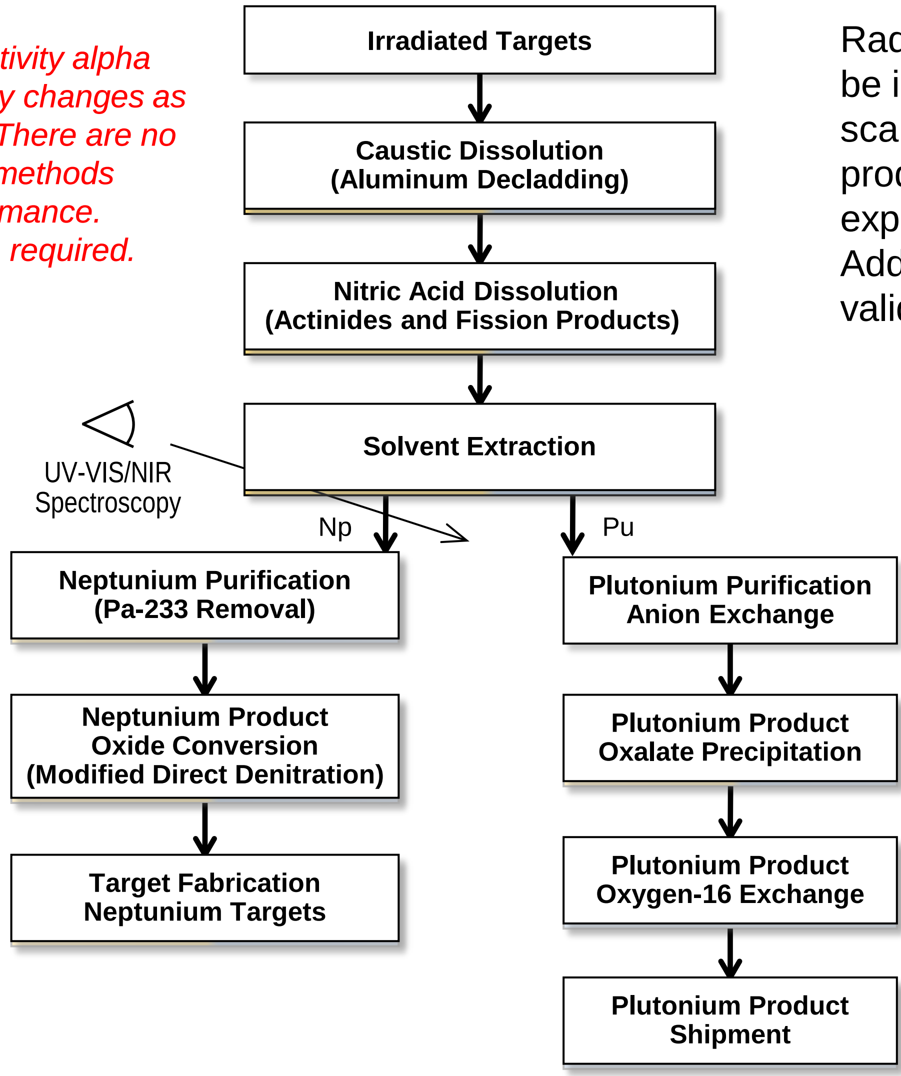
Leading to fully loaded test targets



About 450 g of NpO_2 has been irradiated at the conclusion of the May irradiation cycle

Process Chemistry of Np, ^{238}Pu Will Be Demonstrated to Ensure Delivery of 1.5 kg/year

^{238}Pu is a high specific activity alpha emitter. Process chemistry changes as concentration increases. There are no computational chemistry methods available to predict performance. Testing and validation are required.



Radiochemical separations will first be independently tested at small scale with Np, Pu and fission products then scaled up to expected production levels. Additional end to end process validation tests will be conducted.

FY 2014 Tasks Are Testing Chemical Process Steps to Recover Np/Pu

Dissolution

Target

Actinides in nitric acid solution

Can we dissolve with existing equipment?

Partitioning

Np

Pu

Fission Products

Can we partition into components efficiently?

Pu Valence

Purity

How does ORNL ensure that LANL can use new ^{238}Pu in their existing process line

How do we recycle Np into additional targets? (decontamination from Pu, Fission products)

2014-005 RMW

Questions ?