Potential Mission Applications for Space Nuclear Systems

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The Conference in Brussels
circa 1981

- The common lament among advocates was:
  - Space reactor powers systems take longer to incubate than do the missions that could use them
  - Therefore mission planners won't plan for them
  - Therefore technology funders won't fund them
  - So there you have the Catch 22 of Space Nuclear Power
- To break this paradigm, people said we would need either
  - A technology funder with a vision for the future, or
  - A high priority mission that would take longer to incubate (and cost more to develop) than the space nuclear power system it would need.

Breaking the Paradigm

My Personal Point of View

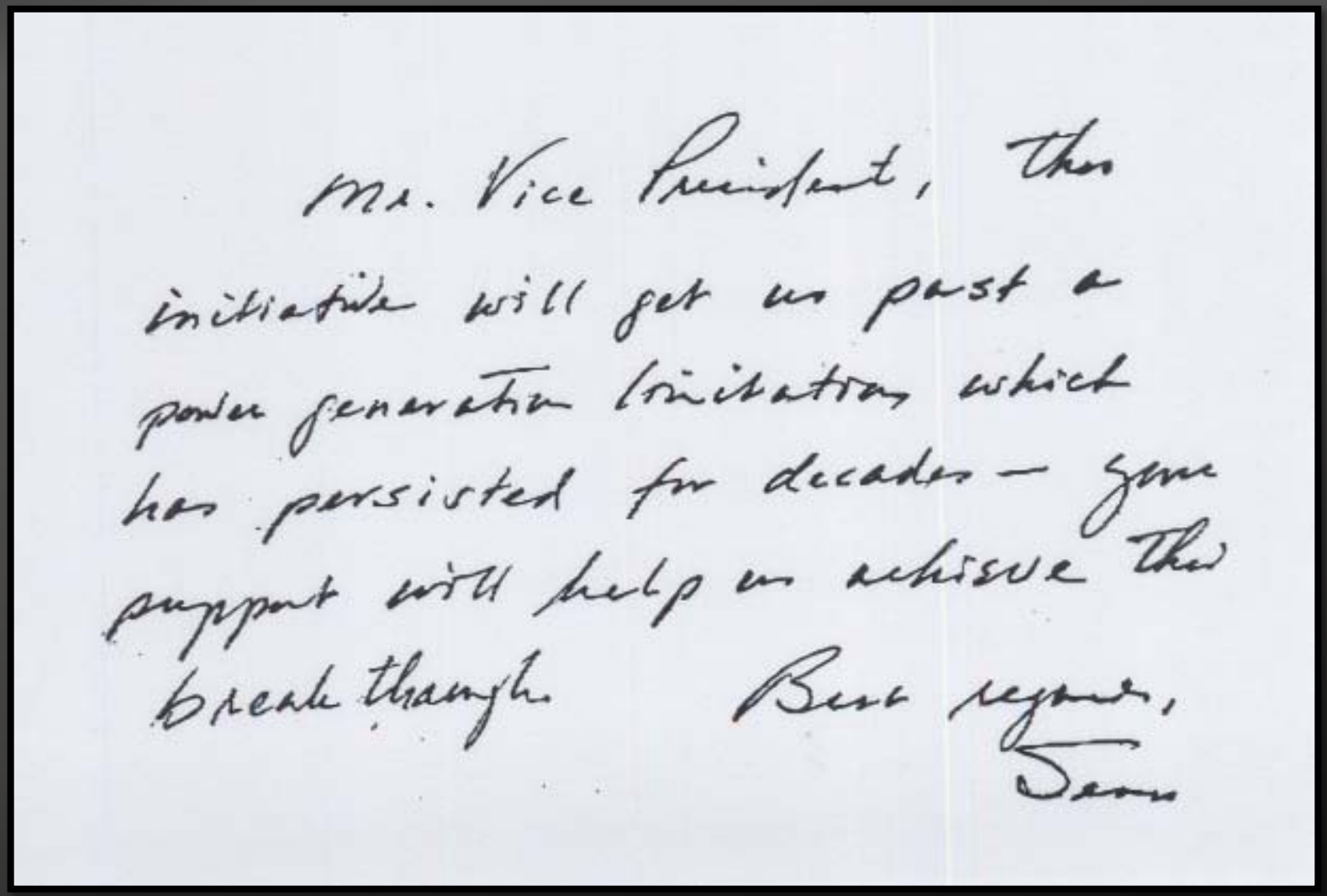
The Conference in Albuquerque
thirty years later

- For Space Exploration – not much has changed:
  - We're still using RTGs
  - except that Pu238 is scarcer and costlier, and
  - Russia no longer flies reactors
- Still no paradigm breaker – but we almost had one of each
  - A visionary: Sean O'Keefe
  - A demanding mission: Constellation

Great Space Visionaries

- In my view, the greatest were:
  - Freeman Dyson, who tried to give us Orion in the 60's - a small town to LEO
  - Gene Roddenberry, who embodied the Orion promise in Star Trek and gave us hope in the 80s
  - Sean O'Keefe, who understood that space nuclear power was a needed breakthrough and almost gave us Prometheus in the 00s.
- But only O'Keefe had the necessary wheelbase to fund the technology

Note from O'Keefe to Cheney



Mr. Vice President, This initiative will get us past a power generation limitation which has persisted for decades — your support will help us achieve the breakthrough. Best regards, Sean

Breaking the Paradigm

- The Sean O'Keefe Vision
  - Establish national capability to develop and safely deploy 200 kWe fission power systems in space for robotic exploration
  - Use resulting capability and infrastructure as stepping stone to NTP and higher power systems (e.g., 200 mWe) for human exploration
- The Demanding Mission Approach
  - Develop 6-8 X 150 mt to LEO for each Mars expedition
  - Develop 20 kt deep gravity well entry and return capability
  - Develop 40 kWe surface power station for human habitat
  - Develop NTP or VASIMIR to reduce number of launches per expedition and flight time

What Happened?

- First, Griffin found that EP development was ill-advised, given that NASA (Constellation) would need NTP before EP, and redirected Prometheus funding to Constellation.
  - The O'Keefe mantra, i.e., "Don't touch Prometheus" was quickly abandoned.
- Then Augustine found Constellation to be un-executable within the Administration's funding constraints, and thus ill-advised.
  - The Administration urged cancelling Constellation, in favor of first developing the needed technology.

The Bigger Problem

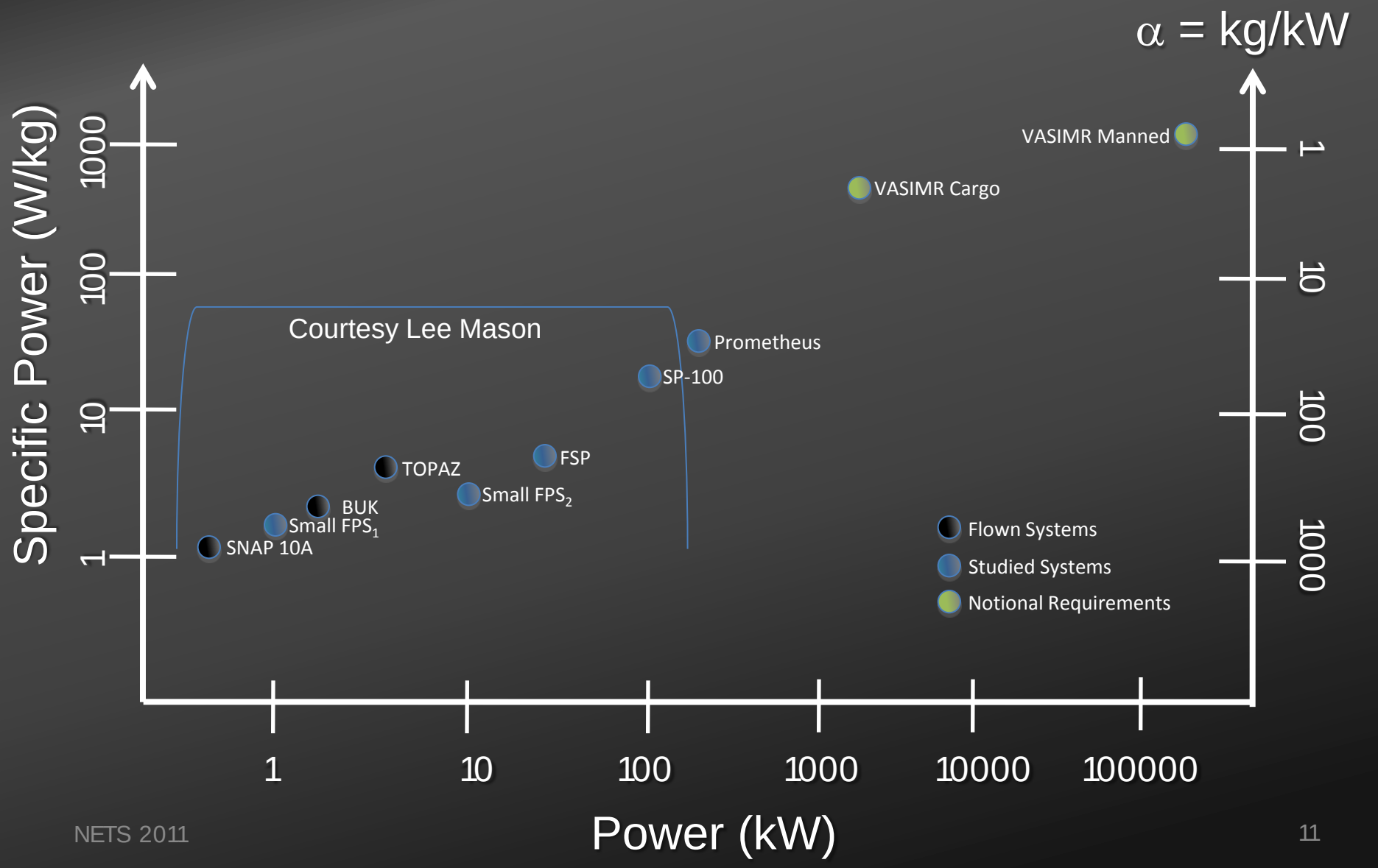
(Where Big Projects Go Wrong)

- It is a truism of space system development that architecture design and requirements development down to Level-4 or 5 is required prior to significant investment in flight hardware development in order to reasonably bound the cost and schedule.
- But this is rarely achieved on major one-of-a-kind developments. Why?
- Because major projects are politically at risk from a change in Administration or the will of Congress
- One way to insure against this, is to get the project vested quickly, i.e. start development before system engineering and requirements development is complete.

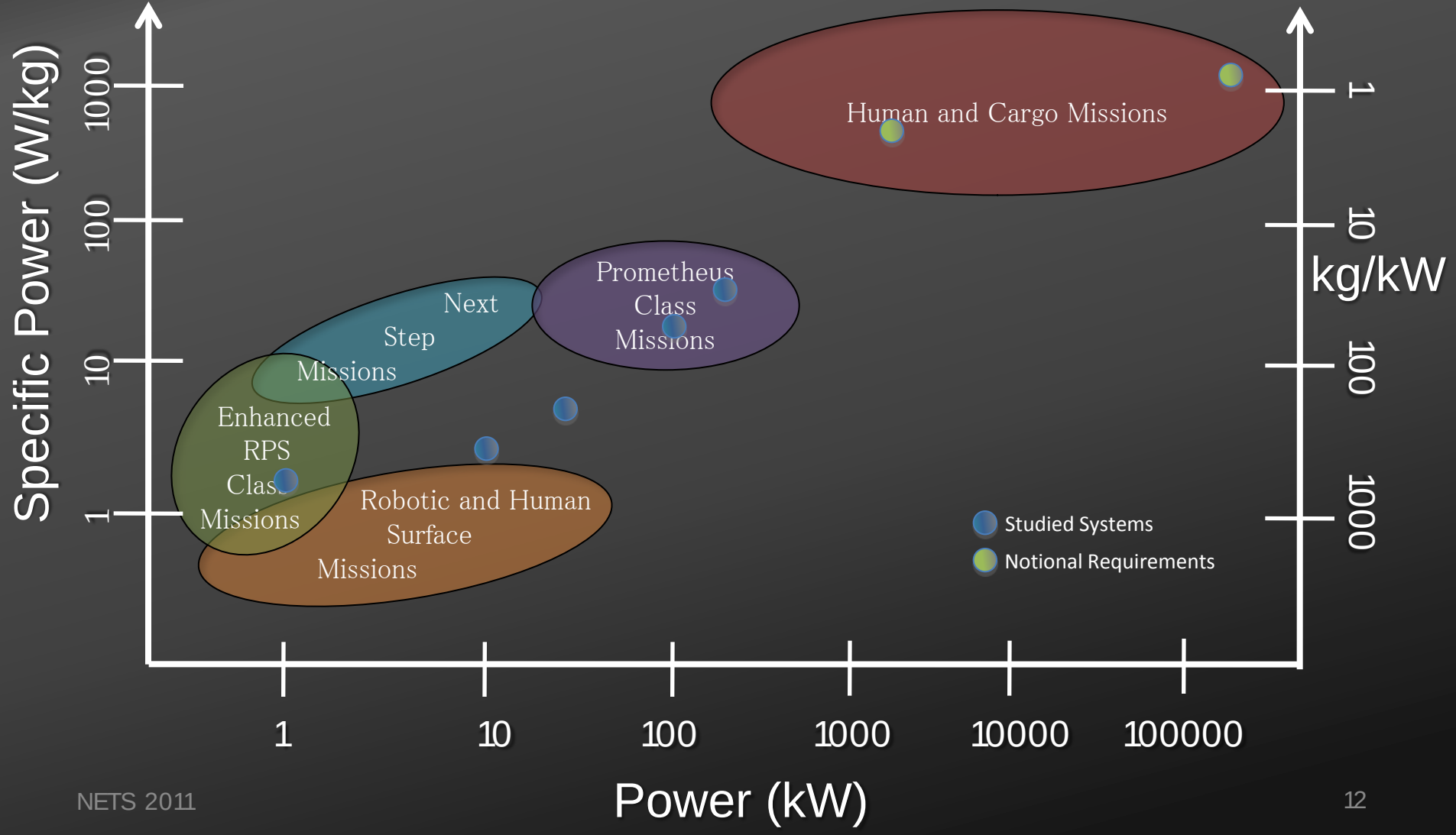
So Where Are We?

- Constellation is gone, or going - at least no deep gravity well missions in the foreseeable future, so no need for the 40 kWe FPS.
  - Will funding for it continue?
- Prometheus is gone, and not likely to get restarted absent a new visionary with longevity and deep pockets.
  - Any on the horizon?
  - Maybe a Hosi Mubarek or Prince Saud)
- Let's start with what's been done and where might it lead us.

Fission Systems



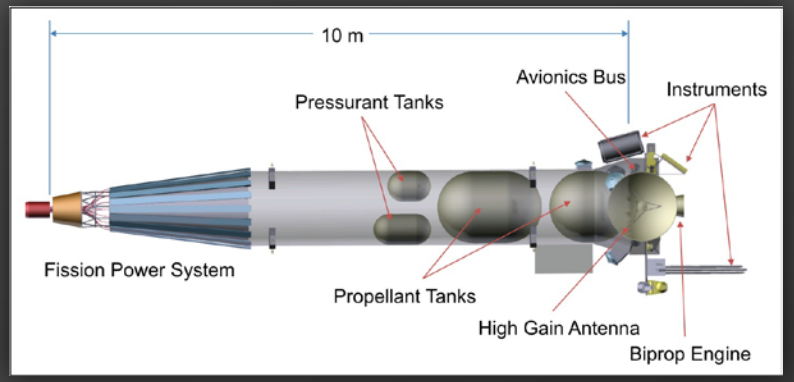
Mission Class Needs

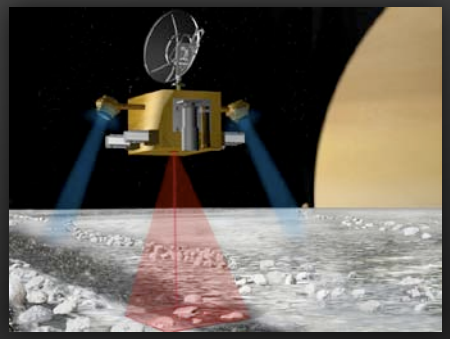


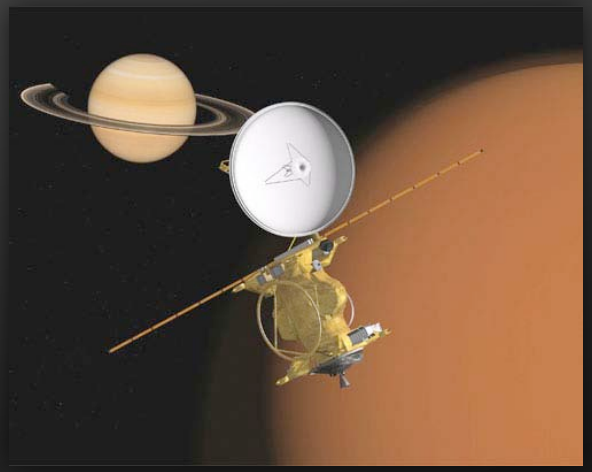
Enhanced RPS Class Missions

More Power for Instruments and RF, Smaller Antenna , Bigger Margins

- Jupiter Europa Orbiter
- Titan Saturn System Orbiter
- Saturn Ring Explorer
- Trojan System Tour

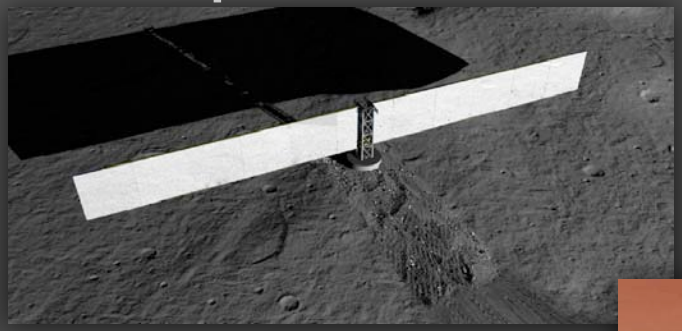




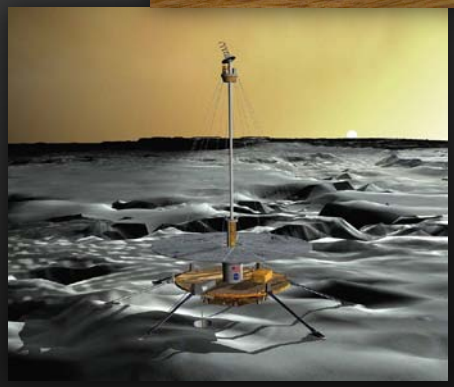


Surface Fission Systems

- In support of human exploration:
  - Lunar FSP
  - Martian FSP



- In support of robotic exploration:
  - Venus Long Term Lander
  - Mars Cryobot
  - MARGE rover

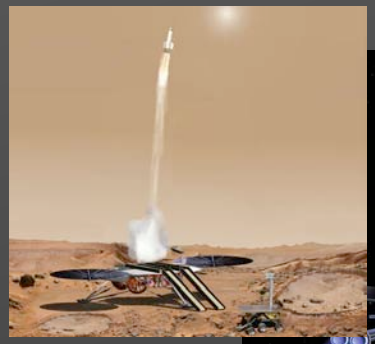


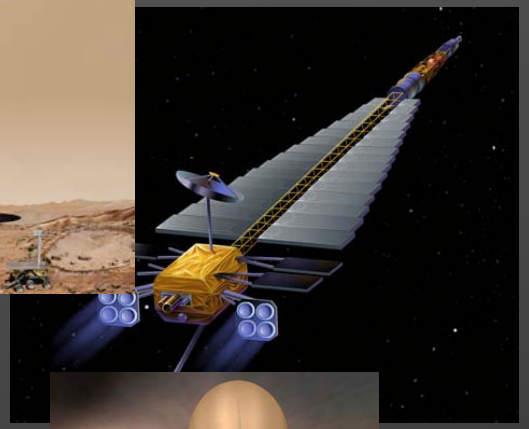
Next Step Missions
(None Studied)

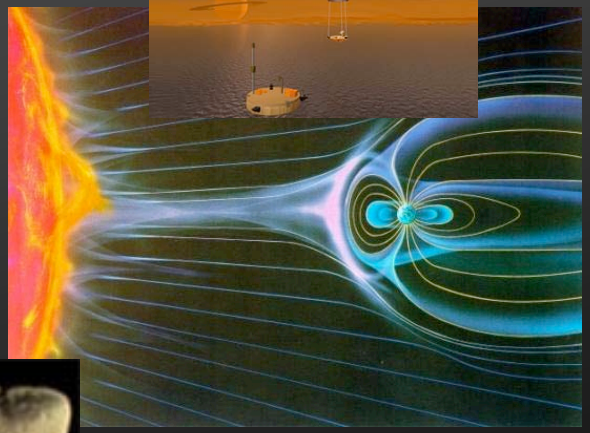
- Next step missions would use larger specific power and power output
  - Shorter trip times using EP
  - More frequent and longer launch periods
  - More flexible and efficient operations in orbital tours
  - Orbital insertion at Uranus and Neptune using EP
- Additional power at destination supports more power intensive science and data operations

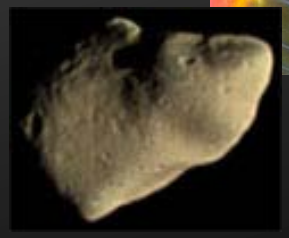
Prometheus-Class Missions

- Mars Sample Return
- Multiple Asteroid Sample Return
- Jupiter Icy Moons
- Saturn System with Titan Surface Systems
- Solar Coronal Cluster
- Interstellar Observatory (150 AU)
- Asteroid Mining/ISRU Testbed







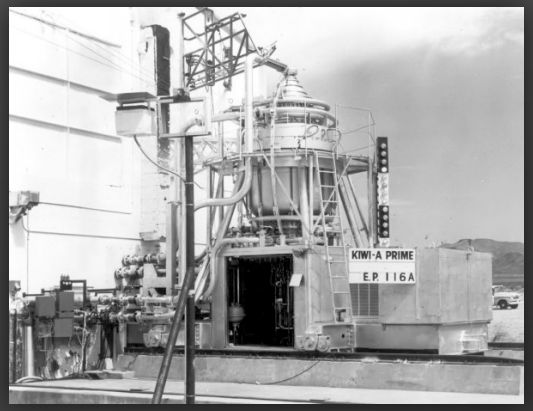


Cargo & Human Missions

- Require increasingly more power at higher efficiencies.
  - NTP may use ~50-5000 MW_{th}
  - 3-4 month VASIMR missions to Mars require ~ 10 MWe
  - 40–50 day VASIMR missions to Mars require ~100 MWe

Nuclear Thermal Propulsion

- Several systems have been developed over the course of decades but never flown
  - Peewee – 500 MW_{th}
  - KIWI – 70-990 MW_{th}
  - Phoebus – 5000 MW_{th}



- Mars DRA-5 used Peewee type reactor for NTP trades
- Environmental concerns today are a much greater driver to test facility costs and activities

VASIMR and Other NEP

- VASIMR, or other high power EP systems, require high specific power (low α) fission power systems

- Cargo Transfer
  - α = 3–4 kg/kW
  - 12–18 MW_e
  - 90–120 day travel time

- Human Transfer
  - α =0.75–1.25 kg/kW
  - 200 MW_e
  - 40–50 day travel time

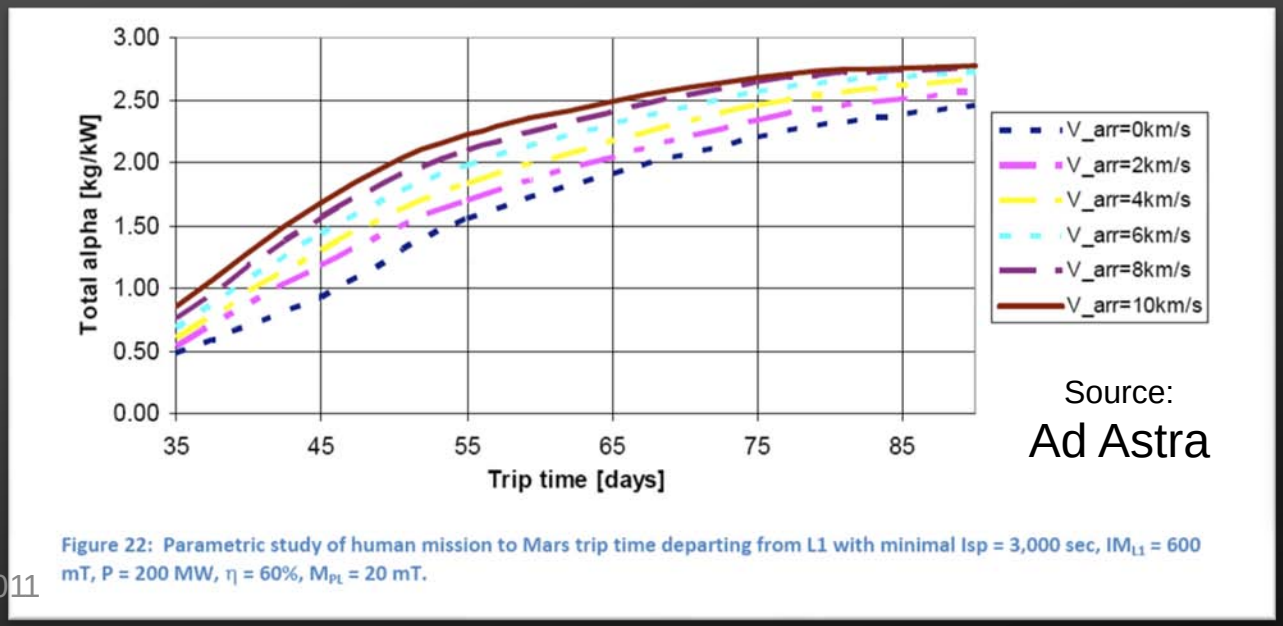
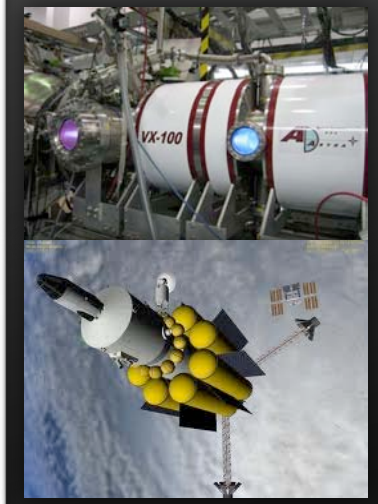


Figure 22: Parametric study of human mission to Mars trip time departing from L1 with minimal Isp = 3,000 sec, IM_{L1} = 600 mT, P = 200 MW, η = 60%, M_{PL} = 20 mT.

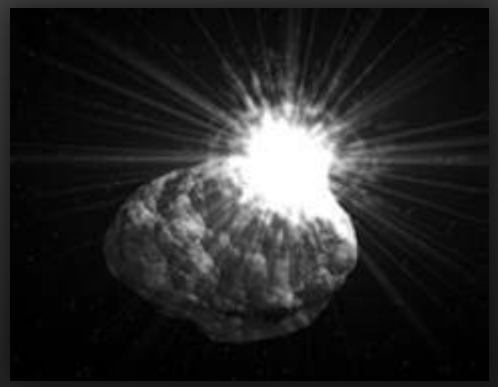
Source:
Ad Astra



Apophis Deflection

(A 200 m Asteroid)

- A Gravity tractor with 10 NEXIS engines will impart <5 mm/s in 10 years
- A space tug with 14 NEXIS engines will impart >5 cm/s in 10 years
- A Stand-off Nuke Detonation can impart >1 m/s in an instant



The Radioisotope Conundrum

- Pu fuel is
  - expensive, >$3M per kg
  - difficult to manufacture and process
  - in high demand with one supplier and few users
  - inherently hazardous
- Uranium fuel is
  - much cheaper - $2500 per kg
  - a commodity item – readily available
  - in high demand with many suppliers and users
  - inherently safe

Today

- We’re still in the same boat we were 30 years ago
- Will we follow the Augustine advice and take the time to develop the technology before mounting an all out assault on the deep gravity wells in our vicinity?
- And finally there is the Pu238 conundrum.
  - Spiraling fuel cost
  - Safety driven operational and logistic costs
  - Which leaves us with limited access to the outer plants.

Conclusion

O’Keefe Had It Right:

The Next Major Step In Space Exploration
Is Going To Require
Space Nuclear Power