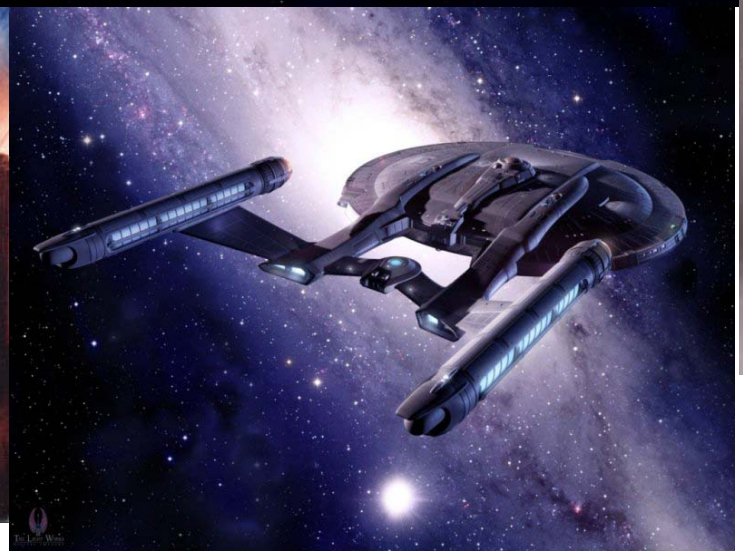
Powering Space Exploration

James Werner
Space Nuclear Systems & Technology Division
July 13, 2010

www.inl.gov
Idaho National Laboratory

BUCK
ROGERS
IN THE 25TH CENTURY
THE COMPLETE EPIC SERIES



Energizer

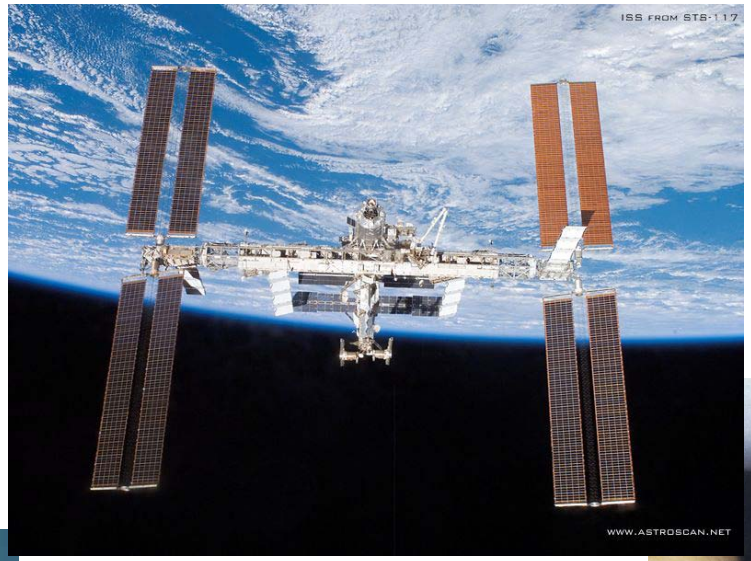
USA
NASA

The Physical Problems of Space Travel

- Large Distances
  - If the Moon were and inch from the Earth, Mars would be 14 feet away at closest approach
- Limited Energy
  - Incident solar energy
  - Carry it with you
- Harsh Environment
  - Galactic Cosmic Rays / Solar Flares
  - Frigid temperatures / Intense temperatures
  - No atmosphere

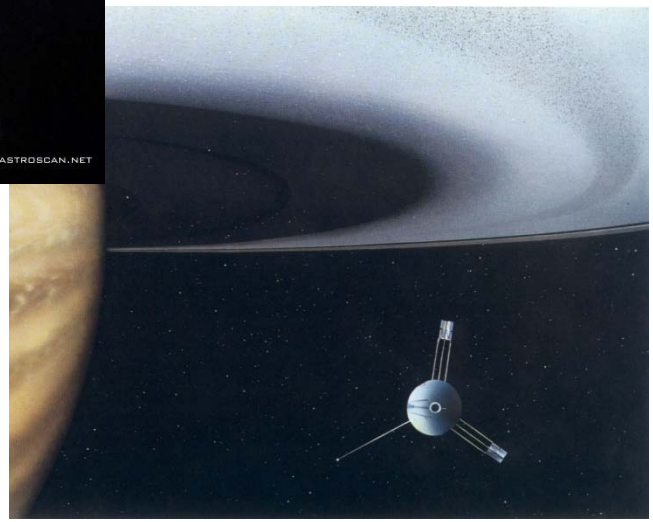
Types of Spacecraft Power

Chemical



Mechanical

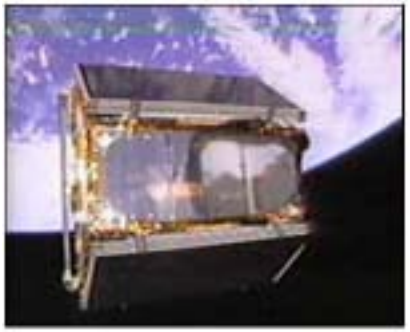
Solar

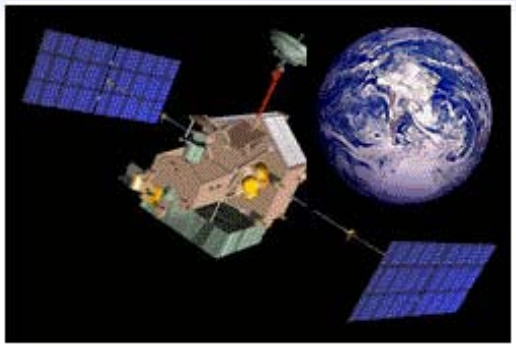


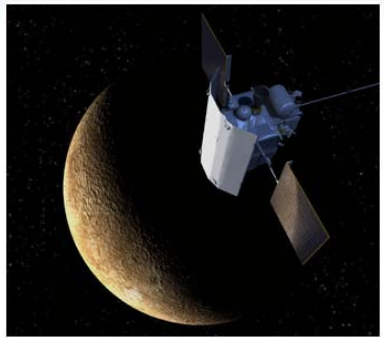
Nuclear

Sources: <http://powerweb.grc.nasa.gov/pvsee/>; <http://space-power.grc.nasa.gov/ppo/projects/flywheel/img/honeywell-facets-module.jpg> <www.grc.nasa.gov/WWW/RT1999/5000/5420manzo.html>; <www.utcfuelcells.com/space/spaceshuttle.shtm>; NASA SP-446

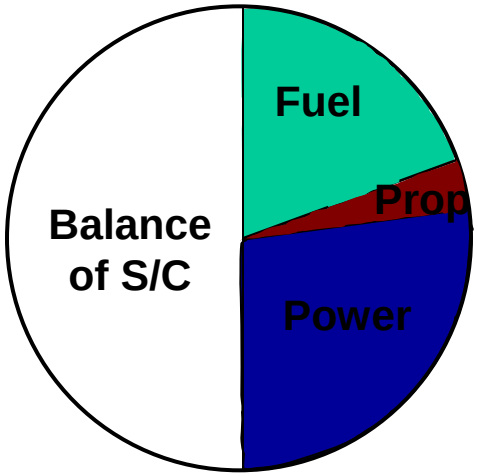
Power and Propulsion Mass Fractions for Different Classes of Spacecraft



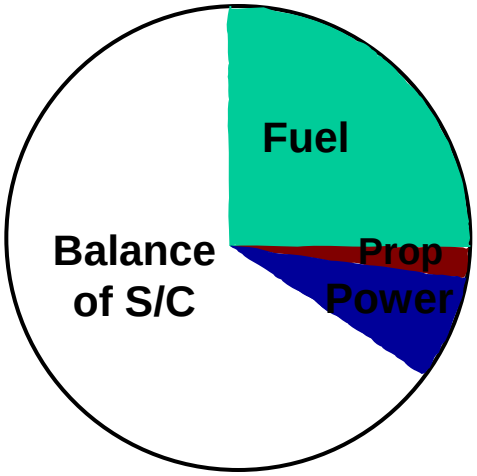




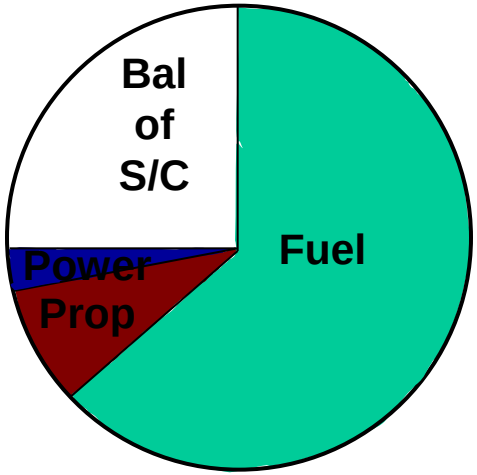
Communications



Earth Sensing



Interplanetary



NOTE: Not to scale

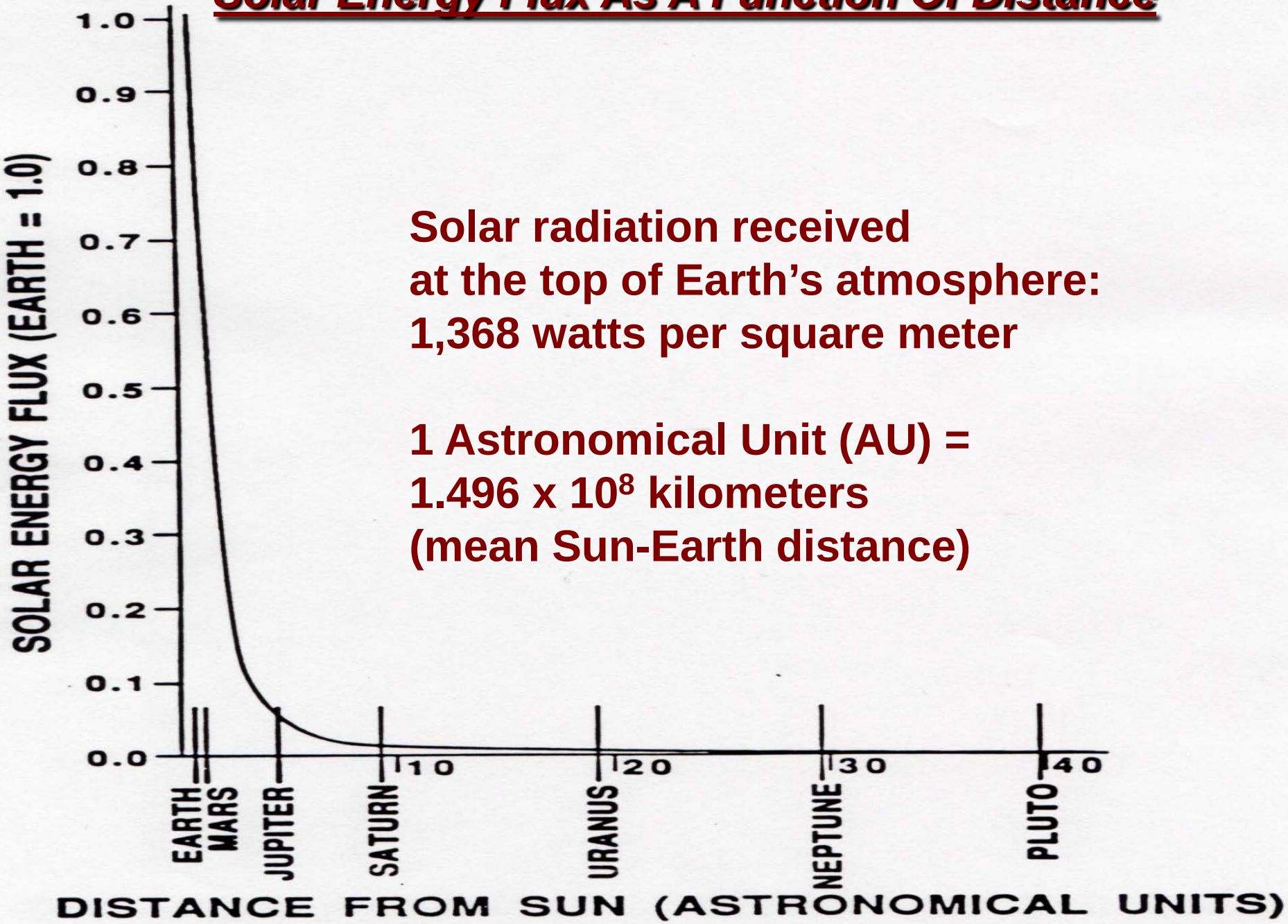
1. Globalstar (450 kg initial mass)
2. TRMM (2730 kg dry mass; 3.4 kWe array BOL)
3. Mercury Orbiter (744 kg dry mass; 420 We array BOL)

Source: NASA/GRC, July 1999

Spacecraft

1. Globalstar (http://www.globalstar.com
2. Tropical Rainfall Measuring Mission (TRMM) (http://trmm.gsfc.nasa.gov)
3. Mercury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) (http:// messenger.jhuapl.edu)

Solar Energy Flux As A Function Of Distance



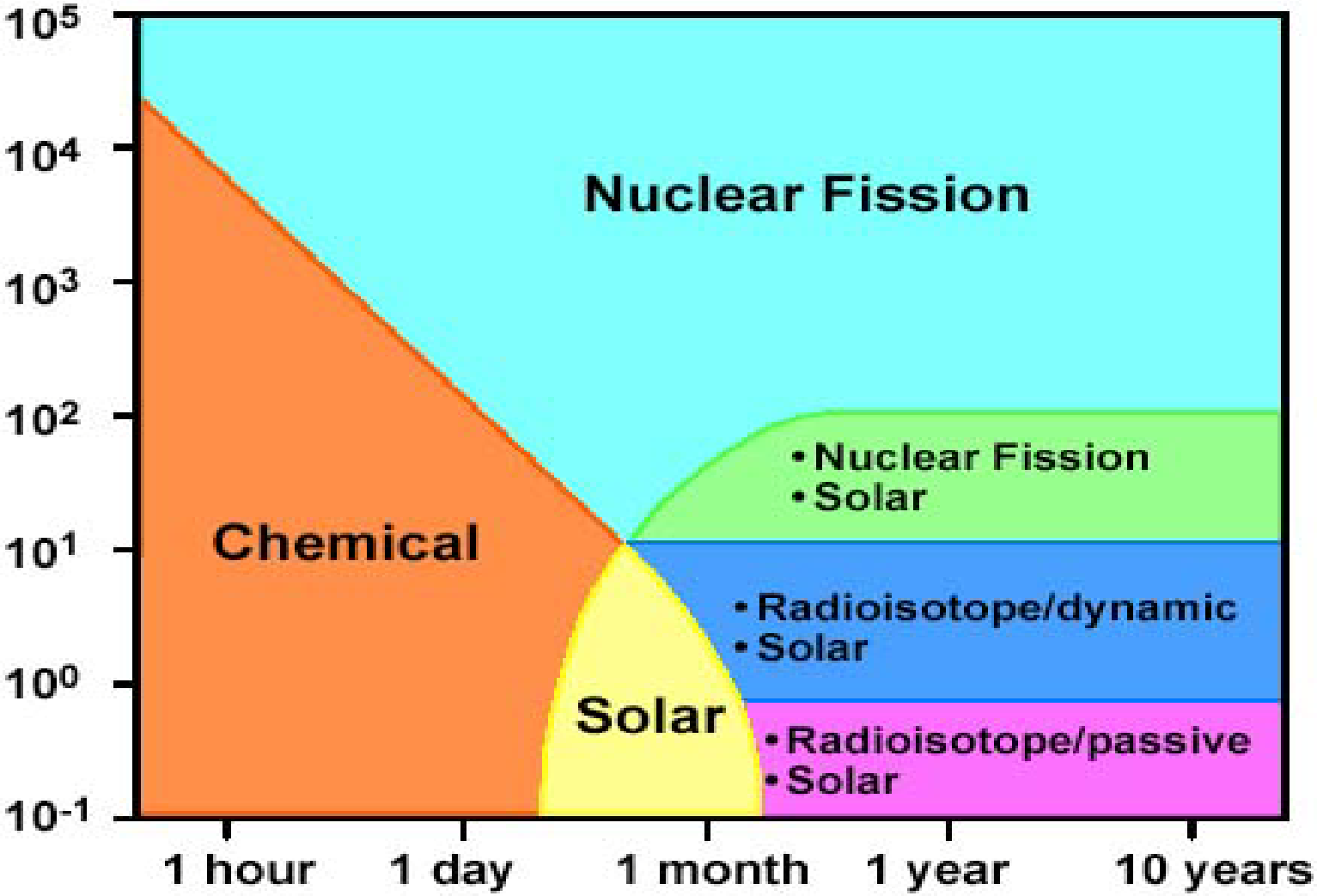
Solar radiation received at the top of Earth's atmosphere: 1,368 watts per square meter

1 Astronomical Unit (AU) = 1.496×10^8 kilometers (mean Sun-Earth distance)

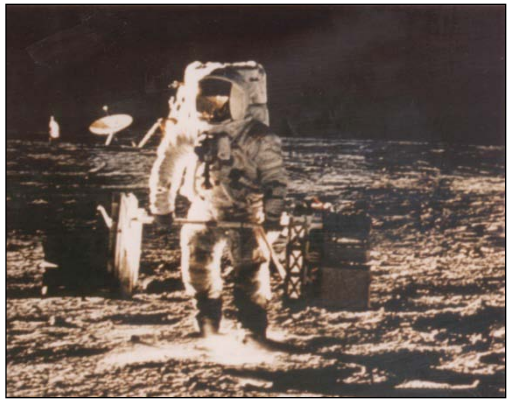
Comparisons of Power Sources

Storage Type	Specific energy (MJ/kg)
Deuterium-tritium fusion	576,000,000
Uranium-235	144,000,000
Pu-238 α-decay	2,200,000
TNT	4.61
Hydrogen peroxide decomposition (as monopropellant)	2.7
battery, Lithium ion nanowire	2.54
battery, Fluoride ion	1.7

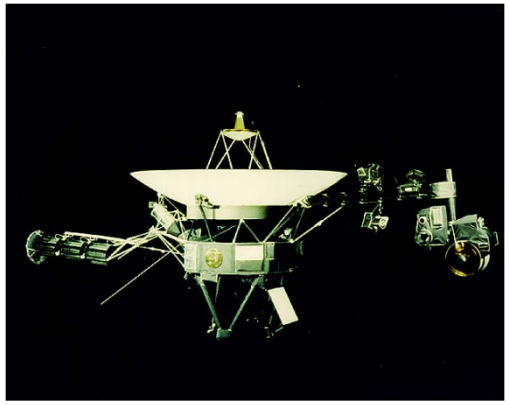
Qualitative Regions of Applicability



Missions That Use Nuclear Power Systems

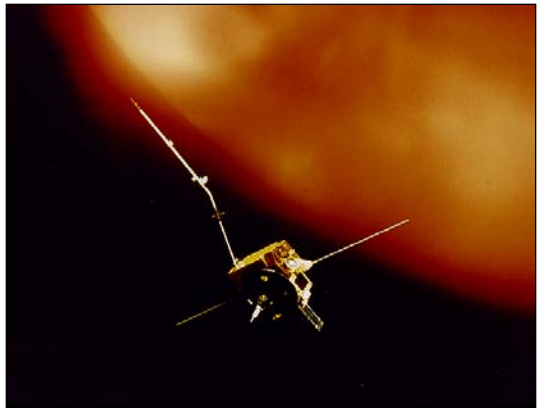


Apollo

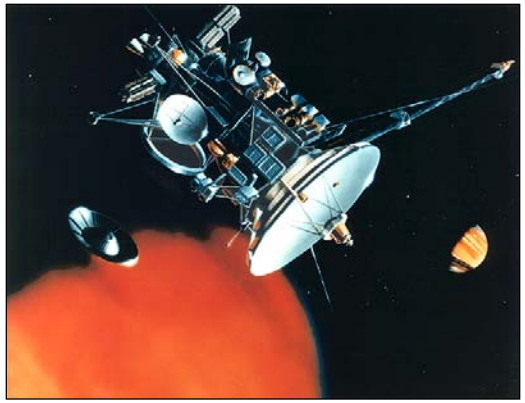


Voyager

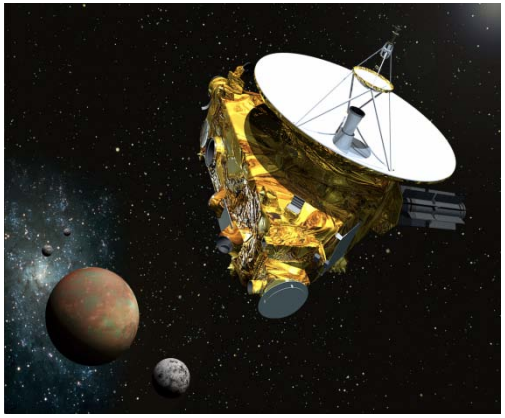
Galileo



Ulysses



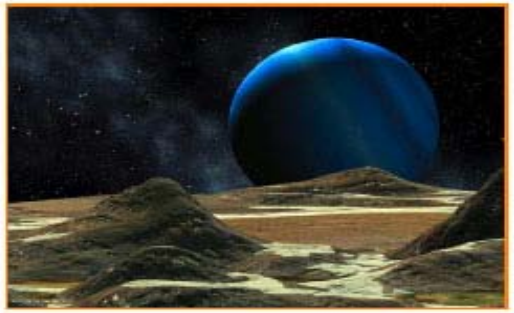
Cassini



Pluto New Horizons

A Whole Universe Awaits Us

PROJECT PROMETHEUS
Potential Future Destinations



Neptune and its Moons

Saturn and its Moons

Kuiper Belt Region

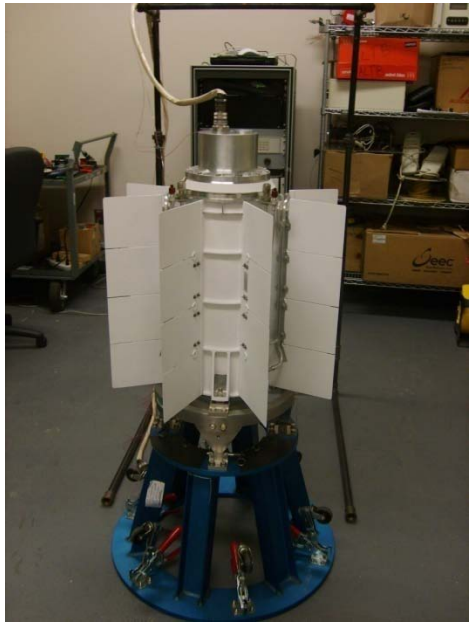
Interstellar Space

Pre-Decisional – for discussion purposes only

How Can We Use Nuclear in Space?

1. **Radioisotope Thermoelectric Generators (RTGs)**
   - Use Plutonium-238 (non-weaponizable)
   - First used in 1961
   - New Horizons to Pluto is most recent
2. **Radioisotope Power Systems (RPS)**
   - Use Plutonium-238 (non-weaponizable)
   - Use Sterling Power conversion
3. **Fission Surface Power**
   - Required for manned mission to Mars
4. **Nuclear Thermal Rockets (NTR)**
   - NASA's Preferred method for human mission to Mars – 2007 study

Comparison of MMRTG and GPHS-RTG

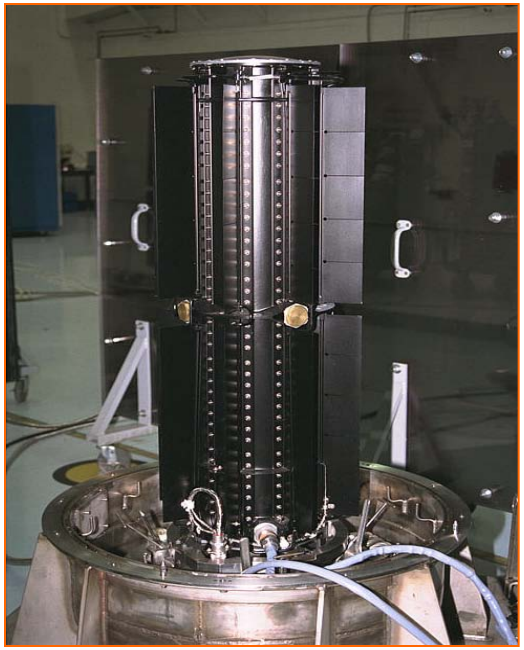


MMRTG

- MSL (1)
- BOM Power (2009) 123 W_e
- Efficiency ~ 6.2%
- Modules 8
- Mass 97 lbs
- Length 2 ft
- Fin tip-to-tip diameter 2 ft
- Launch Window Fall 2011

GPHS-RTG

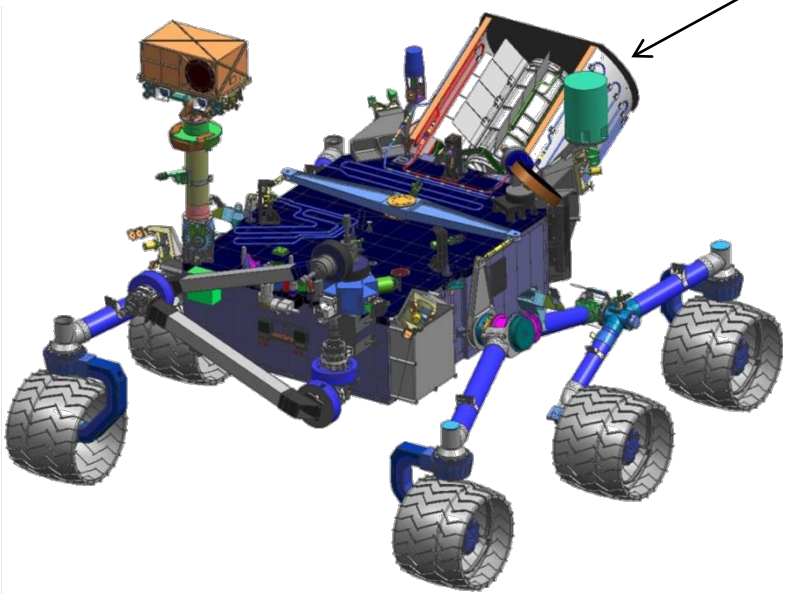
- Galileo (2), Ulysses (1),, Cassini (3) & Pluto New Horizons (1)
- BOM Power (2006) 250 W_e
- Modules 18
- Mass 127 lbs
- Length 4 ft
- Fin tip-to-tip diameter 1.5 ft
- Pluto New Horizons Launched Jan 19, 2006

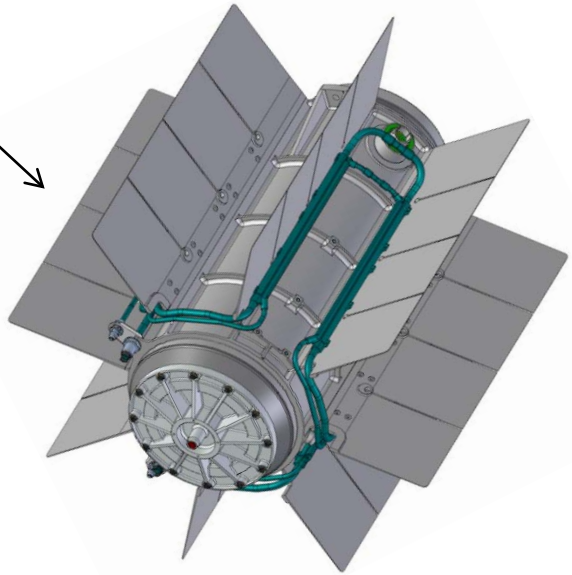


The Next INL Space Battery

- **Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)**
- **INL will Fuel & Test**
- **Instruments and Mobile Platform Powered by the MMRTG**

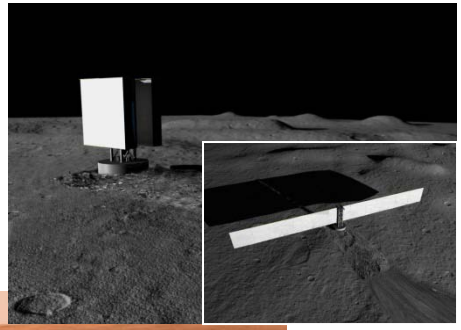
MMRTG

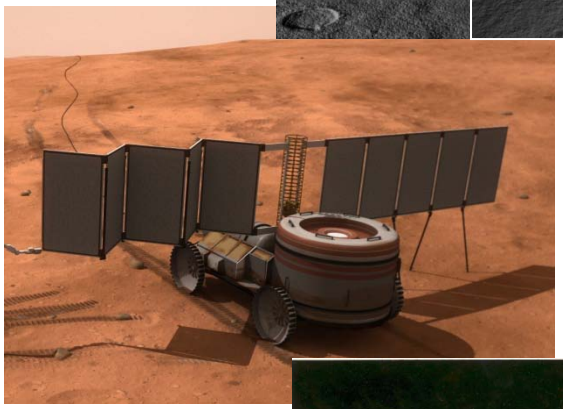


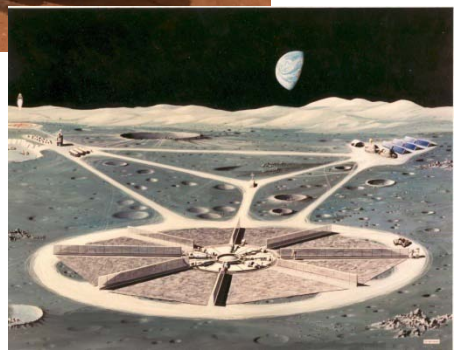


Why Fission Surface Power?

- Continuous day/night power for robust surface operations
- Suitable for any surface location
- Environmentally robust
- Operationally robust
- Highly flexible configurations
- Safe during all mission phases
- Scalable to higher power levels
- Performance and cost advantages compared to alternatives
- Synergistic with other technology development activities

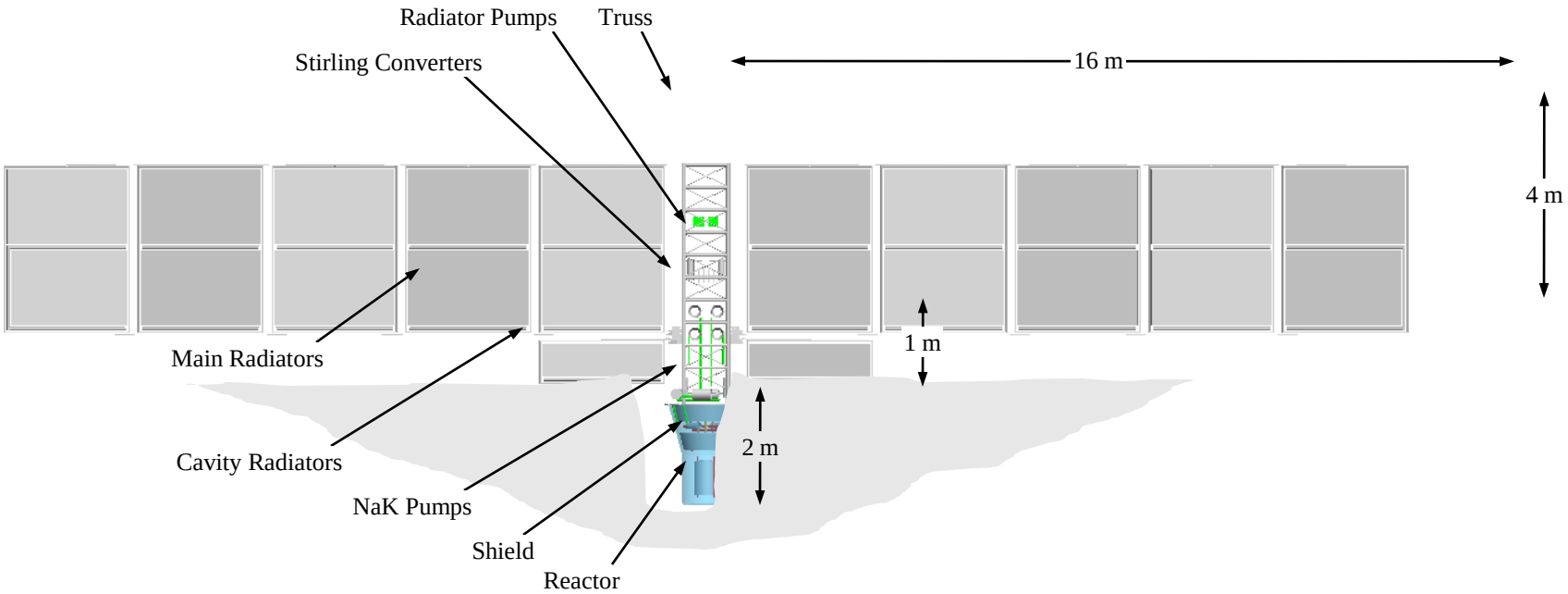




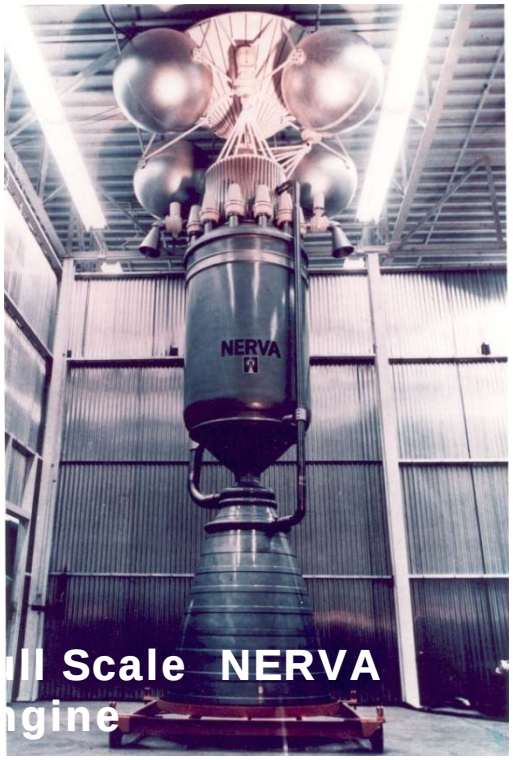


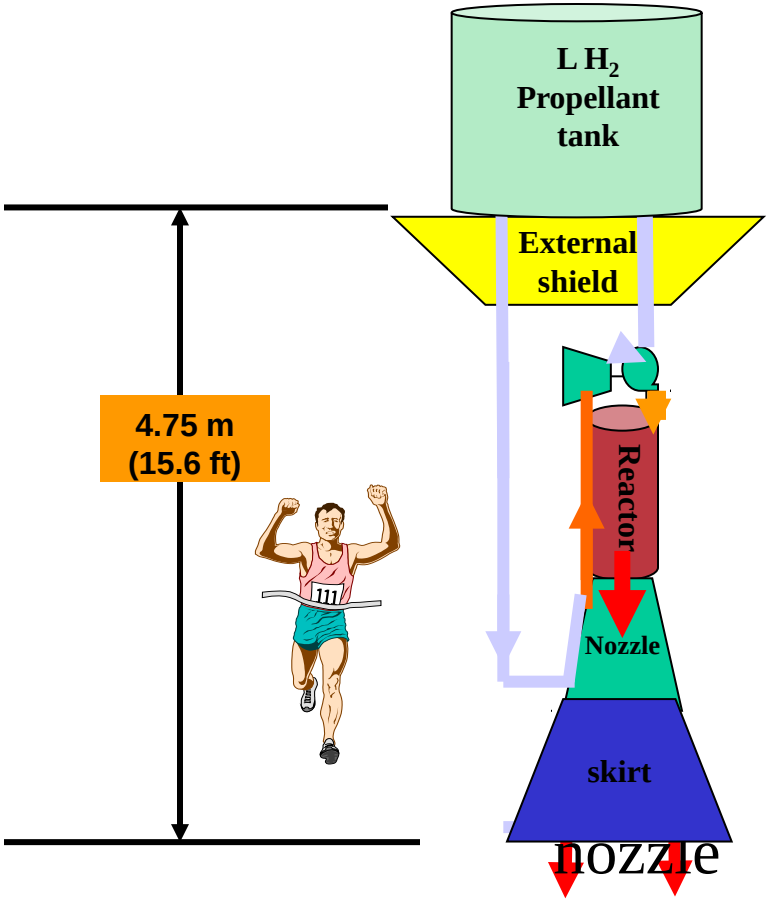
Fission Surface Power Reference Concept

- Modular 40 kWe system with 8-year design life
- Emplaced configuration with regolith shielding augmentation permits near-outpost siting (<5 rem/yr at 100 m separation)
- Low development risk, liquid-metal (NaK) cooled reactor with UO_2 fuel and stainless steel construction

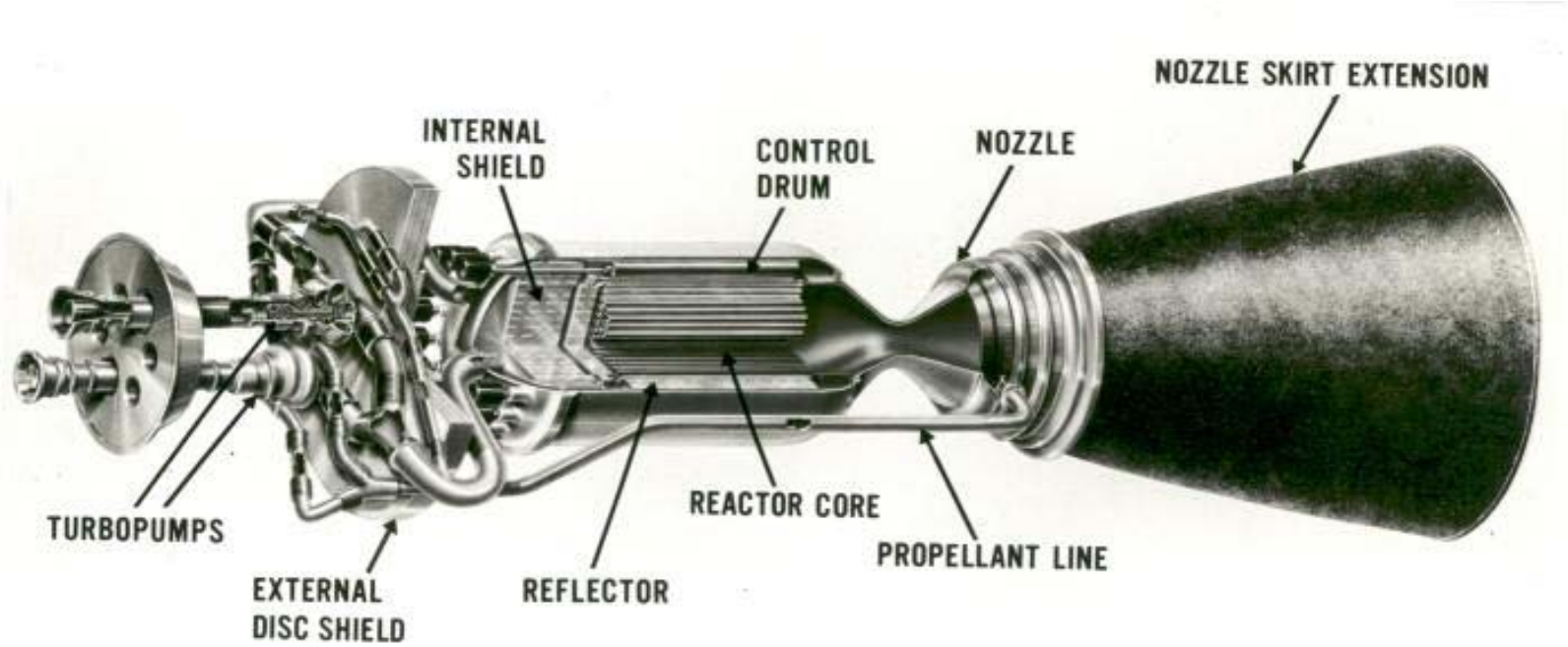


Nuclear Thermal Propulsion





NTR Design


NOZZLE SKIRT EXTENSION
INTERNAL SHIELD
CONTROL DRUM
NOZZLE
TURBOPUMPS
REACTOR CORE
PROPELLANT LINE
EXTERNAL DISC SHIELD
REFLECTOR

Benefits of the NTR Have Been Shown for Several Missions

- **Moon - Reduce costs of implementing a Lunar Outpost**
- **Mars - Faster missions for humans; reduced radiation exposure; lower costs for cargo; adaptability to hazards**
- **Good Asteroid - rendezvous**
- **Bad Asteroid/comet - rapid interception**
- **Outer solar system – time to "first science" within a decade for orbitor missions to outer planets and to Kuiper Belt fly-through**

In short, the NTR opens up access to the entire solar system for humans and robotic probes

Mars Hopper Concept

- Low-power radioisotope decay heat is accumulated into a "thermal capacitor" material

- During the core heating stage, sufficient power is drawn off to run a compressor that liquefies the Martian atmosphere and refills a tank

- The heat is then dumped into the propellant in a short interval for high-power propulsion

Summary

- Nuclear technologies have been used in the US space program from the beginning
- INL is an integral team member in designing and providing nuclear power sources
- Most missions to and beyond Mars have been enabled by RTGs
- Fission power has 10 million times the energy per kilogram as chemical systems
- Nuclear rockets could enabled a human mission to Mars to be completed within 500 days total
- Even including developmental costs, NTR is cheaper than chemical rocket system
- Fission power will be required for the surface of Mars for human support