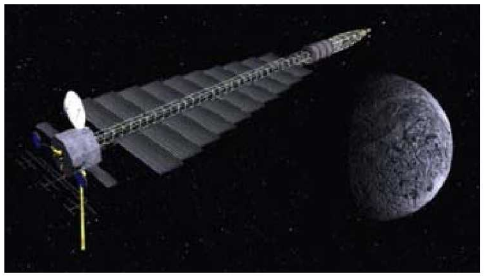
NASA Missions Enabled by Space Nuclear Systems

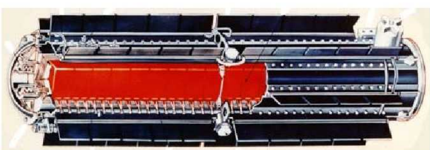
John H. Scott
Chief, Energy Conversion Branch
NASA Lyndon B. Johnson Space Center/EP3
Houston, TX 77058 USA
281.483.3136
John.h.scott@nasa.gov

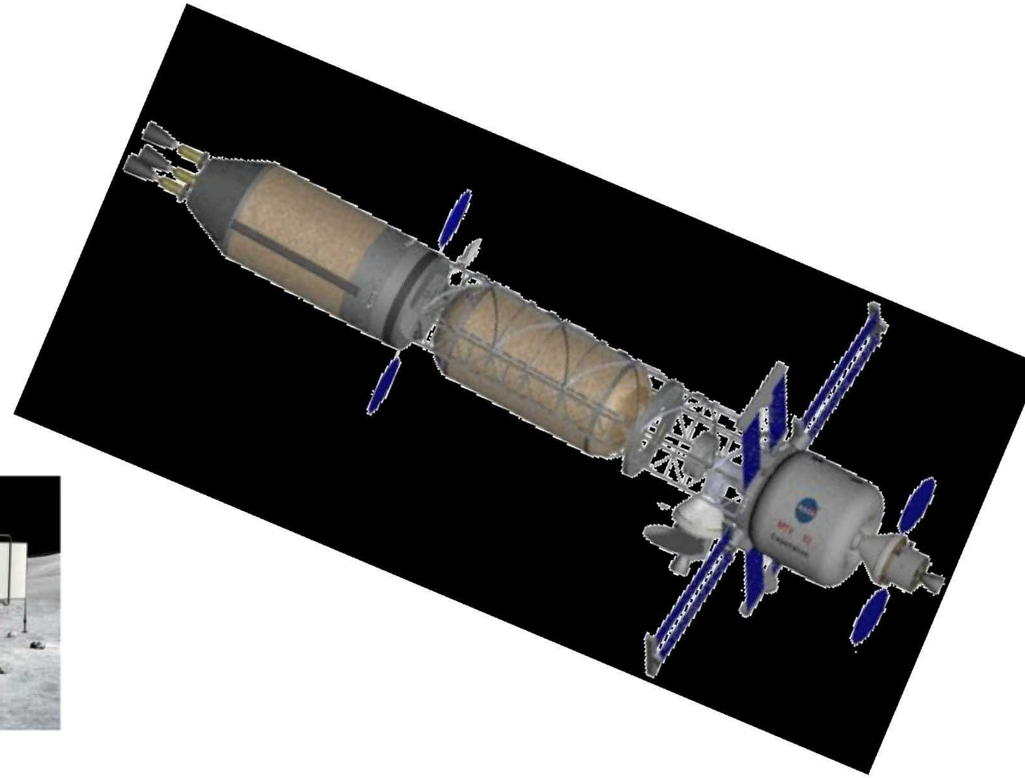
George R. Schmidt, PhD, PE
Deputy Director, Research and Technology
NASA Glenn Research Center, M.S. 3-5
21000 Brookpark Rd.
Cleveland, OH 44135
216.433.3944
george.schmidt@nasa.gov

Space Nuclear System Applications

Lyndon B. Johnson
Space Center







Electric Power Generation

Thermal Propulsion

Commercial/Military Electric Power Systems:

- Development, Production & Operation Cost ($/kW)
- Specific Power/Energy (kW/kg, kWh/kg)
- Emissions (NO_x, CO_x, noise)
-

PUBLIC SAFETY

John H. Scott NASA/JSC/EP3 Houston TX 77058 USA, (281) 483-3136, john.h.scott@nasa.gov

Spacecraft Power Systems:

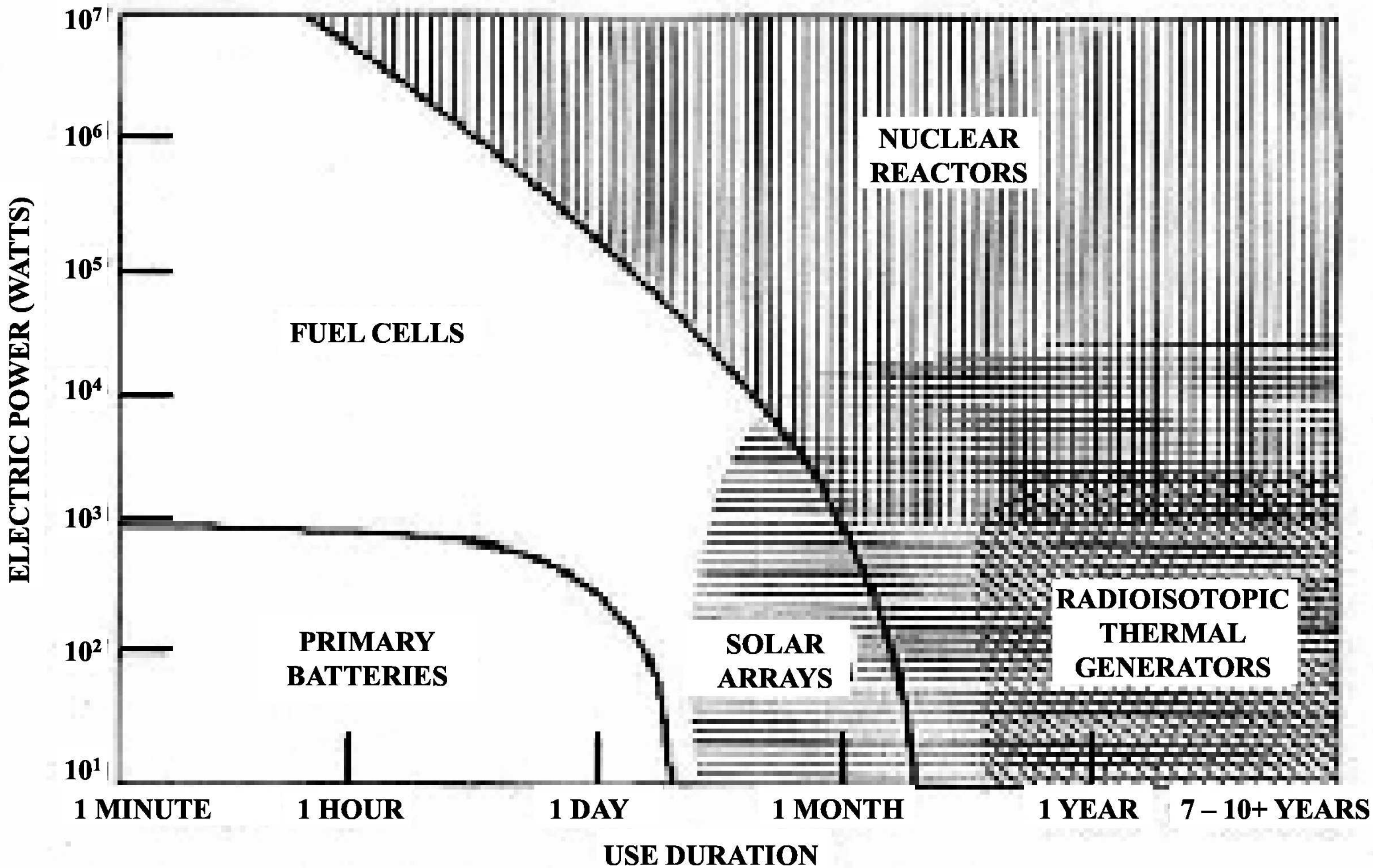
- Specific Energy (kWh/kg)
- Specific Energy (kWh/kg)
- Specific Energy (kWh/kg)
- Development Cost

FULL MISSION RELIABILITY

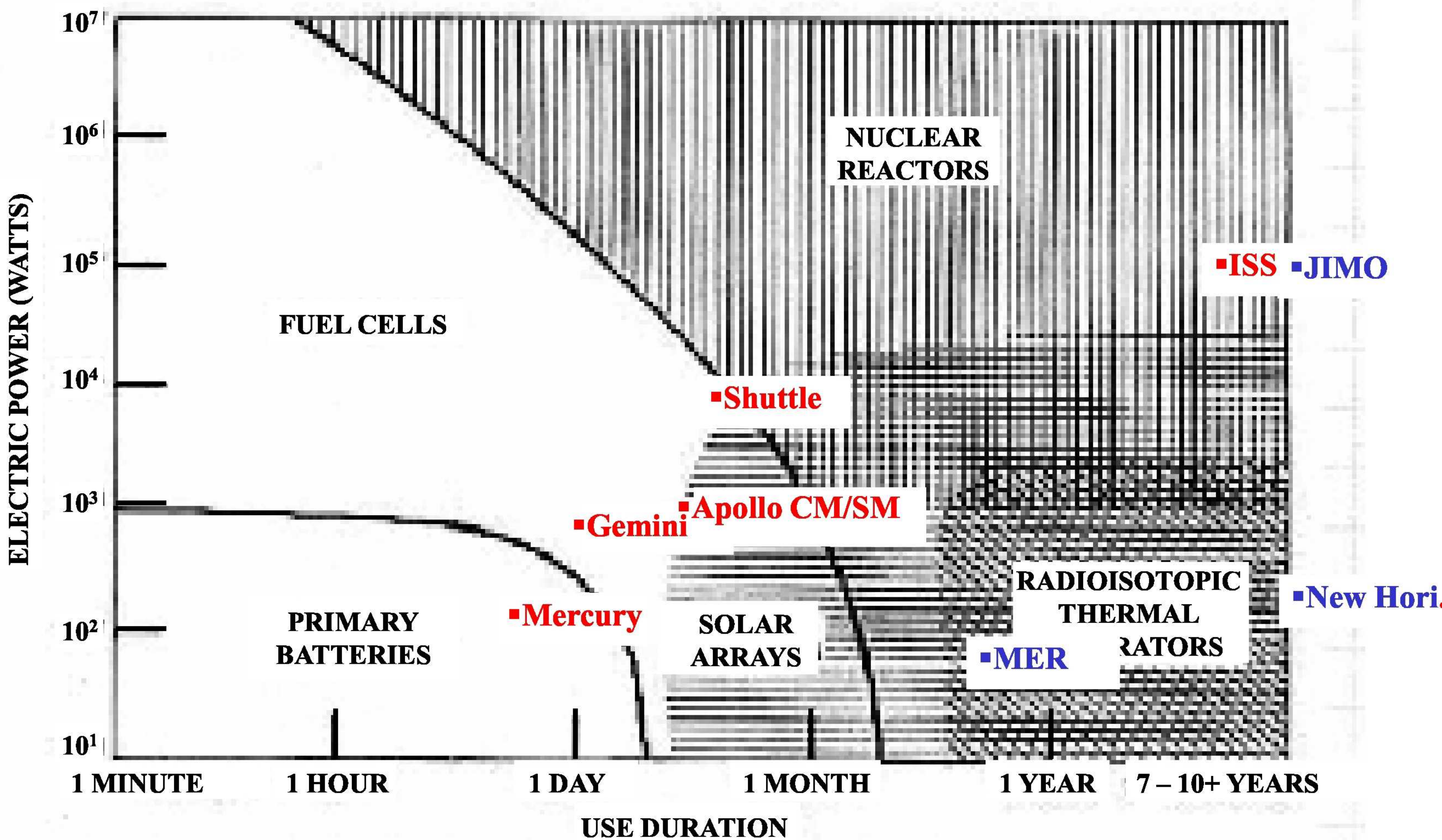
John H. Scott NASA/JSC/EP3 Houston TX 77058 USA, (281) 483-3136, john.h.scott@nasa.gov

Power Generation Specific Energy Trade Space

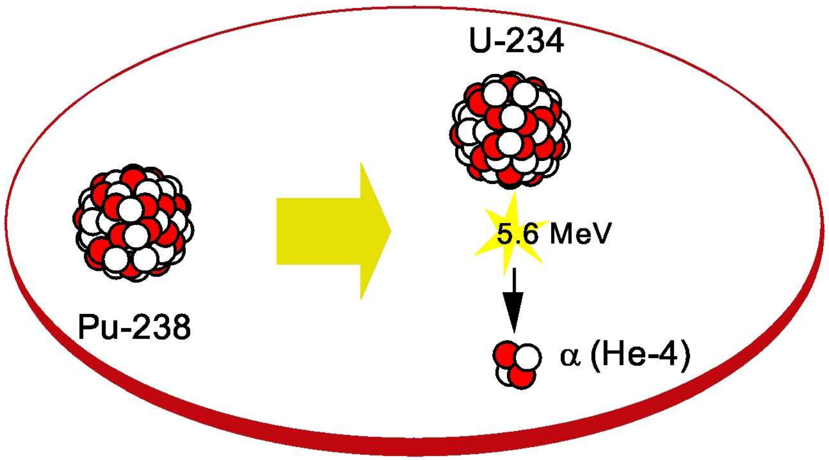
Lyndon B. Johnson
Space Center



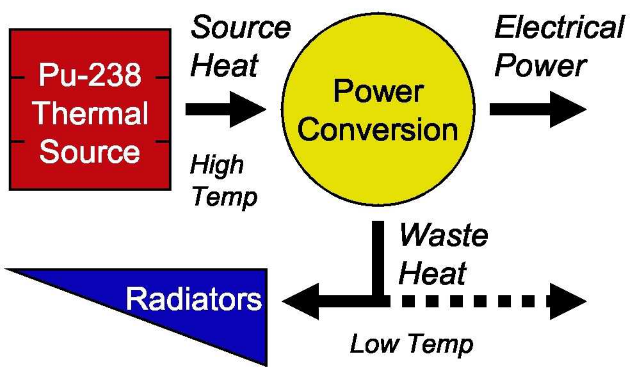
Power Generation Specific Energy Trade Space

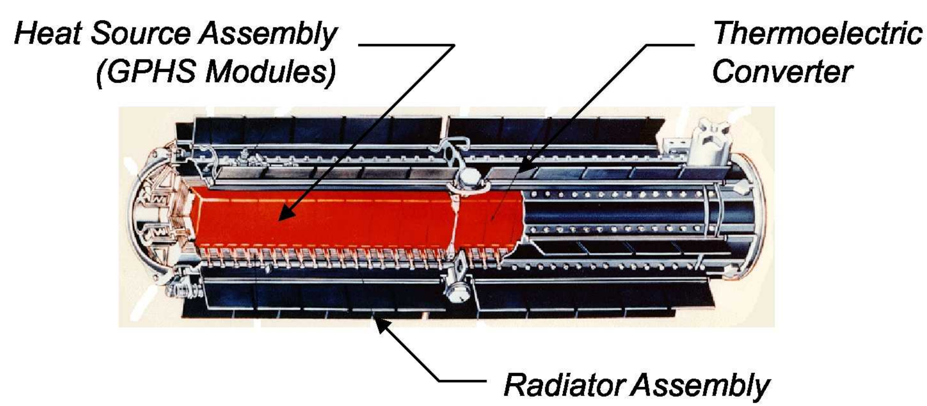


Radioisotope Power Generation



- Heat produced from natural alpha (α) particle decay of Plutonium (Pu-238)
  - 87.7-year half-life
- Waste heat rejected through radiators – or can be utilized for thermal control of spacecraft subsystems

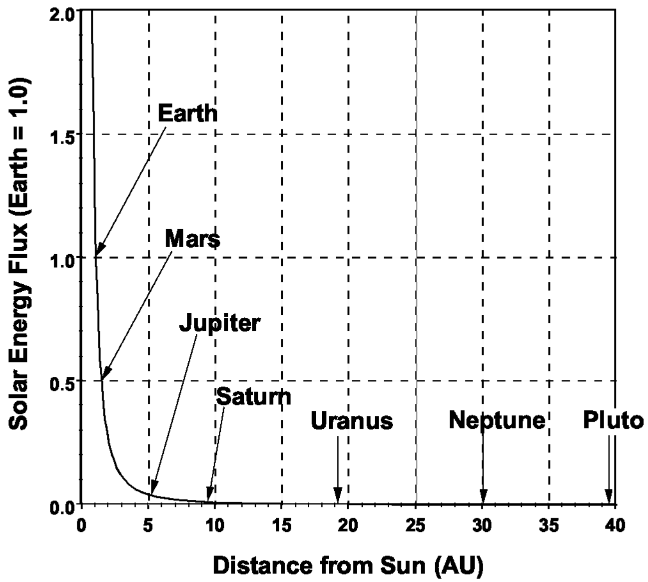


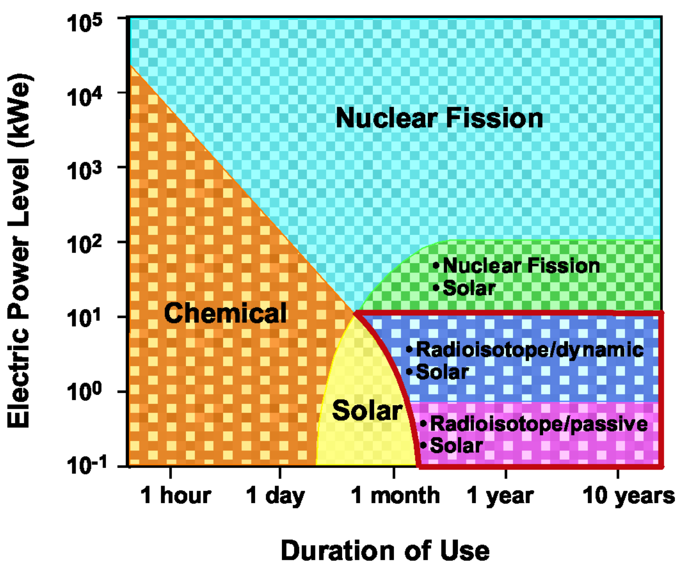


GPHS-Radioisotope Thermoelectric Generator (RTG)

Source: NASA HQ/L. Dudzinski

Radioisotope Power Generation

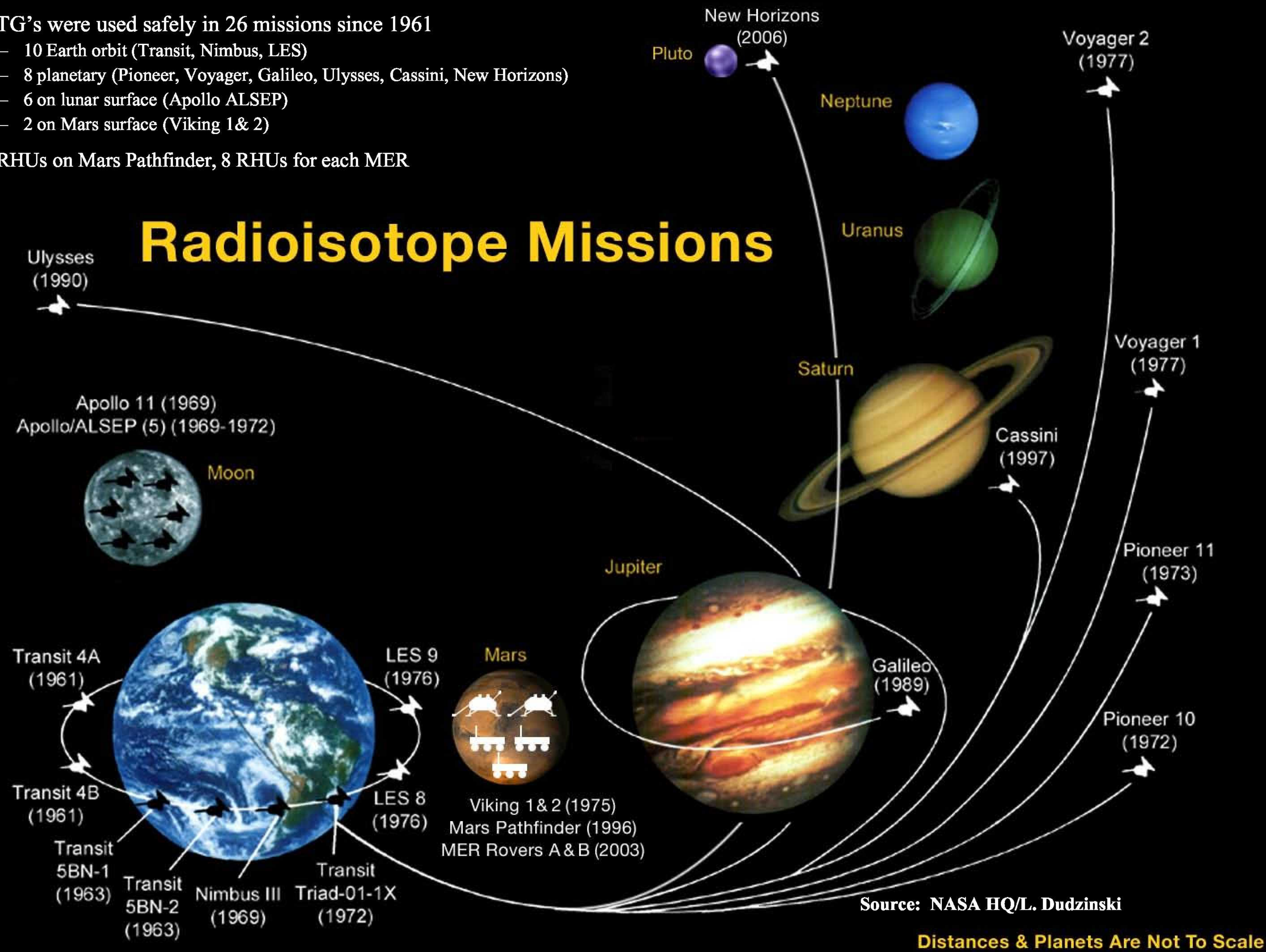




- Steady power independent of distance and orientation w/respect to Sun;
- Operation in thick atmospheres and shadowed areas;
- Operation in extreme and high-radiation environments (e.g., Venus, Titan, Jovian space);
- Long duration operation (≥10 years);
- Scalability to very low power levels (≤1-10 kWe);
- Use in close proximity to crew (low penetrating radiation);
- Readily available excess heat;
- Compactness and ease of transport;
- Enables Radioisotope Electric Propulsion (REP) – benefits of NEP with low power spacecraft (1-5 kWe)
  - High-performance electric propulsion in deep space
  - Specific powers comparable to near-term reactor-based NEP
  - Much smaller spacecraft

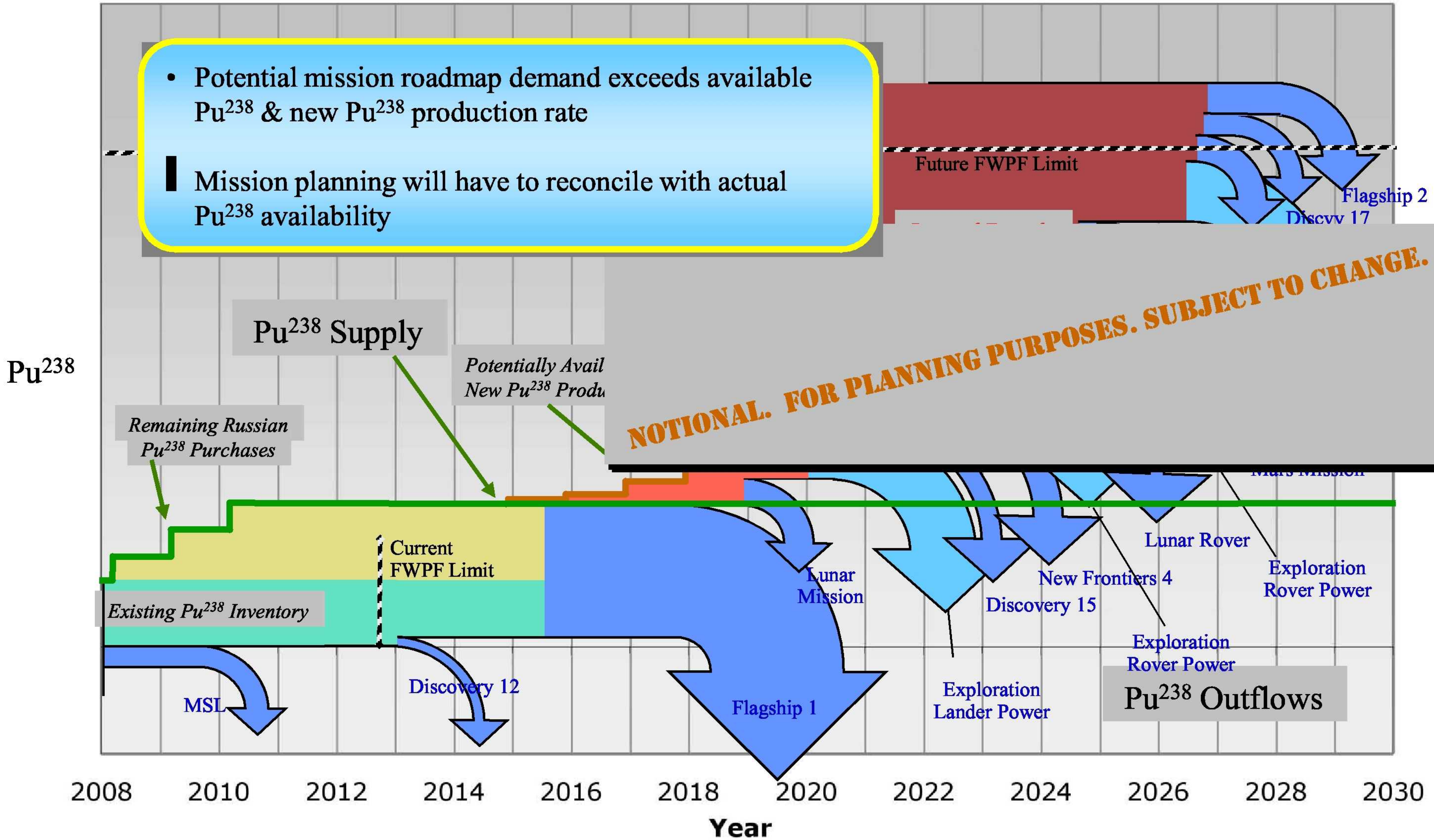
Source: NASA HQ/L. Dudzinski

- RTG's were used safely in 26 missions since 1961
  - 10 Earth orbit (Transit, Nimbus, LES)
  - 8 planetary (Pioneer, Voyager, Galileo, Ulysses, Cassini, New Horizons)
  - 6 on lunar surface (Apollo ALSEP)
  - 2 on Mars surface (Viking 1& 2)
- 3 RHUs on Mars Pathfinder, 8 RHUs for each MER



Source: NASA HQ/L. Dudzinski

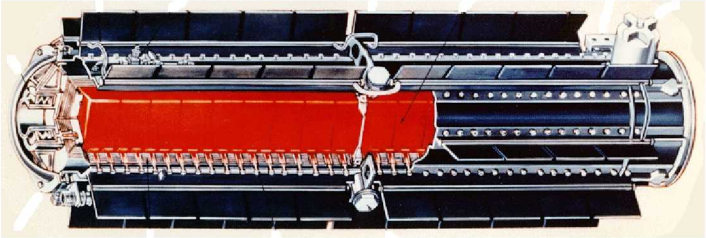
Plutonium Supply Limitations

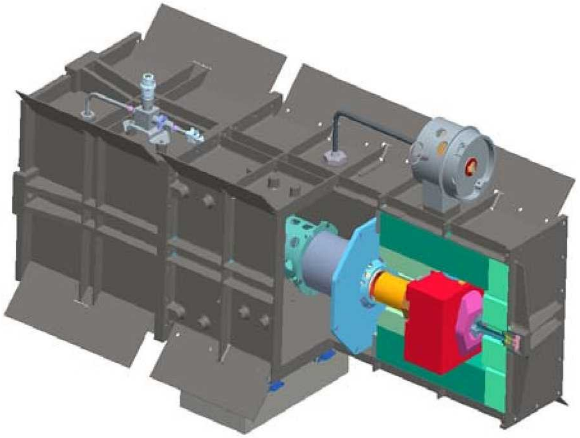


Source: NASA HQ/L. Dudzinski

Radioisotope Power Generation

Development Directions





Radioisotope Thermoelectric Generation (RTG)

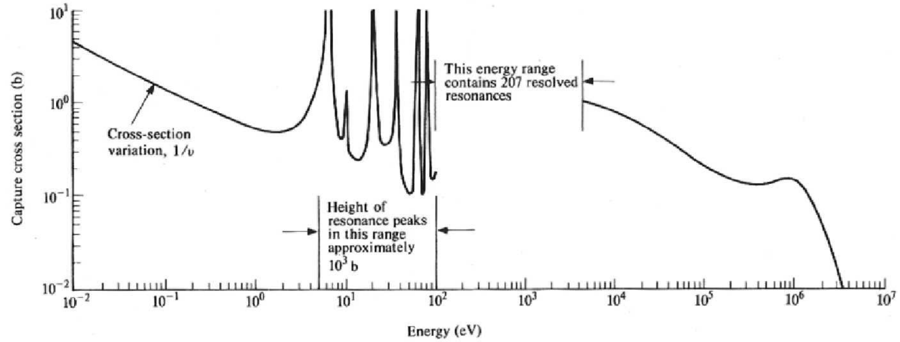
- Decay heat to DC electricity via thermoelectics
- <8% conversion efficiency
- Specific power ~3/W/kg
- Long history in unmanned deep space probes

Advanced Stirling Radioisotope Generator

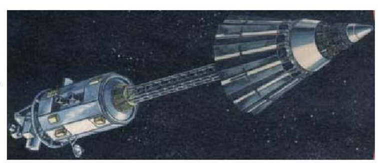
- Decay heat to AC electricity via stirling conversion
- >30% conversion efficiency
- Specific power ~7 W/kg
- Next generation technology

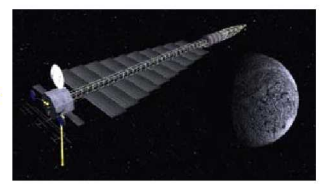
Fission Power Generation

Lyndon B. Johnson
Space Center



U-235 Neutron Capture Spectrum





SNAP-10
- Launched 1965
- ~500 We
- Thermoelectric

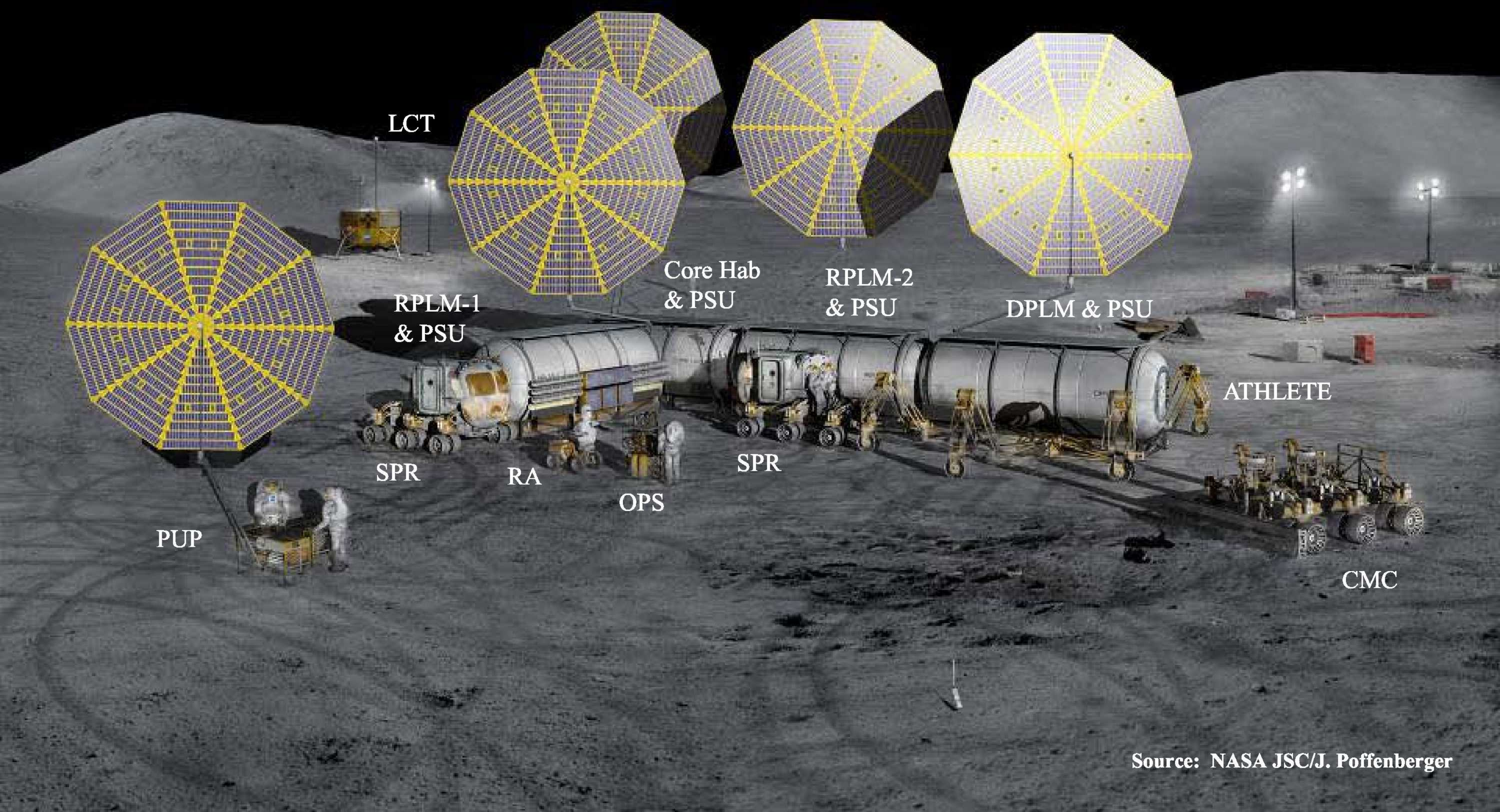
SP-100
- Designed 1990's
- 100 kWe
- Thermoelectric
- Fast spectrum
- Li coolant
- T = 1375K
- Nb-Zr cladding

JIMO
- Designed 2000's
- 200 kWe
- Brayton
- Fast spectrum
- HeXe coolant
- T = 1050K
- Refractory cladding

Fission Surface Power
- Current study group
- 25-100 kWe
- Brayton or stirling
- Fast spectrum
- NaK coolant
- T = 900K
- Stainless steel cladding

Solar Powered Lunar Outpost

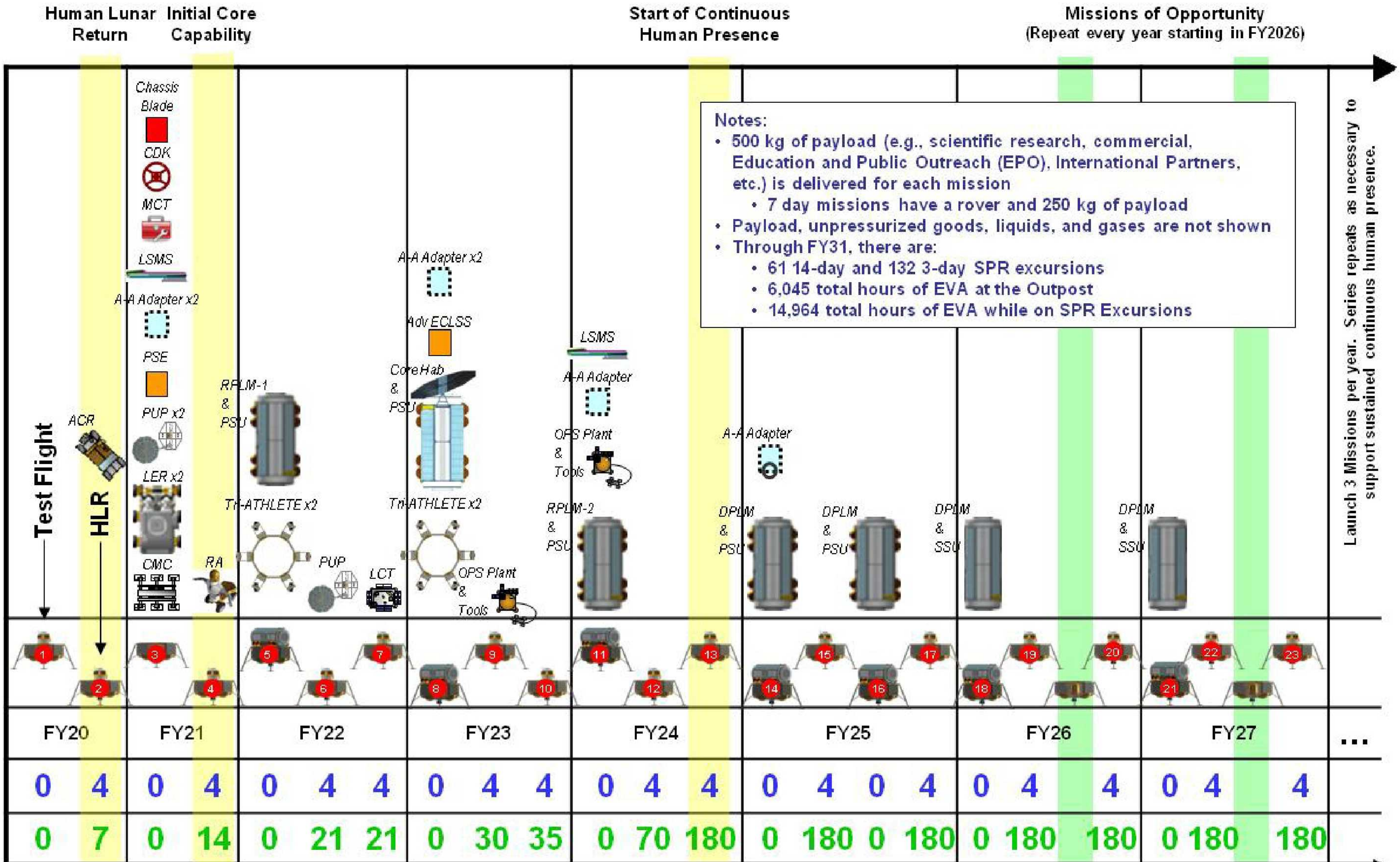
Scenario 4.2.1



Solar Powered Lunar Outpost

Lyndon B. Johnson
Space Center

Static Polar Base with Excursions, LSS Scenario 4.3.1



Source: NASA JSC/J. Poffenberger   # - Crew Size   # - Surface Duration   # - Mission Number

Solar Powered Lunar Outpost

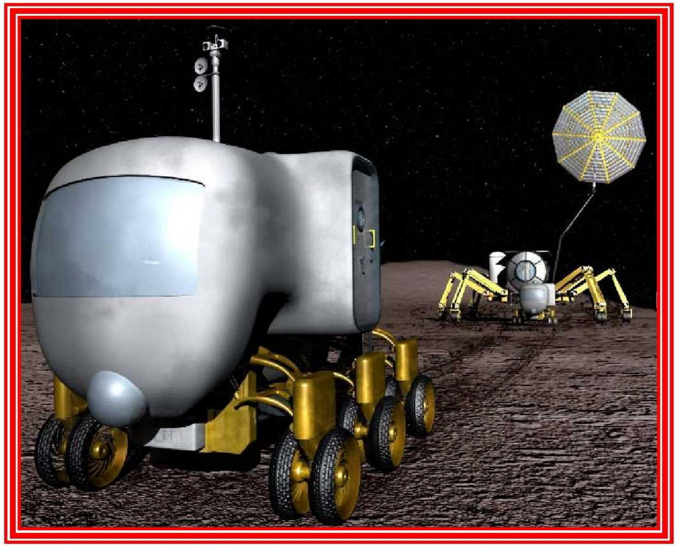
Power System Concept

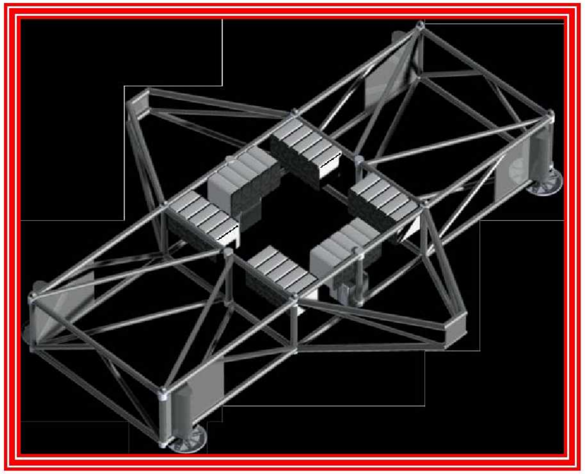
Stationary Outpost

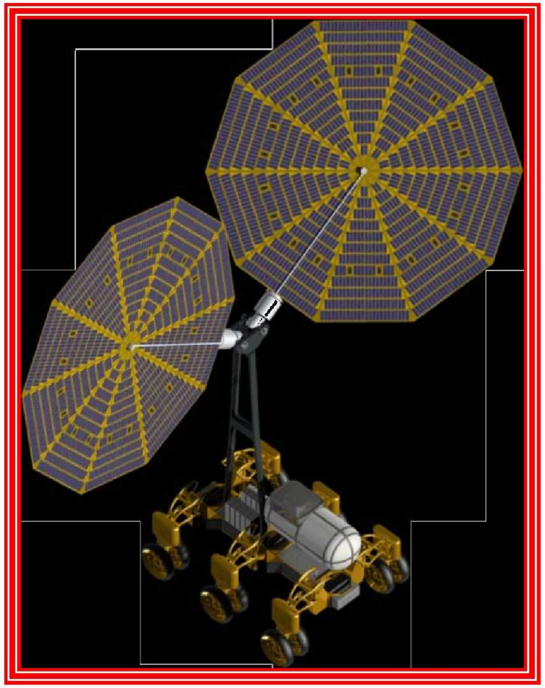
- •Ultraflex solar arrays
- •Sizes from 5.5m diameter (Orion) up to 9.0m
- •Power from 5.7 kWe to 15.9 kWe/array
- •Regenerative fuel cells (gaseous reactant storage) or
- •Advanced Li-ion secondary batteries for night energy storage

Mobility Applications

- •SPRs traverse with logistics support vehicle equipped with a Mobility Power Unit (MPU)
- •MPU is also equipped with solar arrays and Advanced Li-ion batteries
- •SPRs periodically rejoin logistics vehicle to recharge
- •Regenerative fuel cells will be needed on the logistics vehicle for long SPR traverses over the lunar night





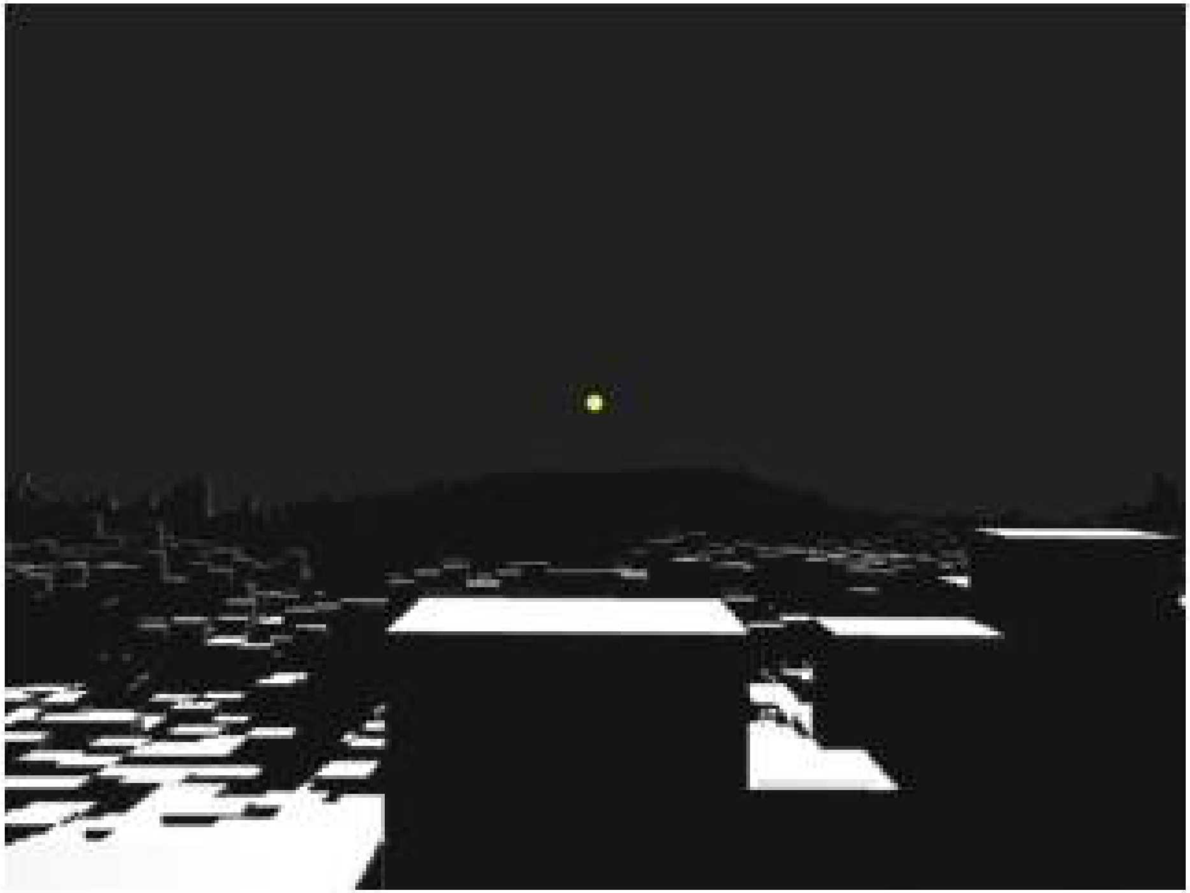


Source: NASA JSC/J. Poffenberger

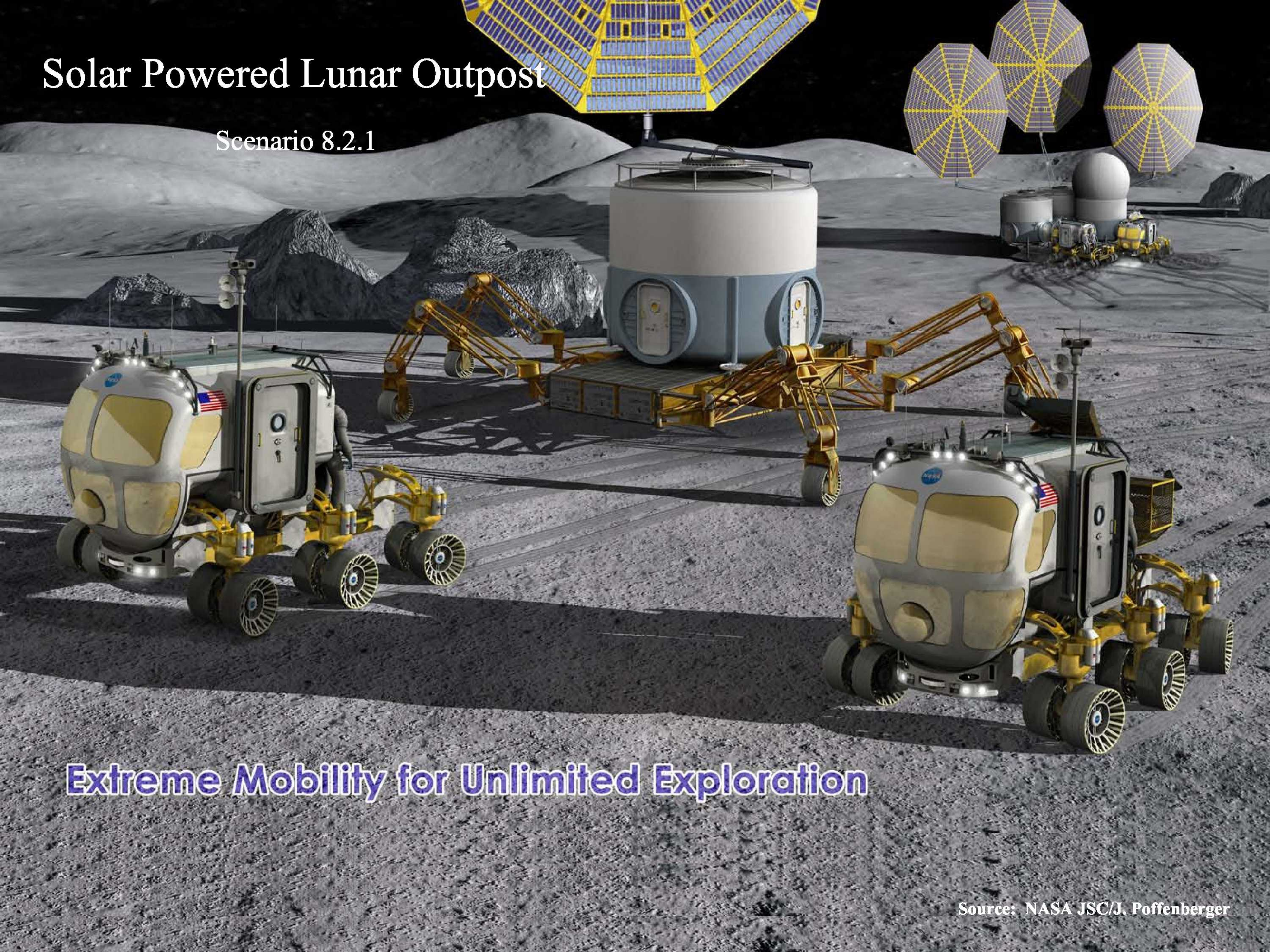
Solar Powered Lunar Outpost

Lyndon B. Johnson
Space Center

Solar Availability Model for Shackleton Rim Outpost



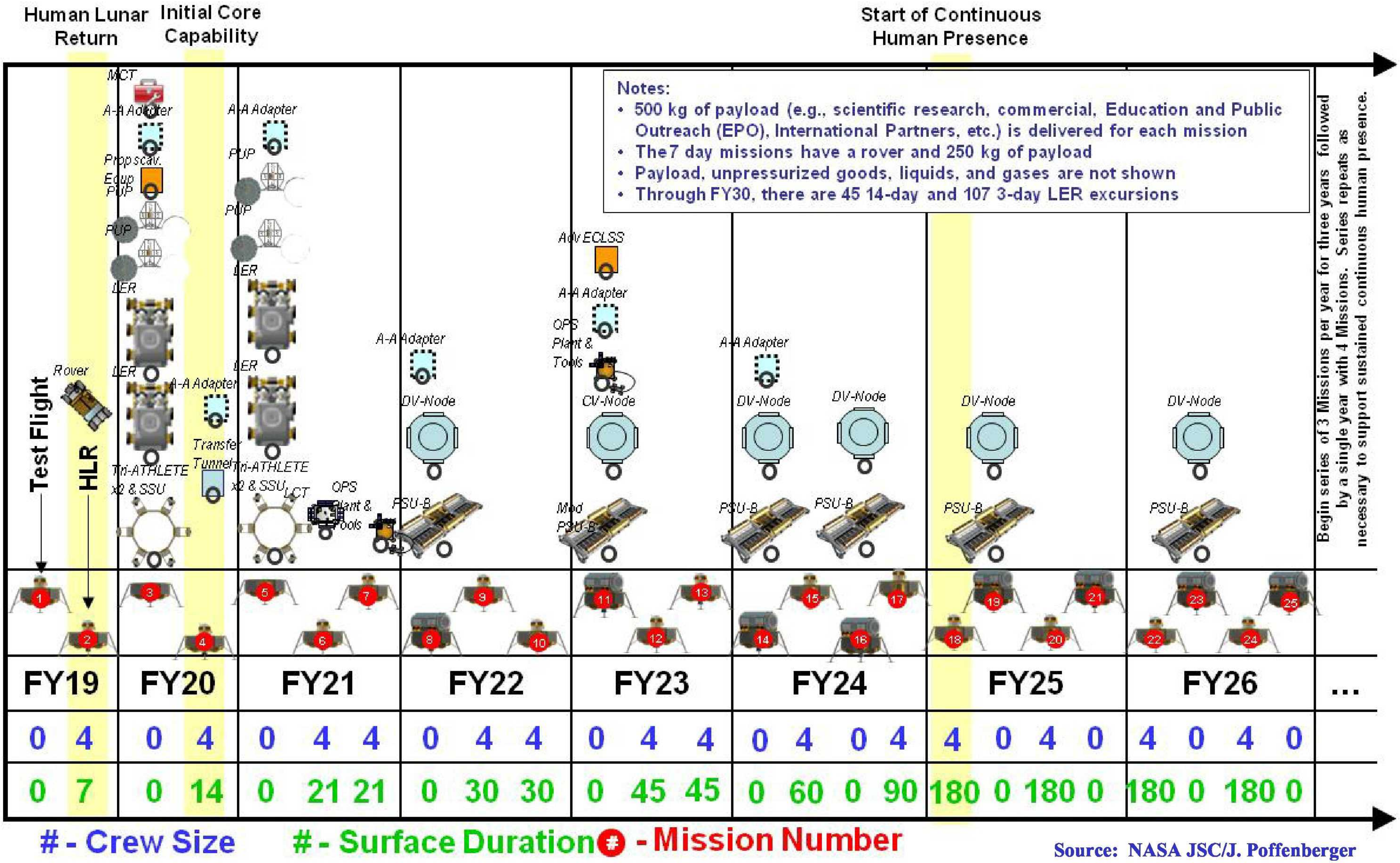
Source: NASA GRC/J. Fincannon


Solar Powered Lunar Outpost
Scenario 8.2.1
Extreme Mobility for Unlimited Exploration
Source: NASA JSC/J. Poffenberger

Solar Powered Lunar Outpost

Lyndon B. Johnson
Space Center

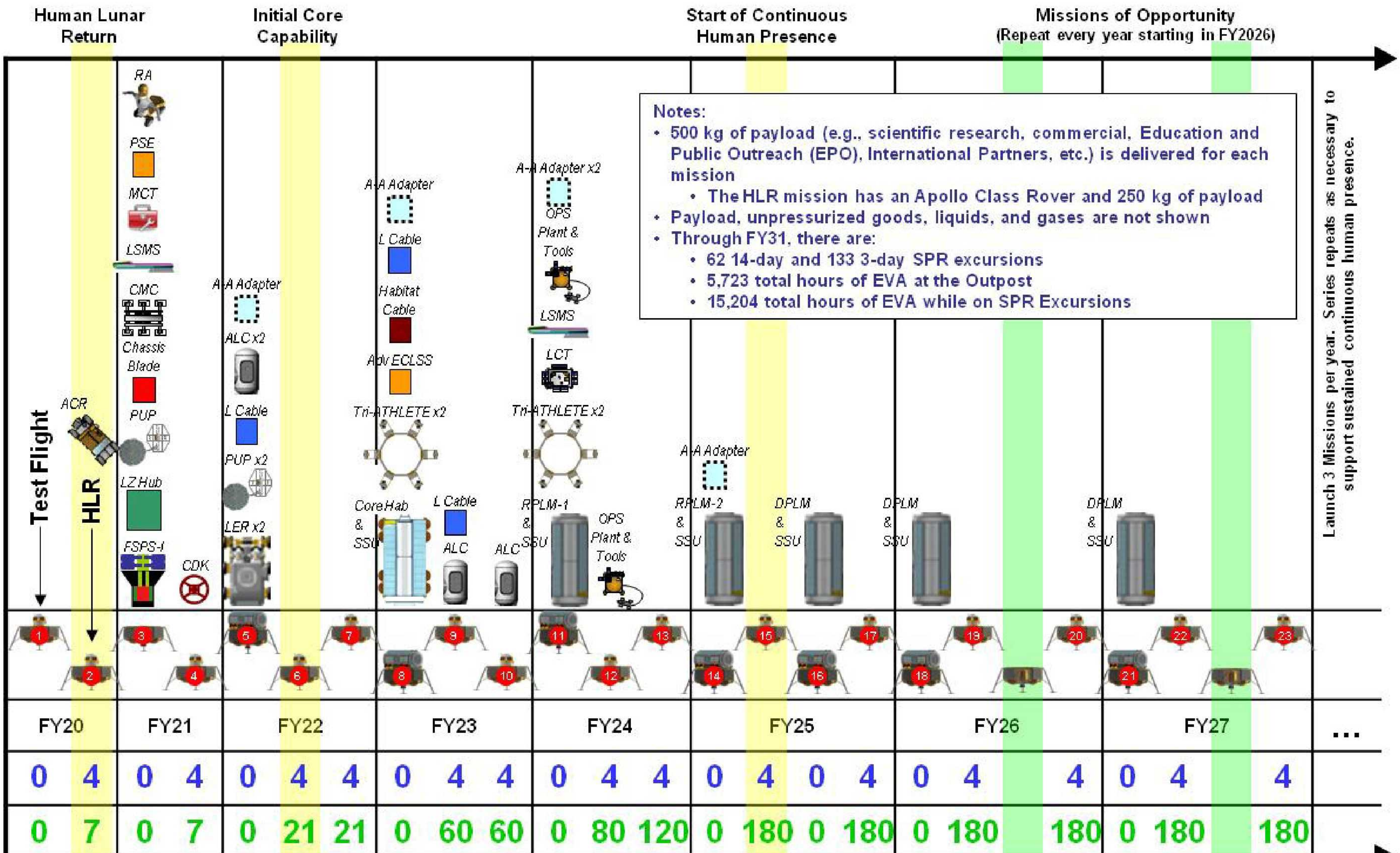
"Pervasive Mobility" Base Concept, LSS Scenario 8.2.1



Source: NASA JSC/J. Poffenberger

Fission Powered Lunar Outpost

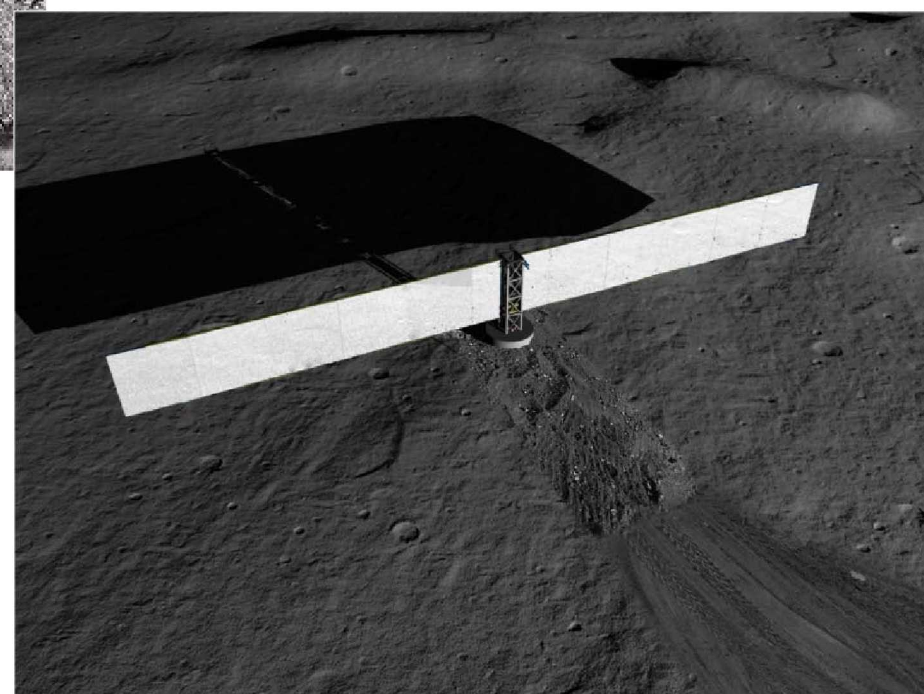
Static Base with Excursions, LSS Scenario 5.6.2



- Crew Size # - Surface Duration # - Mission Number

Source: NASA JSC/J. Poffenberger

Conceptual Fission Surface Power Emplacement Options

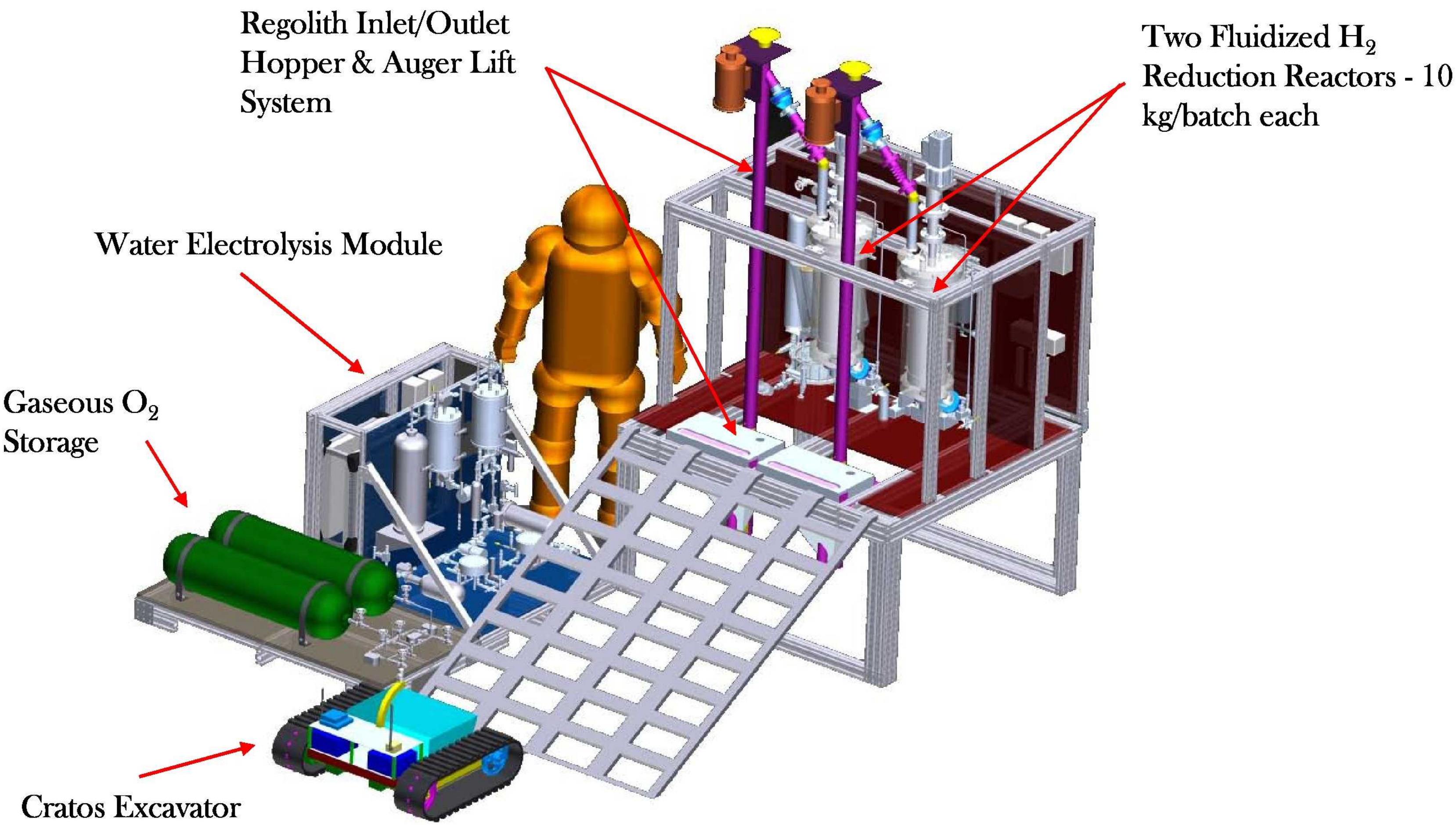


Source: NASA GRC/D. Palac

Fission Powered Lunar Outpost

"ROxygen" End to End O_2 Production from Lunar Regolith

Hydrogen Reduction Process



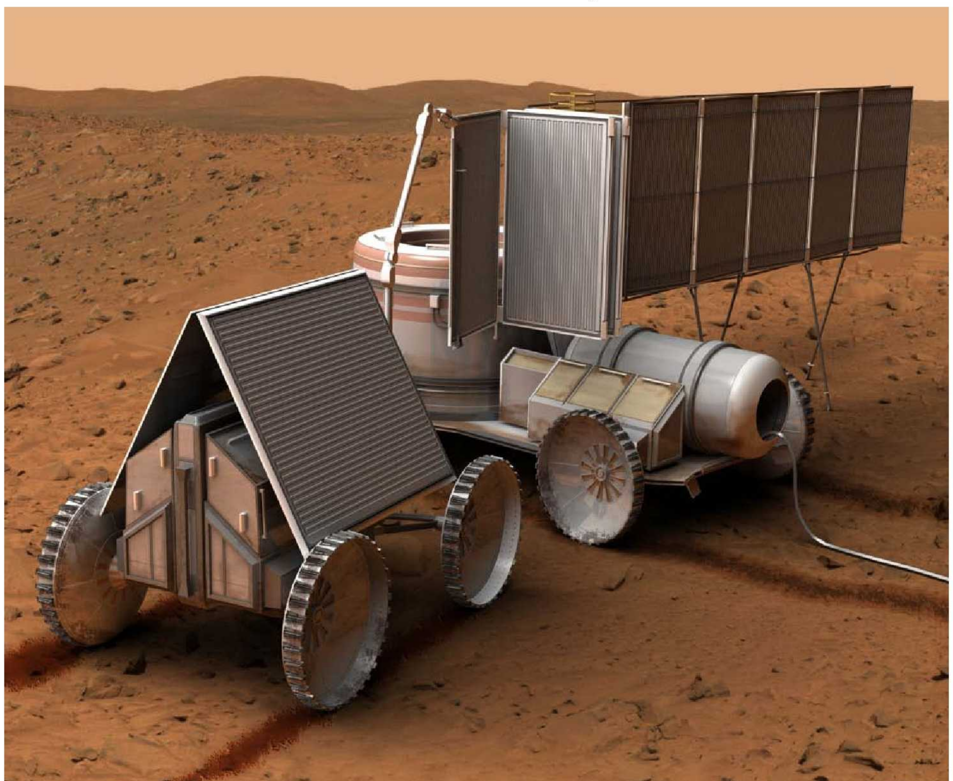
Source: NASA JSC/T. Simon

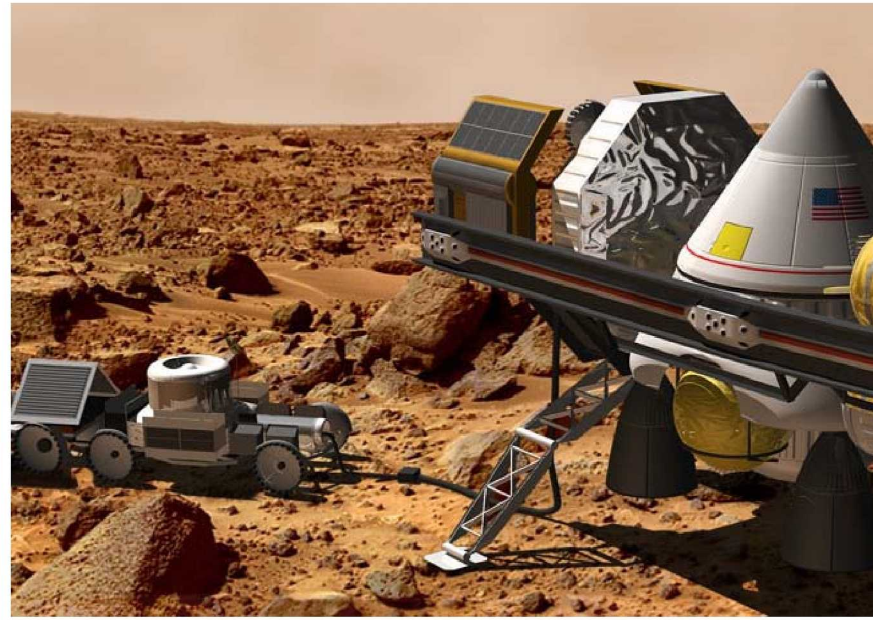
Extensible to Mars

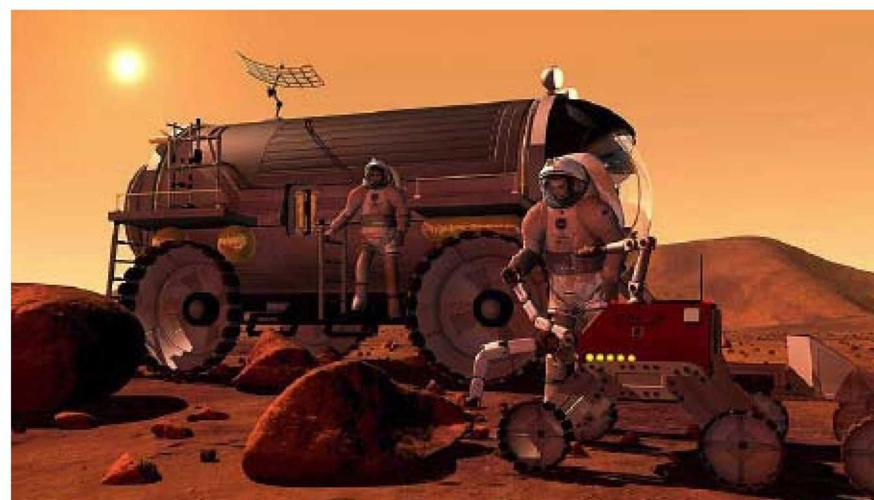
Design Reference Architecture 5.0

Surface Power System

- 30 kWe fission power system supports ISRU (prior to crew arrival) and during crew exploration
- Reactor deployed 1 km from lander remotely
- Close derivative of the lunar system





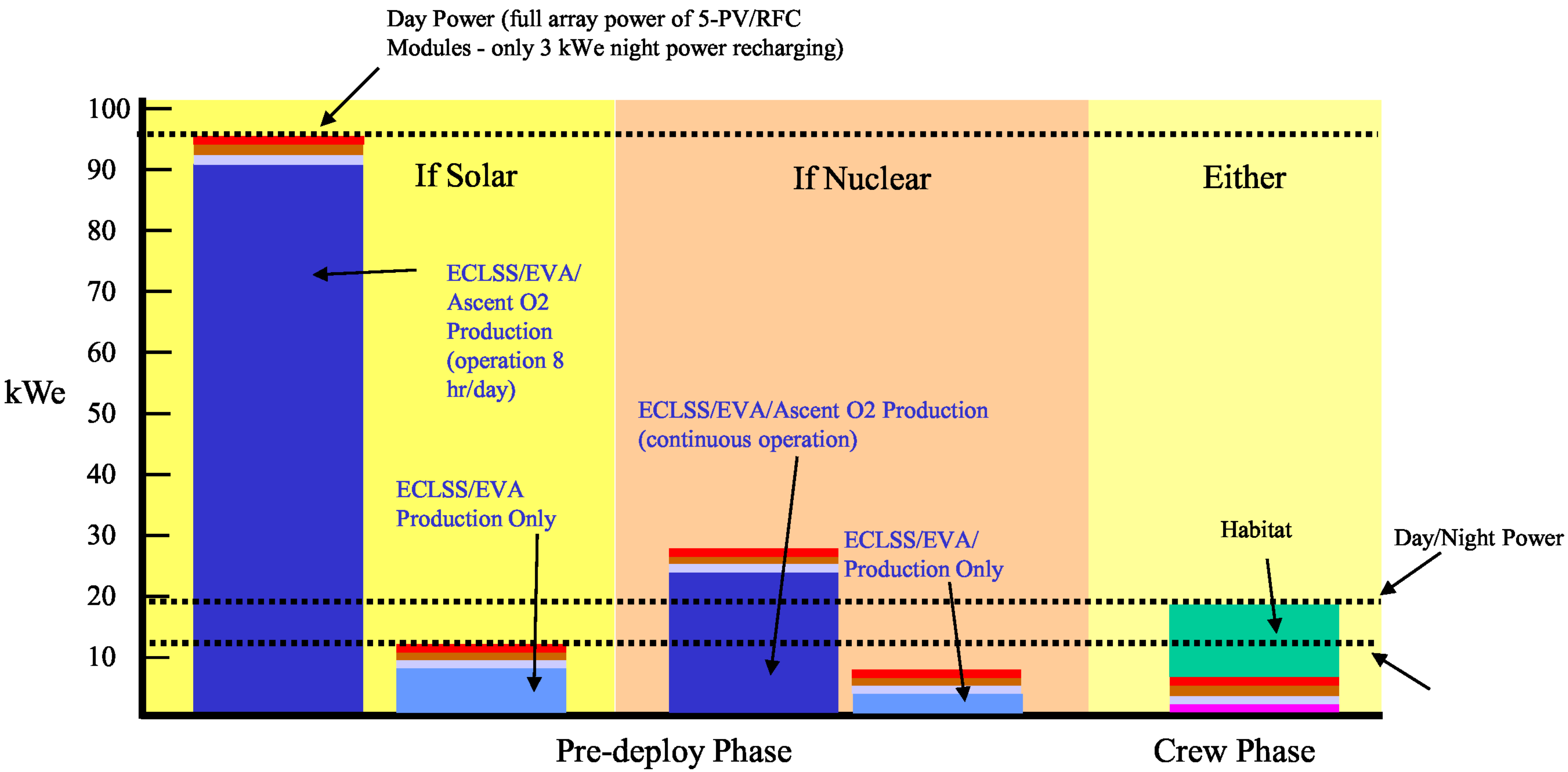


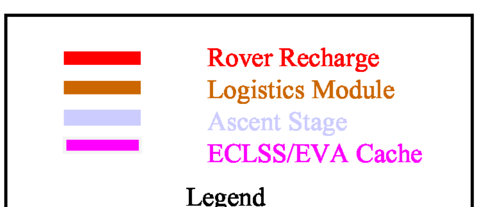
Source: NASA JSC/B. Drake

Lyndon B. Johnson
Space Center

Fission Electric Power Generation

Extensible to Mars





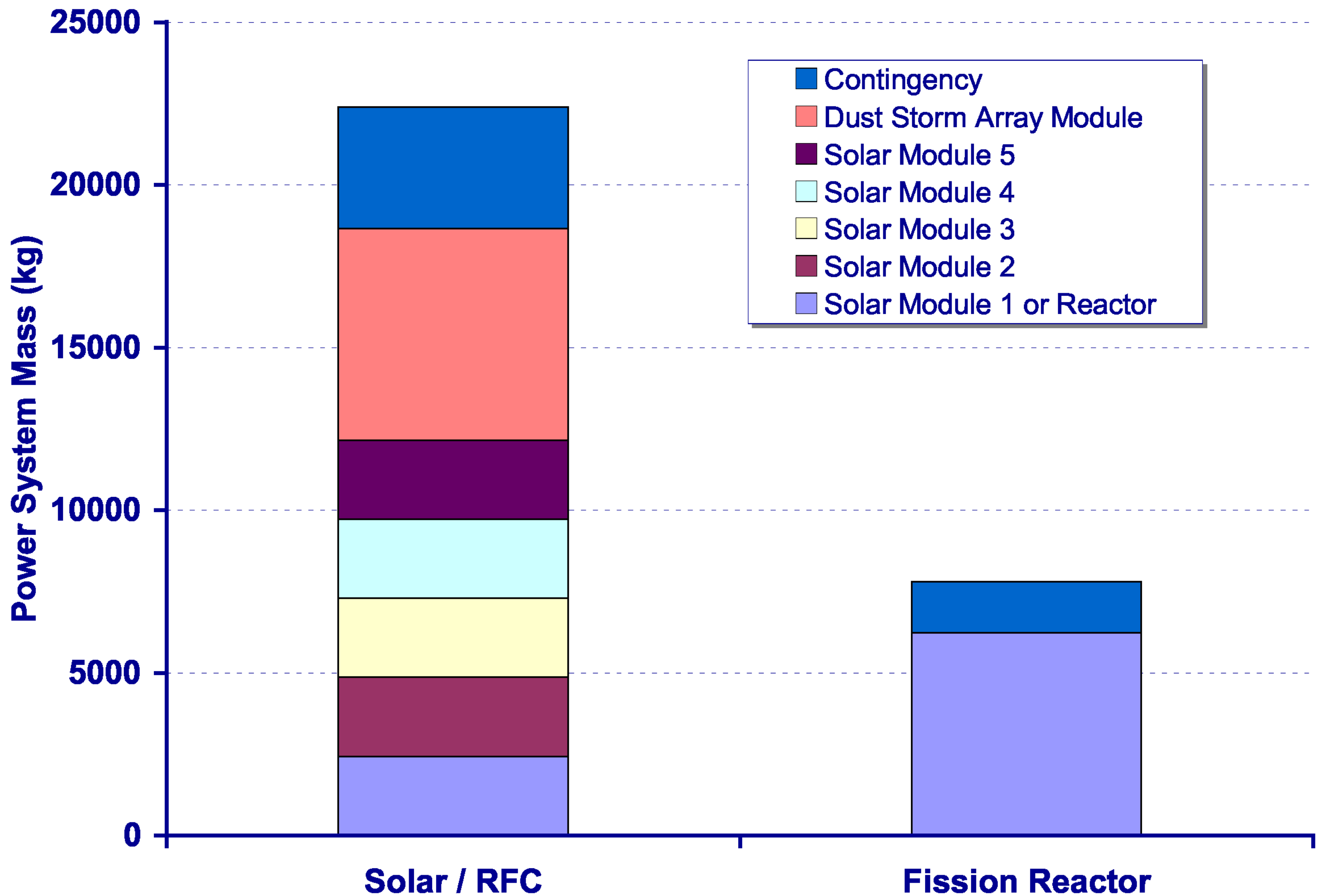
Deliver 5 - 5 kWe PV/RFC Modules
*** Sufficient for O2 production when Habitat in standby Mode**
*** Not capable of dust storm crew survival**

Source: NASA GRC/R. Cataldo

John H. Scott NASA/JSC/EP3 Houston TX 77058 USA, (281) 483-3136, john.h.scott@nasa.gov

Fission Electric Power Generation

Extensible to Mars



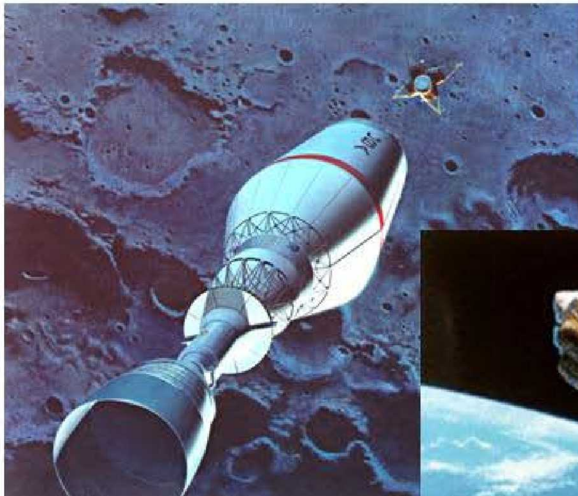
Source: NASA GRC/R. Cataldo

Fission Nuclear Thermal Propulsion

Key for Humans to Mars

Lyndon B. Johnson
Space Center

Design Transition from Single Large NTR to Clustered Smaller Engines Supplying Modest Electrical Power



Reusable Lunar Transfer Vehicle using Single 75 klb_f Engine -- SEI (1990-91)

Expendable TLI Stage for First Lunar Outpost Mission using Clustered 25 klb_f Engines -- "Fast Track Study" (1992)

Reusable Mars Transfer Vehicle using Single 75 klb_f Engine -- SEI (1990-91)

"Bimodal" NTR Earth Return Vehicle using Clustered 15 klb_f / 25 kW_e Engines -- Mars DRM 1.0 (1993)

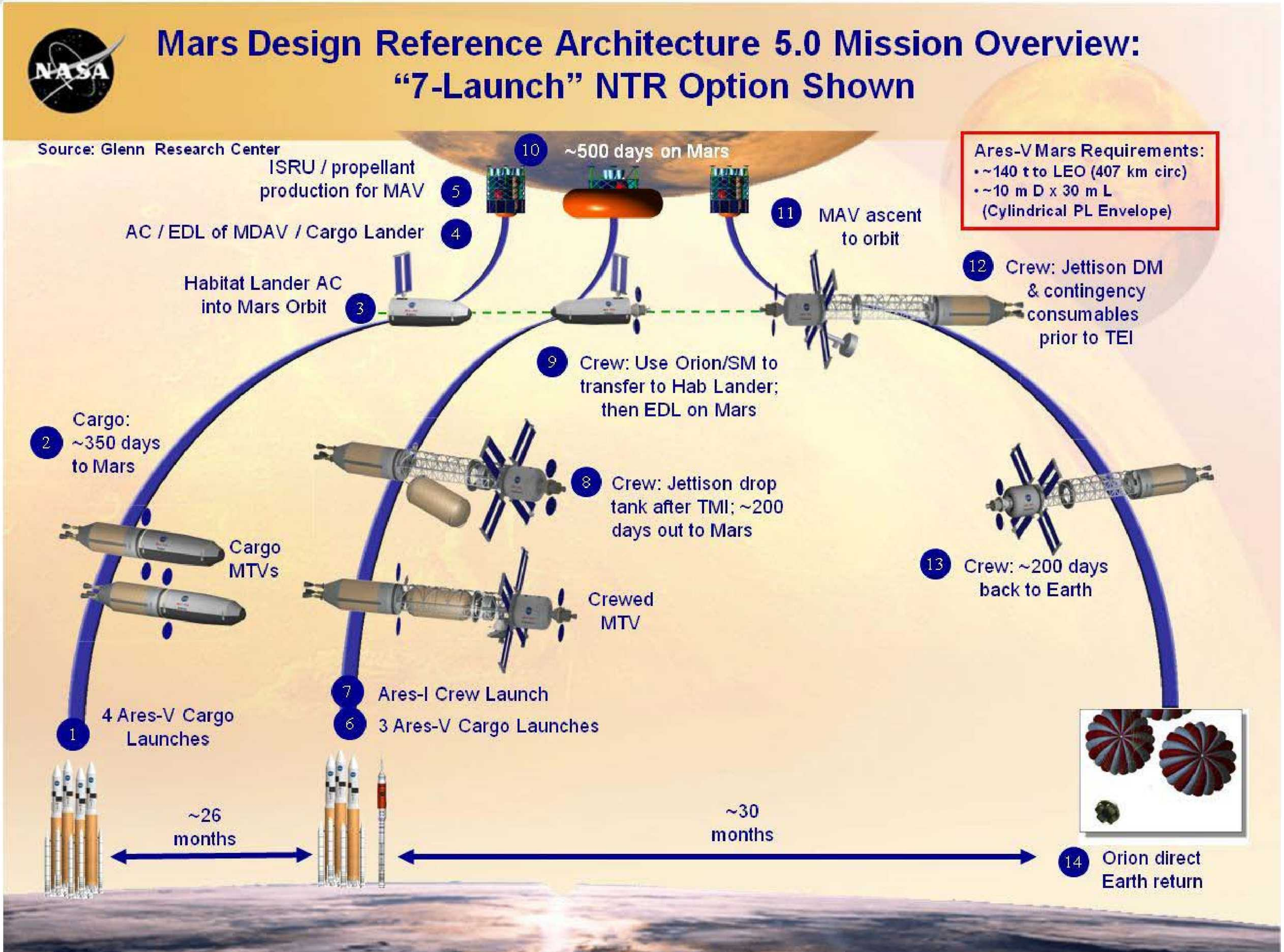
Artificial Gravity BNTR Crewed Transfer Vehicle also using Clustered 15 klb_f / 25 kW_e Engines -- Mars DRM 4.0 (1999)

Source: NASA GRC/S. Borowski

Fission Nuclear Thermal Propulsion

Key for Humans to Mars

Lyndon B. Johnson
Space Center



Source: NASA GRC/S. Borowski

"The first person to set foot on Mars is alive today in America"

-Boeing Outreach Poster